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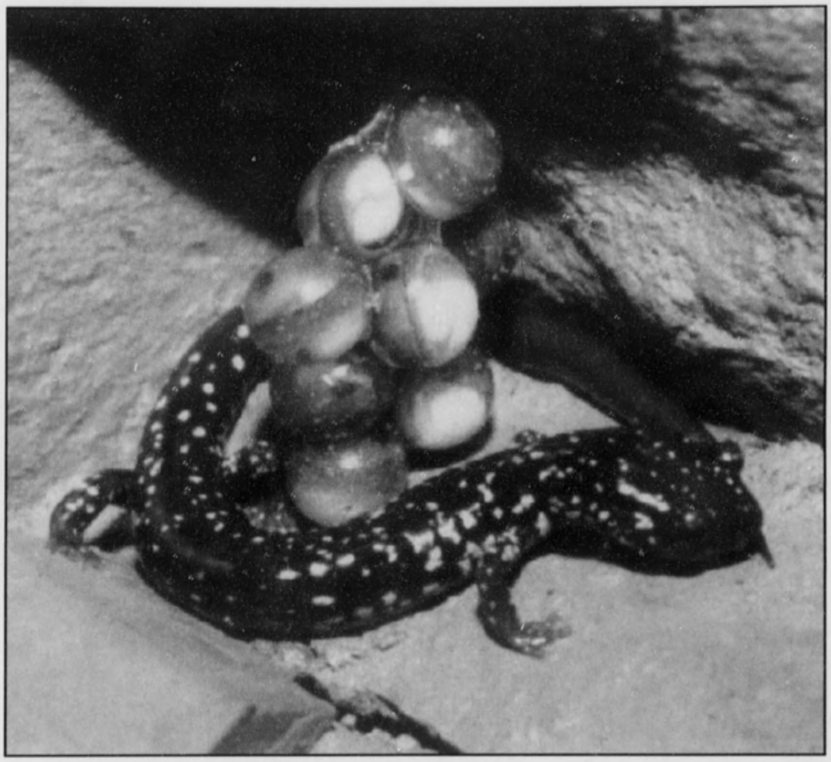

ARKANSAS ACADEMY OF SCIENCE
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DEPT. OF PHYSIOLOGY AND BIOPHYSICS
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Joe Nix, 1978
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Edmond Bacon, 1987
Gary Tucker, 1988
David Chittenden, 1989
Richard 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
Rose McConnell, 1999
Mostafa Hemmati, 2000

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EDITORIAL STAFF

COVER: Brooding female western slimy salamander (*Plethodon albagula*) from an abandoned mine shaft in Garland County, Arkansas. Photo by Stan Trauth.

Arkansas Academy of Science 2001

April 13-14, 2001
85th Annual Meeting

College of Natural Sciences and Mathematics
University of Central Arkansas
Conway, Arkansas

JOURNAL
ARKANSAS ACADEMY OF SCIENCE

ANNUAL MEETING 13-14 APRIL 2001
UNIVERSITY OF CENTRAL ARKANSAS

Mark Draganjac
President

John Rickett
President-Elect

Michael Soulsby
Secretary

Joyce Hardin
Treasurer

Ed Griffin
NAAS Delegate

Henry Robison
Historian

Secretary's Report

MINUTES OF THE 85TH MEETING

FIRST BUSINESS MEETING
UCA LEWIS SCIENCE CENTER ROOM 102
APRIL 13, 2001 - 10:30 AM

1. Minutes: Mark Draganjac opened the meeting by tabling the minutes until the 2nd Business Meeting to allow the Executive Committee time to review them.

2. Welcome: Mark turned the meeting over to Paul Hamilton, Local Arrangements Committee Chairman. Paul turned the floor over to Dean Ronald Toll. On behalf of the UCA campus, Dean Toll welcomed everyone to the 85th meeting of the Arkansas Academy of Science. Paul then acknowledged that Dean Toll's office is sponsoring the keynote speaker. Paul then described changes in the agenda for the meetings. A total of 120 tickets was sold for the banquet.

3. Secretary's Report: Mike addressed the problem associated with the number of *Journal* #53 volumes ordered. He explained that approximately 25 foreign institutions did not receive a copy, and therefore were not billed by the Fayetteville Campus. This is reflected in the treasurer's report, and the problem should not recur again this year. A motion to accept was made by Dr. Rickett, was seconded by Dr. Hemmati, and was passed.

4. Treasurer's Report: Joyce discussed about $1,000 yet to be received for membership dues and asked for prompt payment. She then discussed her written report that is attached to these minutes. She thanked David Saugey for about $1,000.00 from the sale of his book describing mammals in Arkansas. Income from the Harp Endowment was discussed, for there was concern about whether an adjustment for inflation was included, so that the value would not decrease. Joyce explained that the annual interest will exceed the award, and the basic amount in the endowment should increase annually. Dr. Rickett indicated that, as the endowment grows, a sec-

2000 FINANCIAL STATEMENT

Ending Balance - December 31, 2000	**$29,615.76**
Beginning Balance - January 1, 2001	**$26,168.49**
Net Gain	**$ 3,447.27**

DISTRIBUTION OF FUNDS

Checking Account (Firstar Bank, Conway, AR)	**$ 1,139.59**
Certificates of Deposit	
Dwight Moore Endowment (Firstar Bank, Conway, AR)	**$ 4,249.79**
Life Membership Endowment (Firstar Bank, Conway, AR)	**$14,226.38**
CD Unrestricted (Firstar Bank,Conway, AR)	**$ 5,000.00**
Phoebe and George Harp Endowment (Firstar Bank,Conway, AR)	**$ 5,000.00**
TOTAL	**$29,615.76**

INCOME:

1. ANNUAL MEETING		**$ 2,520.00**
2. ENDOWMENT DONATIONS		
a. AAS Unrestricted	$ 960.00	
b. Dwight Moore	$ 25.00	
c. Life	$ 25.00	
	$ 1,010.00	**$ 1,010.00**
3. INTEREST (Endowment)		**$ 1,441.31**
4. INDIVIDUAL MEMBERSHIPS		
a. Associate	$ 285.00	
b. Regular	$ 2,130.00	
c. Sustaining	$ 105.00	
d. Sponsoring	$ 45.00	
e. Life	$ 375.00	
	$ 2,940.00	**$ 2,940.00**

5. INSTITUTIONAL MEMBERSHIPS		$ 1,500.00
6. MISCELLANEOUS		$ 10.00
7. JOURNAL		
a. Miscellaneous Sales	-0-	
b. Page Charges	$ 4,240.00	
c. Subscriptions	$ 2,917.94	
	$ 7,157.94	$ 7,157.94
8. INFLOWS		
Phoebe and George Harp Endowment		$ 5,000.00
TOTAL INCOME		**$ 21,579.25**
EXPENSES:		
1. ANNUAL MEETING		
a. Conway Trophy (657)	$ 95.52	
b. Castleberry's Grocery (666)	$ 89.27	
c. Aramark Campus Services (684)	$ 407.48	
d. David Saugey (686)	$ 359.84	
	$ 952.11	$ 952.11
2. AWARDS		
a. Arkansas Junior Academy (660)	$ 250.00	
b. Arkansas Science Fair (661)	$ 450.00	
c. Conway Trophy (665)	$ 281.49	
d. Student Awards	$ 650.00	
	$ 1,631.49	$ 1,631.49
3. DUES		
National Association of Acadamies of Science (649)		$ 62.50
4. MISCELLANEOUS		
a. Ed Griffin Travel to AAS Conference (656)	$ 278.00	
b. Arkansas Flag and Banner (654)	$ 250.80	
c. Arkansas Flag and Banner (655)	$ 281.52	
d. Arkansas Flora Conference (662)	$ 200.00	
e. John Rickett (663)	$ 79.17	
f. Member Underpaid Annual Meeting	$ 10.00	
	$ 1,099.49	$ 1,099.49
5. *NEWSLETTER*		-0-
6. OFFICE EXPENSES		-0-
7. *JOURNAL*		
a. Stan Trauth - Editorial Consultation and Travel Volume 53 (653)	$ 200.00	
b. Pinpoint Color Volume 53 (667)	$13,686.39	
c. Joy Trauth - Editorial Consultant Volume 54 (687)	$ 500.00	
	$14,386.39	$14,386.39
TOTAL EXPENSES		**$18,131.98**

ond and third place award may be added. A motion to accept was made by Dr. Hemmati, seconded by Dr. Rickett, and passed.

5. *Journal* Editor-in-Chief: Stan Trauth reported that *Journal* volume #54 has 160 pages within it, same as last year. Stan also requested that the Academy agree to pay the sum of $200.00 to the Editor-in-Chief for expenses. A motion to do so was made, and that motion will be voted upon at the Second Business Meeting since it involves money.

6. *Journal* Managing Editor's Report: David Saugey described the problem with submission of papers using the wrong format. About 30 to 40 manuscripts will be sent out for review in mid May. Manuscript authors are being asked to provide more information about their plans during the summer months, so that David can find them for manuscript revision. David also requested that the Academy provide the sum of $600.00 for editorial assistance this year. This is an increase over the $500.00 received during past years, but is necessary. A motion to provide $600 this year was made and seconded. Since this involves money, it will be voted upon tomorrow in the Second Business Meeting.

7. *Newsletter* Editor: Jeff Robertson presented his report indicating that any problems associated with the current *Newsletter*, like a place to order banquet tickets, turned out not to be a problem for the banquet is sold out.

8. Historian: Henry Robison described this as the 85th meeting of the Academy, and indicated the years when previous meetings of the Academy were held at UCA.

9. Science Fair Association: Mike Rapp was not present at this meeting, but provided a report presented by Dr. Hemmati and read by Mark. Thanks for 18 years of support by the Academy was mentioned. A copy of Mike's report describing meetings during the year 2000 is attached to these minutes. Over 280 students participated in the State Science Fair, and about 80 student participated in the Junior Academy of Science Fair. Again this year, the State Science Fair is requesting the sum of $450.00 to help cover expenses for nine affiliated Fairs and the State Fair. Motion to provide these funds was made and seconded. That motion will be voted upon at the Second Business Meeting. Rick Geraci and Mark Eakin will be replacing the Skinners for the Junior Academy of Science. A sum of $250.00 is requested again this year to aid with expenses related to the Junior Academy Science Fairs. A motion to provide this amount was made and seconded. This motion will also be voted upon at the Second Business Meeting.

10. Junior Science and Humanities Association: Tom Palko was not present, and no report was provided.

11. Intel Talent Search: Jim Murray asked Mark to say that they had only one person in the Search this year, and that this person was given the award. Jim is asking for the sum of $60.00 to be provided to purchase a plaque for this winner. A motion to provide this amount was made by Dr. Rickett, seconded by Dr. Hardin, and will be voted upon in the Second Business Meeting.

12. Committee Reports:

    a. Biota Committee: Doug James was not present, so Mark presented the report. Mark indicated that Doug is requesting the sum of $300.00 from the Academy to put the Biota series on the web. This would involve scanning, editing, up-dating, and proof reading. A motion to approve this amount was made by Dr. Rickett, seconded, and it will be voted upon at the Second Business Meeting.

    b. Development Committee: David Saugey indicated that an attempt is being made to solicit money from corporations for an endowment, or for an award at the annual meetings.

    c. Nominations: Bob Watson was not present, so Scott Kirkconnell presented the report. Henry Robison was nominated to continue as Historian. There were no additional nominations from the floor, so a motion to appoint was made and seconded. Nominations for vice-president were John Harris of the Arkansas Highway and Transportation Department and Wayne Gray of UAMS. Additional nominations were solicited from the floor. None were forthcoming.

    d. Science Education Committee: John Rickett informed the meeting that James Daly is stepping down as head of the Science Education Committee. Mark informed that meeting that this committee is trying to contact two year colleges to encourage there attendance and participation. Dr. Hemmati has graciously agreed to chair the Science Education Committee.

    e. AAAS: Ed Griffin is our local representative and was out of town. Mark made the motion to pay Dr. Griffin's expenses. Motion passed.

    f. Ad Hoc Committee on Awards: John Rickett presented the material about the Awards Committee. He also outlined the duties and responsibilities of the secretary. A copy of motions outlined by Dr. Rickett is attached to these minutes. Joyce Hardin recommended that we vote on resolutions #4 and #5 in tomorrow's meeting, and table resolutions #1, #2 and #3 until the Fall Executive Committee Meeting. After considerable discussion a motion to accept this recommendation was made by Dr. Rickett, seconded and passed. Matt brought up the possibility of awards for posters. It was decided that this would be up to the local arrangements committees.

13. 2002 Meeting: Dr. Rickett indicated that UALR will host the 2002 meeting. The local arrangement committee is attempting to get a UALR alumnus as a Biodiversity speaker at the meetings to be held during the first weekend in April.

14. 2003 and 2004 meetings: Mark indicated that he has sent letters to UAF and ASU indicating that the executive committee has accepted their bids to host these meetings.

15. Bids for 2005: Joyce mentioned that Hendrix College would like to host the 2005 meetings.

16. Old Business: Conflicting meetings of the Junior Science Fair prevented these meetings from being held during the first weekend in April. Henry Robison suggested this is the reason attendance is down.

17. Webpage: Walt Godwin indicated "the web is out there!"

18. Brochure: Dr. Hemmati reminded the meeting that copies of the brochure are present at these meetings. Mark advised Mike to alter the membership forms, so that dues can be paid in advance.

19. Resolution Committee: Mark reminded the Committee of his earlier suggestion, that the Chairman of the Resolution Committee be a responsibility of the Vice President. This should by inserted into the Constitution as recommended by the Executive Committee at the Fall meeting. This was brought before the membership of the Academy.

20. New Business: Matt Walker presented his suggestion that a new award be presented at each annual meeting. This would be a young investigator award, and might be called the Charles Burkover Award, honoring the first president of the Arkansas Academy of Science. It would be presented to an investigator who is employed by a public or private institution in Arkansas, during the first six years of that employment. The recipient should not hold a rank higher than Assistant Professor or its equivalent. Credentials of a recipient, and mechanism for a nomination were discussed. A three-member committee would be developed to screen individuals nominated. The award could consist of paid travel

expenses to the annual meetings and a plaque. Stan discussed eligibility for nomination. John Rickett expressed some concern about particular issues and suggested that the consideration be tabled and studied further at the Fall Executive Committee meeting.

21 Publication Committee: Mark indicated that he would charge the Constitution Committee to look into a potential change in the Publication Committee. The Publication Committee presently consists of the Editor-in-Chief, the Managing Editor, plus two additional members. We currently have a pool of associate members. Mark suggests that the two additional members be two of the associate members, so that decisions can be made more easily and without undo delay.

22. Judicial Committee: Mark included this issue because it was addressed at the last Executive Committee meeting. The issue is whether we should have a Judiciary Committee. This question evolved out of the problem with the abstract that was not accepted for presentation at the general meeting in Hot Springs. Following much discussion, it was decided that a portion of the Executive Committee should act as the Judiciary Committee only when one is needed. John Rickett suggested that a statement describing worthiness be included with the abstract instructions. Mark brought up a second situation during the banquet in Hot Springs. It was decided to bring this issue up for discussion at the Fall Executive Committee Meeting.

23. Other: Bill Shepherd discussed the pairing of sessions at the meetings. For example, Botany and Invertebrate Zoology would be a better pairing than Botany and Vertebrate Zoology. Finally, Dick discussed news from the Forest Service and its "SST" program. This apparently has to do with a "Sweet Smelling Toilet" which he may bring up in the meeting tomorrow.

There being no other new business, a motion to adjourn was accepted.

SECOND BUSINESS MEETING
UCA LEWIS SCIENCE CENTER ROOM 102
APRIL 14, 2001 - NOON

1. Call to Order: Mark officially called the meeting to order at 12:05 pm.

2. Approval of Minutes: Mike Soulsby addressed the minutes of the previous Executive Committee Meeting at UALR in September 23, 2000. Misspelled names were addressed. Motion for approval, seconded and approved.

3. Nominating Committee: John Rickett presented the report for Dr. Watson, Chairman. His committee submits the following nominations: Historian - Dr. Henry Robison for another term, Vice President - Dr. Wayne Gray (UAMS) and Dr. John Harris (AHTD). There being no additional nominations from the floor, the motion to cease was made, seconded and passed. Ballots were then distributed for the office of Vice-President for Henry Robison was elected by acclamation.

4. Treasurer's Report: Joyce Hardin made certain that all present had a copy of her financial statement. Before going over that statement, Joyce indicated that some page charges for volume #53 are still out. This totals about $1,000.00. Volume #54 was passed out at the meeting and page charge invoices were mailed out yesterday. Please pay for these invoices by the May 15 due date. Joyce then went over the financial statement, a copy of which is attached to these minutes. David Saugey was applauded for his contribution of proceeds from the Bibliography of Mammals. A motion to accept the report was made by Walter, seconded by Dr. Hemmati, and passed. Mike Soulsby then asked members who were finished with their Vol #53, to please donate them back to the Academy to help cover the shortfall from last year. Joyce indicated that we have received about 75 additional copies of Vol. #54, and we were not charged for them. Hence no shortfall is anticipated this year.

5. Auditor's Report: Bob Wiley introduced members of the committee, presented his report and thanked David Saugey for a $3,500.00 profit from his Bibliography on Mammals. Motion to accept was made, seconded and passed.

6. *Journal* Editor-in-Chief's Report: Stan Trauth reminded the membership that Vol. #54 is available. Since the mailing list is not updated, Stan asked those taking copies back to their respective campuses to scan through and remove copies designated for students and retired faculty. Stan also asked for the Academy to continue an allotment of $200.00 for the Editor-in-Chief to cover expenses involved. Mark reminded that a motion was made and seconded at yesterday's meeting to allot this amount. That motion passed at this time.

7. *Journal* Managing Editor's Report: David Saugey reminded those in attendance who are submitting a publication for publication to be sure and follow the guidelines in the back inside cover of Vol. #54. Also please let him know how to get in touch with you during the summer for editing and corrections. David also requested the sum of $600.00 to handle expenses. This is a increase of $100.00 over previous years' allotments, but is needed to cover increasing expenses. Mark reminded the membership that a motion to fund this amount of $600.00 was made at yesterday's meeting. That motion was passed at this time.

8. *Newsletter* Report: Jeff Robertson was not present and Dr. Hemmati presented a report.

9. Historian's Report: Henry Robison indicated that this is the 85th annual meeting of the Academy. He indicated that the annual meeting has been held at UCA during six previous years (1934, 1964, 1974, 1983, 1992, and this year).

10. Committee Reports:

    a. Biota Committee: Doug James provided a report presented by Mark. The Committee is requesting the sum of $300.00 to place the Biota Series on the Web. The Executive Committee approved this amount to scan, edit and send to authors for proofreading. This amount of $300.00 was passed at this time.

    b. Development Committee: David Saugey indicated that this committee is looking into funding sources in Arkansas and around the country for improving the endowment, scholarships, awards, etc.

    c. Science Education Committee: Mark indicated that James Daly has found it necessary to resign, and that Dr. Hemmati has agreed to take over the chairmanship of this committee. Mark indicated that a goal of the committee will be to get the two-year community colleges involved in the Academy.

    d. AAAS: Mark indicated that Ed Griffin is our representative. A motion to pay airfare for Ed to attend the upcoming annual meeting if San Francisco was made yesterday. The motion to provide the airfare was passed. Ed takes care of all other related expenses.

11. Science Fair Association: Mike Rapp was not present, but provided a report read by Mark. The report thanked the membership of the Academy for their support in previous years. It also listed the names of the State Junior Science Fair winners, and a copy is appended to these minutes. A renewed request for the Academy to continue its support of the State Science Fair, and the Junior Academy activities, to the amount of $450.00. A motion to provide these funds was made at yesterday's meeting. That motion was passed by the membership.

12. Junior Science and Humanities Association: No report given.

13. Intel Talent Search: Jim Murray indicated that they had only one person in the search this year, and that this person was given the award. Jim is asking for the sum of $60.00 to be provided to purchase a plaque for this winner. A motion to provide this amount was in the First Business Meeting. That motion passed at this time.

14. Resolution Committee Report: Walt Godwin as committee chairman read the report. He thanked UCA for the meeting, and the local arrangements committee for their labor. He thanked the Guest Speaker and Dean Toll for an excellent meeting. He also thanked the judges for their time and efforts. Winners at the meetings were congratulated. A copy of the report is attached to these minutes.

15. Awards: Mark turned the awards presentation over to Paul Hamilton. A copy of Paul's report listing the recipients of the awards is attached to these minutes. Photographs of winners present were taken. Poster awards were also presented. Joyce reminded that monetary awards will be mailed directly to the winners.

Level	Award Type	Category	Name	School
Undergraduate	1st	Physical Sciences	Matthew Tilley	Arkansas State University
Undergraduate	2nd	Physical Sciences	Reagan Baber	Harding University
Undergraduate	3rd	Physical Sciences	Brandon Lindley	University of Central Arkansas
Undergraduate	Honorable Mention	Physical Sciences	Kyland Holmes	Hendrix College
Undergraduate	Honorable Mention	Physical Sciences	L. A. Thornton, Jr.	Arkansas State University
Undergraduate	Honorable Mention	Physical Sciences	Bryan Gipson	University of Central Arkansas
Undergraduate	1st	Life Sciences	Leah Lucio	University of Arkansas at Little Rock
Undergradeate	2nd	Life Sciences	Becky Hicklin	University of Arkansas at Little Rock
Undergraduate	3rd	Life Sciences	Cameron Good	University of Central Arkansas
Undergraduate	1st	Environmental Sciences	Brenna Fitzgerald	Hendrix College
Undergraduate	2nd	Environmental Sciences	Randall Staley	Arkansas State University
Undergraduate	3rd	Environmental Sciences	Kelly Osborn	Hendrix College
Graduate	1st	Physical Sciences	Marilyn Egan	University of Arkansas at Little Rock
Graduate	2nd	Physical Sciences	Daniel Bullock	University of Arkansas
Graduate	3rd	Physical Sciences	Abbas Eyuboglu	University of Arkansas at Little Rock
Graduate	1st	Life Sciences	Malcolm McCallum	Arkansas State University
Graduate	2nd	Life Sciences	Robin Stingley	University of Arkansas for Medical Sciences
Graduate	3rd	Life Sciences	David Feldman	Arkansas State University
Graduate	1st	Environmental Sciences	Michele Renschin	University of Arkansas at Monticello
Graduate	2nd	Environmental Sciences	Lann Wilf	Arkansas State University
Graduate	3rd	Environmental Sciences	Jeremy Jackson	Arkansas State University
Undergraduate	1st	Poster Presentation	Erin Sizemore	University of Central Arkansas
Undergraduate	2nd	Poster Presentation	Emily Rickman	Arkansas State University
Undergraduate	3rd	Poster Presentation	Sara Richardson	University of Central Arkansas
Graduate	1st	Poster Presentation	DeLynn Hearn Holleman	University of Central Arkansas
Graduate	2nd	Poster Presentation	Jason Walker	University of Central Arkansas
Graduate	3rd	Poster Presentation	Ralph Meeker	University of Central Arkansas

1. Arrangements Committee: Paul Hamilton indicated that 233 persons registered for this meeting, 120 tickets were sold for the mixer and banquet, 125 presentations, 104 oral and 21 poster presentations.

1 Old Business: Henry Robison suggested that if a host institution finds a conflict for its meetings during the first weekend in April, the Executive Committee be notified, and it find an alternate institution.

1. Webpage: Walt Godwin indicated the address, and emphasized that it is up and running.

19. Brochure: Dr. Hemmati reminded those present that the brochure is available to be distributed at institutions throughout Arkansas.

20. Resolution Committee: Mark defined the motion to add to the Constitution that the Vice-President serve as chair of the Resolution committee. This motion was passed at this time.

21. Young Investigator Award: Matt Walker reminded the meeting that this will be discussed at the Fall Executive Committee Meeting. He redefined the intent of the Young Investigator Award, the qualifications of nominees, and the method of nomination.

22. Publication Committee: Mark indicated that the Constitutional Committee will look into the make-up of this committee. Associate Editors could be used as a pool of individuals to serve on this committee. This charge will also be considered at the Fall Executive Committee Meeting.

23. Judicial Committee: Mark included this issue because it was addressed at the last Executive Committee meeting. The issue is whether we should have a Judiciary Committee? This question evolved out of the problem with the abstract that was not accepted for presentation at the general meeting in Hot Springs. Following much discussion, it was decided that a portion of the Executive Committee should act as the Judiciary Committee only when one is needed. Mark also brought up a second situation during the banquet in Hot Springs. It was decided to bring this issue up for consideration at the Fall Executive Committee Meeting.

24. New Business:

    a. Election of Officers: Dr. Hemmati indicated that Dr. Wayne Gray was the winner of the election for vice-president.

    b. Other: There was no additional new business.

25. Recognitions: Mark expressed his appreciation to those involved in this meeting. He also thanked the current officers. Robert and Raynell Skinner have a plaque waiting for them. Rick Geraci and Mark Eakin will take over for the Skinners. Dr. Rickett then presented a plaque to Mark Draganjac and discussed his plans for the upcoming year.

The meeting was adjourned following Dr. Rickett's comments.

APPENDIX A

TO: Arkansas Academy of Science Members
(c/o Dr. Joyce Hardin)
FROM: Michael Rapp, Director - State Science Fair
Bob & Raynell Skinner, Co-Directors, Arkansas Junior Academy of Science
DATE: April 6, 2001
RE: Report on Science Fairs & Arkansas Junior Academy of Science

Thank you for the support the Academy has provided for the past eighteen years, both in terms of members of the AAS serving as judges and in terms of financial support. This memo serves as a report of the Science Fairs and Junior Academy of Science Meetings held in Arkansas during 2000.

Central (held at UAMS, Mar. 10): Gary Earleywine, fair director, and Marian Douglas, Jr. Acad. director.

North Central (Lyon College, Batesville, Mar. 16): Beverly Meinzer, fair director, and Kathy Campbell, Jr. Acad. director.

North East (Ark. State Univ., Jonesboro, Mar. 2-3): Marty Huss, fair director, and Ron Johnson, Jr. Acad. director.

North West (Univ. of Ark., Fayetteville, Mar. 16): Lynne Hehr, director of fair and Junior Academy.

South Central (Henderson State Univ., Arkadelphia, Mar. 16): Sherry Lane, fair director, and David Brooks, Jr. Acad. director.

South East (Univ. of Ark-Monticello, Mar. 6): Jim Edson fair director.

South West (Camden, Mar. 23): Cindy Riggs, director of fair and Junior Academy.

West Central (ASMS, Hot Springs, Mar. 12-13): Shane Willbanks, director of fair and Junior Academy.

State Science Fair (UCA, Conway, Apr. 5-6): Michael Rapp, director of fair and Bob & Raynell, co-directors of Junior Academy.

Over 280 students participated in the state science fair, and about 80 students in the state Junior Academy of Science meeting, held April 5-6 in Conway, on the campus of the University of Central Arkansas.

A previous request has been submitted that the Academy continue its support of this year's state science fair activities and Junior Academy of Science meeting. Specifically, $450 is requested by the Arkansas Science Fair Association to help cover expenses ($50 for each of the nine affiliated fairs in Arkansas) for students being sent to the Intel International Science & Engineering Fair.(ISEF), and $250 is requested by the Arkansas Junior Academy to help send students to the American Junior Academy of Science meeting. A previous request has also been submitted that the work of the above individuals be recognized by the Academy membership and that this acknowledgement be included in the *Journal*. Those requests are duplicated below.

APPENDIX B

RESOLUTIONS

Be it resolved that we, the membership of the Arkansas Academy of Science, offer our sincere thanks to the University of Central Arkansas for hosting the 2001 meeting of the Arkansas Academy of Science. In particular, we thank the Local Arrangements Committee for an outstanding job of organizing the meeting: Paul V. Hamilton (Chair), Thomas M. Walker (Co-Chair, Abstracts/Program), James Murray (Audio/Visual), Patrick Desrochers (Poster Session), Rahul Mehta (Judging), Dave Peterson (Registration), Ben Waggoner (Web Design), and all the student workers and staff who collectively contributed to a very successful meeting. Appreciation is expressed for the excellent facilities and the hospitality shown to us by all University of Central Arkansas personnel. We truly appreciate Dr. Jere Lipps for his presentation "Beyond Reason: Science and the Mass Media", which delivers a most timely (and entertaining) reminder of our need to create a more scientifically literate public. We thank Dean Ronald Toll for his support in bringing Dr. Lipps as our keynote speaker.

The Academy recognizes the important role played by the various section chairpersons and expresses sincere appreciation to George Harp (Invertebrate Zoology), Wayne Gray (Microbiology, Parasitology, & Biomedical Sciences), Haydar J. Al-Shukri (Geology & Hydrology), Rose McConnell (Biological & Organic Chemistry), Elizabeth Murray (Terrestrial Ecology), Jim Winter (Mathematics & Science Education), Danny Arrigo and Fred Hickling (Mathematics), David Jamieson, J.D. Wilhide, and David Dussourd (Vertebrate Zoology), Gary Tucker, Daniel Marsh, and Hong Li Wang (Botany & Plant Biology), Brian Wagner, Elizabeth Murray, and John Rickett (Aquatic Ecology & Ecotoxicology), Wally Cordes, Jon Russ, and Scott Reeve (General & Inorganic Chemistry), Bin Zhang and Andrew Sustich (Physics & Astronomy).

A special thanks is owed to individuals devoting considerable time and energy to judging student papers: Haydar J. Al-Shukri, Cathy Baker, Steven Barger, C. F. Chen, John Graham, Mostafa Hemmati, J. Bruce Johnson, Bao-An Li, Rahul Mehta, Matt Moran, Russell Nordeen, Thomas E. Nupp, Ann Paterson, John D. Rickett, Jeff Robertson, Andrew Sustich, Hong Li Wang, and Heather Woolverton.

We express gratitude to the various directors and the science and youth activities that are supported by the Academy: Steve Long (President, Arkansas Science Teachers Association), Michael Rapp (Director, State Science Fair), Robert and Raynell Skinner (Co-Directors, Arkansas Junior Academy of Science), Tom Palko (Junior Science and Humanities Association), and Jim Murray (Director, Intel Talent Search). We wish to thank all those who served as directors at science fairs and Junior Academy meetings: Gary Earleywine and Marian Douglas (Central Region), Beverly Meinzer and Kathy Campbell (North Cenral Region), Marty Huss and Ron Johnson (North East Region), Lynne Hehr (North West Region), Sherry Lane and David Brooks (South Central Region), Jim Edson (South East Region), Shane Wilbanks (West Central Region), and Michael Rapp (State Meeting, UCA, Conway).

The continued success of the Academy is due to its strong leadership. We offer sincere thanks to our officers for another excellent year: Mark Draganjac (President), John Rickett (President-Elect), Walt Godwin (Vice-President), Michael Soulsby (Secretary), Joyce Hardin (Treasurer), Mostafa Hemmati (Past President), Stanley Trauth (*Journal* Editor-in-Chief), David Saugey (*Journal* Managing Editor), Jeff Robertson (*Newsletter* Editor), and Henry Robison (Historian). In addition, the Academy expresses appreciation to all those individuals who have contributed their time and effort on various committees of the Academy.

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

Respectfully submitted,
Resolution committee:
Dr. Walt Godwin (chair)
Dr. Bao-An Li
Dr. Andrew Sustich

APPENDIX C

Report to the ARKANSAS ACADEMY of SCIENCE by the ARKANSAS JUNIOR ACADEMY of SCIENCE April 13, 2001

Participation. The AJAS state contest was held at the University of Central Arkansas on April 7, 2001. 82 high school Students participated, an increase of 18% over 2000, from 7 of 8 regions representing 16 high schools participated.

Abstracts volume. For this meeting, Vol. 7 of the abstracts of the students participating in the Arkansas Junior Academy of Science Abstracts was published and distributed to the entrants. A copy is attached.

Attendance at American Junior Academy of Science meeting. Attending the meeting of the American Junior Academy of Science in San Francisco, CA February 14-18, 2001 and representing the AJAS were two students and a teacher/sponsor. The students, who were top winners in the state AJAS Jr./Soph/Fresh division in Apr. 2000, were: Alexandria Toll (Conway H.S. East) and Michael Johnson (Nettleton H.S., Jonesboro, AR). The sponsor, a high school science teacher, was Mr. Ron Seymour (Conway H.S. East). The AJAS paid 50% of the travel and registration fees for one student and the teacher/sponsor. This meeting is held in conjunction with the meeting of the American Association for the Advancement of Science. The Arkansas delegation has a second registration for the AAAS meeting and interacts with working scientists in breakfast meetings, poster presentation sessions, and informal discussions.

New AJAS directors. The incoming directors of the AJAS, Mr. Rick Geraci, P.E. and Mr. Mark Eakin, P.E. attended the meeting with regional AJAS directors and science teachers at noon on Friday, April 6. They also attended the meeting of the Junior Academy on Saturday morning, participated as judges in the contests, and observed the behind-the-scenes activities. The Junior Academy is very excited about having Rick and Mark assume the directorship of the AJAS.

Thanks. The AJAS wishes to thank the senior academy for their continued encouragement and monetary support.

Submitted by:

Robert D. Skinner, Ph.D.
Past State Director

APPENDIX D

MOTIONS TO: Arkansas Academy of Science Executive Committee and General Membership

FROM: John Rickett, Chair of Constitution Committee and ad hoc awards program revision committee

DATE: 13 April 2001

MOTION 1: The proposed guidelines (attached) **for administering the Arkansas Academy of Science student awards program be adopted.**

MOTION 2: The proposed guidelines (attached) **for administering the Arkansas Academy of Science student awards program, if adopted, be added to the Constitution as Appendix C.**

MOTION 3: The following bold-faced phrase be inserted into the description and charge of the AWARDS COMMITTEE in the Constitution. (section to be deleted is italicized)

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* **adhere to approved guidelines (Appendix C of Constitution) for evaluating** undergraduate and graduate paper presentations during the annual meeting and make recommendations for the various awards established by the Executive committee.

MOTION 4: The document titled "General suggestions and outline for hosting an Arkansas Academy of Science annual meeting" be adopted as our formal set of guidelines, and the Secretary be charged to maintain custody of the document and provide at least one copy of such to each Local Arrangements Committee chair.

Comment: The Executive Committee has reviewed this document and approved it. Since it is fairly sizable, we decided not to prepare a copy for every member in attendance to review, but there are a few copies around should you wish to review it before voting.

MOTION 5: The Secretary shall be the permanent custodian of our Constitution and instructed to provide each newly elected Vice President a current copy.

ARKANSAS ACADEMY OF SCIENCE

GUIDELINES FOR STUDENT PAPER JUDGING & AWARDS PROCEDURES

NOTE TO LOCAL ARRANGEMENTS COMMITTEE: You must assign some papers to the Environmental Science section–enough to provide three winning places at the undergraduate and one at the graduate level. We have to keep this pattern consistent or AEF may pull their contribution and the Harp Endowment award is specifically targeted to the graduate level environmental. The committee is allowed the judgment as to which papers fit into the Environmental section best.

The Local Arrangements Committee shall establish a reasonable registration fee sufficient to cover expenses of the meeting, open a checking account briefly to pay local expenses, settle up after the meeting and submit any leftover monies to the Academy Treasurer. Keep in mind the Annual Meeting should pay for itself, but should not be used as a money-making endeavor. (Although this isn't in the Constitution, it has been the general attitude of the Executive Committee and standard procedure for the past 20 or so years).

GUIDELINES FOR AWARDS COMMITTEE:

A. Categories –

	Undergraduate	Graduate
1. Environmental Science	1st, 2nd, 3rd	1st(*)
(May include certain papers on aquatic environments, environmental chemicals zoology, etc.)		
2. Life Science	1st, 2nd, 3rd	1st, 2nd, 3rd
(Includes Botany, Biomedical, some Biochemical, some Aquatic/ Environmental, Invert. Zoo., Vert. Zoo.)		
3. Physical Science	1st, 2nd, 3rd	1st, 2nd, 3rd
(Includes Applied Science, Chemistry, Biochemistry, Geology, Physics & Astronomy)		

Notes –

1. Awards are given <u>per category</u>; not per session (there may be more that one session of some categories)
2. Second or third places may not be used, depending on the number of papers in a given category and/or the quality of the presentations.

(*) As this endowment grows, 2nd and possibly 3rd place levels may be added

B. Monetary awards –

1. All undergraduate awards are supported by an annual gift from Arkansas Environmental Federation; 1st place receives $100, 2nd and 3rd places receive $50 each.
2. The graduate Environmental Science award is supported by interest from the George and Phoebe Harp Endowment fund (1st place receives $150; 2nd place [when instituted] will receive $100; 3rd place [when instituted] to be determined by mutual consent)
3. Graduate Life Science and graduate Physical Science awards are supported by the Arkansas chapters of Sigma Xi (??amounts??)

C. Papers in each category at each level shall be heard by at least two judges (three are recommended) (18 total). Each judge must hear and evaluate every qualified paper in his/her category/level. A judge who has a student presenting a paper being evaluated for an award shall excuse himself/herself due to a conflict of interests. (WHOEVER IS ARRANGING THE SEQUENCE OF PAPERS MUST ALLOW FOR JUDGES TO MOVE BETWEEN SESSIONS/ROOMS EASILY, IF NECESSARY, AND HEAR EACH PAPER IN HIS/HER ASSIGNED CATEGORY.)

D. Poster presented papers shall not be judged with the same criteria or with the same judges as orally presented papers. A panel of three additional judges shall evaluate all posters and award "honorable mention" to the better ones, if determined appropriate by the Local Arrangements Committee.

E. The abstract form shall contain the three category options in which the author(s) shall designate the paper to be judged.

F. Some variability in the foregoing shall be allowed, depending on the number and nature of the papers/posters being presented, but every reasonable effort shall be made to maintain fidelity with the procedures agreed to by the donors of the monetary awards.

G. All judges should be provided with a standard paper judging form.

Suggested standard paper judging form:

ARKANSAS ACADEMY OF SCIENCE
STANDARD STUDENT PAPER JUDGING FORM

N ıme of presenter ______________________________ Category ______________

T le ____

C iteria: (assign a score of 1 (worst) to 5 (best) for each item:

A Scientific merit
1. Experimental design (completeness, complexity, appropriateness) ______
2. Adequacy of the data ______
3. Use of statistics ______
4. How well do the conclusions fit the data? ______
5. Thoroughness and appropriateness of literature references ______

B. The presentation
1. How clearly did the speaker talk? ______
2. Were visual aids well done and used appropriately? ______
3. Were details clearly explained? ______
4. Were the conclusions clearly stated? ______

C. Project appropriateness
1. Does this project contribute valuably to science? ______
2. Appropriate narrowness/broadness of the paper ______
3. How much practical, social or commercial value? ______

TOTAL ______

RANK IN CATEGORY ______ of ______

MEMBERS 2001

FIRST MI	LAST NAME	INSTITUTION
Al	Adams	University of Arkansas at Little Rock
Robbin C.	Anderson	University of Arkansas at Fayetteville
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
Stephen K.	Boss	University of Arkansas at Fayetteville
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
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
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
Terry	Keisling	University of Arkansas at Fayetteville
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
James A.	Murray	University of Central Arkansas
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
Stephen A.	Sewell	University of Mississippi
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
Joe E.	Winstead	Southern Arkansas 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

FIRST MI	LAST NAME	INSTITUTION
Edmond E.	Griffin	University of Central Arkansas
Paul M.	Nave	Arkansas State University
Alex R.	Nisbet	Ouachita Baptist University
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
Diana	Lindquist	University of Arkansas at Little Rock
Donna	Moore	University of Arkansas at Fayetteville
Dan C.	Phan	University of Arkansas for Medical Sciences
Robin	Roggio	University of Arkansas at Fayetteville
Lori	Sale	Arkansas Tech University
Garrett	Sanford	University of Arkansas at Fayetteville
Stephen R.	Skinner	University of Arkansas at Fayetteville
Frances	Terry	Arkansas Tech University
Jeremy	Warford	Hendrix College
Theo	Witsell	University of Arkansas at Little Rock
Timothy W.	Wofford	University of Arkansas at Little Rock

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

Mathues S.	Doss	Arkansas Tech University
David C.	Hearn	University of Arkansas at Fayetteville
Kristy	Jones	John Brown University
Sailesh	Kumar	University of Arkansas at Little Rock

PROGRAM

Arkansas Academy of Science
85th Annual Meeting
April 13-14, 2001
Conway, Arkansas

SCHEDULE OF EVENTS

Friday, April 13, 2001

Time	Event	Location
9:00 am. - 41:00 p.m.	Registration	LSC 104
8:30 a.m. - 10:00 a.m.	Executive Committee Meeting	LSC 102
10:30 a.m. - 10:00 p.m.	First Business Meeting	LSC 102
	Oral Presentations	
1:15 p.m. - 2:30 p.m.	Invertebrate Zoology	LSC 126
1:15 p.m. - 2:45 p.m	Microbiology, Parasitology, & Biomedical Sciences	LSC 132
1:15 p.m. - 2:45 p.m.	Geology & Hydrology	LSC 133
1:15 p.m. - 2:45 p.m.	Biological & Organic Chemistry	LSC 168
1:15 p.m. - 2:30 p.m.	Terrestrial Ecology	LSC 170
1:15 p.m. - 2:45 p.m.	Mathematics & Science Education	LSC 172
3:00 p.m. - 4:00 p.m.	Poster Presentations	LSC 113
4:00 p.m. - 5:00 p.m.	Keynote Address: Jere H. Lipps *Beyond Reality: Science and the Mass Media*	LSC 102
5:30 p.m. - 6:30 p.m.	Reception / Social Mixer	Buffalo Alumni Hall
7:00 p.m. - 9:00 p.m.	Banquet	Student Center 205

Saturday, April 14, 2001

Time	Event	Location
8:00 a.m. - 1:00 p.m.	Registration	LSC 104
	Oral Presentations	
8:00 a.m. - 11:15 am.	Mathematics	LSC 126
8:00 a.m. - 11:45 am.	Vertebrate Zoology	LSC 132
8:00 a.m. - 11:30 am.	Botany & Plant Biology	LSC 133
8:00 a.m. - 10:45 am.	Aquatic Ecology & Ecotoxicology	LSC 168
8:00 a.m. - 11:45 am.	General & Inorganic Chemistry	LSC 170
8:00 a.m. - 11:00 am.	Physics & Astronomy	LSC 172
12:00 p.m. - 1:00 p.m.	Second Business Meeting Presentation of Student Awards	LSC 102

SECTION PROGRAMS

*** Undergraduate **Graduate**

ORAL PRESENTATIONS

Friday, April 13, 2001
Invertebrate Zoology
Location: Room 126, Lewis Science Center

Time	Topic
1:15	C. H. Good, R. L. Redondo, J. Alexander, and J. A. Murray, Department of Biology, University of Central Arkansas, Conway, AR 72035. **ROLE OF INDIVIDUAL NEURONS IN TURNING WHILE CRAWLING IN THE MARINE SLUG *TRITONIA DIOMEDEA***
1:30	Becky Hicklin and Janet Lanza, Biology Department, University of Arkansas at Little Rock, 2801 South University, Little Rock, AR 72204. **DO MONARCH BUTTERFLIES PREFER NECTARS WITH AMINO ACIDS?**
1:45	George L. Harp[1], Linden Trial[2] and Phoebe A. Harp[1], [1]Department of Biological Sciences, Arkansas State University, State University, AR 72467. [2]Fish and Wildlife Research Center, Missouri Department of Conservation, 1110 S. College Ave., Columbia, MO 65201. **DISTRIBUTION AND STATUS OF *OPHIOGOMPHUS WESTFALLI* (GOMPHIDAE: ODONATA) IN MISSOURI AND ARKANSAS**
2:00	Matthew D. Moran and Charles D. Baldridge, Department of Biology, Hendrix College, 1600 Washington Avenue, Conway, AR 72032. **NEW RECORDS OF THE DIANA FRITILLARY (*SPEYERIA DIANA*) IN ARKANSAS WITH NOTES ON NECTAR PLANT PREFERENCE**

Friday, April 13, 2001
Microbiology, Parasitology, & Biomedical Sciences
Location: Room 132, Lewis Science Center

Time	Topic
1:15	Julie Crawford[1], John Sorenson[2], and James Daly[3], [1]Department of Pharmacology, University of Arkansas for Medical Sciences, Little Rock AR 72205; [2]College of Pharmacy, University of Arkansas for Medical Sciences, Little Rock, AR 72205; [3]Southwest Arkansas College, Pine Bluff, AR 71603. **THE EFFECT OF COPPER ON THE *IN VITRO* SURVIVAL OF TREMATODE PARASITES OF BLACK BASS (*MICROPTEROUS* SPP.)**
1:30	Lisa Mullis[1], Andrew Goodwin[2], and Wayne Gray[1], [1]Department of Microbiology and Immunology, University of Arkansas for Medical Sciences, Little Rock AR 72205; [2]Department of Aquaculture and Fisheries, University of Arkansas at Pine Bluff, Pine Bluff, AR 71611. **A NOVEL HERPESVIRUS AFFECTING KOI CARP**
1:45	Robin L. Stingley[1], Billy R. Griffin[2], and Wayne L. Gray[3],

[1]Department of Microbiology and Immunology, University of Arkansas for Medical Sciences, Little Rock AR 72205; [2]National Aquaculture Research Center, ARS-USDA, Stuttgart, AR 72160. **EXPRESSION OF CHANNEL CATFISH HERPESVIRUS GENES *IN VIVO***

2:00 Chris T. McAllister[1], Fredric L. Frye[2], and Stephen R. Goldberg[3], [1]Department of Biology, Texas A & M University-Texarkana, Texarkana, TX 75505; [2]Fredric L. Frye & Associates, Diagnostic Pathology, 875 South Orchard, Suite #4, Ukiah, CA 95482-7448; [3]Department of Biology, Whittier College, 13406 Philadelphia Street, P.O. Box 634, Whittier, CA 90608. **PHACOCLASTIC UVEITIS IN A WILD-CAUGHT COPE'S GRAY TREEFROG, *HYLA CHRYSOSCELIS* (AMPHIBIA: HYLIDAE)**

2:15 Chris T. McAllister[1], Steve J. Upton[2], Stanley E. Trauth[3], and David W. Allard[1], [1]Department of Biology, Texas A & M University-Texarkana, Texarkana, TX 75505; [2]Division of Biology, Kansas State University, Manhattan, KS 66506; [3]Department of Biological Sciences, Arkansas State University, State University, AR 72467. **A REDESCRIPTION OF *EIMERIA MACYI* (APICOMPLEXA; EIMERIIDAE) FROM THE EASTERN PIPISTRELLE, *PIPISTRELLUS SUBFLAVUS* (MAMMALIA: CHIROPTERA,) FROM ARKANSAS**

2:30 Whitney Williams and Mohammad Jamali, Health Professions Department, Arkansas State University, Jonesboro, AR 72467. **HODGKIN'S DISEASE AND THE REED-STERNBERG CELL**

Friday, April 13, 2001
Geology & Hydrology
Location: Room 133, Lewis Science Center

Time	Topic
1:15	Laura E. Ewing[1], and Haydar J. Al-Shukri[2], [1]Arkansas School for Mathematics and Sciences, 200 Whittington Ave., Hot Springs, AR; [2]University of Arkansas at Little Rock, 2801 South University Avenue, Little Rock, AR 72204. **RESEARCH OF THE EARTHQUAKES AT NEW MADRID, MISSOURI**
1:30	Marilyn Egan and Haydar J. Al-Shukri, Department of Applied Science, University of Arkansas at Little Rock, Little Rock, AR 72204. **ENHANCED EVALUATION OF EJECTED MATERIALS FROM EARTHQUAKE INDUCED PALEOLIQUEFACTINO FEATURES USING GROUND PENETRATING RADAR**
1:45	L. Jeffrey B. Connelly, Hanan H. Mahdi, Robert E. Lemmer, Marilyn Egan, and Haydar J. Al-Shukri, University of Arkansas at Little Rock, Little Rock, AR 72204. **PALEOSEISMIC FEATURES IN THE SOUTHERN PART OF THE NEW MADRID SEISMIC ZONE**
2:00	Abbas S. Eyuboglu and Haydar J. Al-Shukri, University of Arkansas at Little Rock, 2801 South University Avenue, Little Rock, AR 72204. **GROUND PENETRATING RADAR: A GEOPHYSICAL TOOL TO SEARCH FOR WATER ON MARS**
2:15	W. Reed Green[1], and Brian E. Haggard[2], [1]Hydrologist, U.S. Geological Survey, 401 Hardin Road, Little Rock, AR 72211; [2]Hydrologist, U.S. Geological Survey, 10205-D East 61st Street, Tulsa, OK 74133. **USING REGRESSION MODELS AND HYDROGRAPH SEPARATION TECHNIQUES TO ESTIMATE AND ASSESS STREAMFLOW LOADING**
2:30	Cathy Baker, Physical Sciences Department, Arkansas Tech University, Russellville, AR 72801. **NUMERICAL DETERMINATION OF BEDROCK OUTCROP STABILITY OF SELECTED PENNSYLVANIAN AGE FORMATIONS IN WESTERN ARKANSAS**

Friday, April 13, 2001
Biological & Organic Chemistry
Location: Room 168, Lewis Science Center

Time	Topic
1:15	S. Jernigan, W. B. Melchior, Jr., G. R. Jenkins, D. Roberts, P. Howard, and W. Tolleson, Division of Biochemical Toxicology, National Center for Toxicological Research, FDA, Jefferson, AR 72079. **CHARACTERIZATION OF FUMONISIN AFFINITY CHROMATOGRAPHY FOR THE ISOLATION OF CERAMIDE SYNTHASE**
1:30	Dallas Broadway and Michael J. Panigot, Department of Chemistry, Arkansas State University, State University, AR 72467. **PREPARATION OF BETA ALLYL-C-GLUCOSIDES AND THEIR ATTEMPTED FUNCTIONALIZATION TO PREPARE A C-GLYCOSIDE CORE MOLECULE**
1:45	Ranjini Murthy and Michael J. Panigot, Department of Chemistry, Arkansas State University, State University, AR 72467. **SYNTHESIS OF ALPHA ALLYL-C-GLUCOSIDES AND THEIR ATTEMPTED CONVERSION INTO A C-GLYCOSIDE CORE MOLECULE PRECURSOR**
2:00	Shonda M. Winn, Kim Tran, Melissa W. Arnold, and Michael J. Panigot, Department of Chemistry, Arkansas State University, State University, AR 72467. **SUCCESSES AND DIFFICULTIES IN THE REGIOSELECTIVE PROTECTION AND FUNCTIONALIZATION OF THE 6-POSITION OF METHYL-alpha-D-GLUCOPYRANOSIDE AS A MODEL STUDY FOR THE SYNTHESIS OF C-GLYCOSIDE DENDRIMERS**
2:15	Shang-U Kim, and Michael J. Panigot, Department of Chemistry, Arkansas State University, State University, AR 72467. **EFFORTS TOWARD THE PREPARATION OF ETHYNYL-C-GLYCOSIDE CONTAINING DENDRIMERS**
2:30	Michael J. Panigot, Jason P. Boggs, and Jennifer L. Faulkner-Calvert, Department of Chemistry, Arkansas State University, State University, AR 72467. **INVESTIGATIONS INTO THE SYNTHESIS OF ISOTOPICALLY LABELED HISTIDINE AND TRYPTOPHAN - DIFFICULTIES AND RESULTS**

Friday, April 13, 2001
Terrestrial Ecology
Location: Room 170, Lewis Science Center

Time	Topic
1:15	Sara K. Gremillion, Kelly A. Osborn, Chris T. Fortson, Alison R. Sheidler, and Matthew D. Moran, Department of Biology, Hendrix College, 1600 Washington Avenue, Conway, AR 72032. **TOP-DOWN AND BOTTOM-UP REGULATION IN A NATURAL AND HUMAN-MAINTAINED GRASSLAND**
1:30	Brenna C. Fitzgerald[1], Laura Skelton[2], Amy Polk[1], and Matthew D. Moran[1], [1]Department of Biology, Hendrix

College, 1600 Washington Avenue, Conway, AR 72032; 2Institute of Ecology, University of Georgia, Athens, GA 30602-2202. **TOP-DOWN AND BOTTOM-UP REGULATION IN A NATURAL AND HUMAN-MAINTAINED GRASSLAND**

1:45 Tim Eubanks, Arkansas STRIVE, Harrison High School, 925 Goblin Dr., Harrison, AR 72601. **EFFECTS OF BURNING ON SOIL NITROGEN IN A TALL GRASS PRAIRIE**

2:00 Michele L. Renschin[1], Hal O. Liechty[1] and Michael G. Shelton[2], [1]School of Forest Resources, P. O. Box 3468, University of Arkansas at Monticello, Monticello, AR 71656; [2]USDA Forest Service, Southern Research Station, P. O. Box 3516, University of Arkansas at Monticello, Monticello, AR 71656. **DECOMPOSITION RATE COMPARISONS BETWEEN FREQUENTLY BURNED AND UNBURNED AREAS OF UNEVEN-AGED LOBLOLLY PINE IN THE ARKANSAS COASTAL PLAIN**

2:15 Robert S. Sikes[1], Kristin M. Kramer[2], and David W. Clark[1], [1]Department of Biology, University of Arkansas at Little Rock, 2801 S. University Ave., Little Rock, AR 72204; [2]Department of Biology, University of Maryland, College Park, MD 20742. **LACTATION INCREASES PREDATION RISKS BY ALTERING ACTIVITY PATTERNS**

2:30 M. Victoria McDonald and Chuck R. Munson, Department of Biology, University of Central Arkansas, Conway, AR 72035. **SEASONAL OCCUPATION OF MIGRATORY AND NON-MIGRATORY BIRDS IN A TYPICAL ARKANSAS BOTTOMLAND HARDWOOD FOREST**

Friday, April 13, 2001
Mathematics & Science Education
Location: Room 172, Lewis Science Center

Time Topic

1:15 David W. Allard, Biology Department, Texas A&M University-Texarkana, 2600 North Robison Road, Texarkana, TX 75501. **ONLINE EARTH SYSTEM SCIENCE EDUCATION FOR K-12 TEACHERS**

1:30 Donna Foss, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **PARALLEL CONCEPTIONS OF MATHEMATICS TEACHING: MIDDLE LEVEL AND SECONDARY PRESERVICE TEACHERS**

1:45 Donna R. Shanklin[1], Kelly Loftin[2], Tom Riley[2], Brian Richardson[2], Bob Reynolds[2], and Jason Shivers[2], [1]University of Arkansas Cooperative Extension Service, P. O. Box 3468, Monticello, AR 71656; [2]University of Arkansas Cooperative Extension Service, P. O. Box 391, Little Rock, AR 72203. **THE ANTS UNDERGROUND: FIRE ANT YOUTH EDUCATION**

2:00 M. C. Hirrel and J. S. Choinski, Jr., Department of Biology, University of Central Arkansas, Conway, AR 72035-5003. **CREATING MORE ACTIVE LEARNING BY INTEGRATING TECHNOLOGY INTO UNDERGRADUATE BIOLOGY LABORATORIES**

2:15 Jim Winter and Janet Lanza, Arkansas STRIVE Program, University of Arkansas at Little Rock, AR 72204. **HOW TO IMPLEMENT INQUIRY-BASED TEACHING ACTIVITIES**

2:30 D. W. Bullock, C. Emery, Z. Ding, V. P. Labella, G. Stewart, and P. M. Thibado, Physics Department, University of Arkansas, Fayetteville. **HYPER-INTERACTIVE TEACHING METHODS USING REMOTE CONTROL TECHNOLOGY**

POSTER PRESENTATIONS

Friday, April 13, 2001
Location: Room 113, Lewis Science Center

Time Topic

Mark Denton and Rahul Mehta, Department of Physics & Astronomy, University of Central Arkansas, Conway, AR 72035. **MICROANALYSIS OF SELECTED SAMPLES USING SCANNING ELECTRON MICROSCOPE AND X-RAY FLUORESCENCE**

Elizabeth Geesaman[1], Dan Buzatu[2], Jon Wilkes[2], Jack Lay[1,2], and Jerry A. Darsey[1,2], [1]Department of Chemistry, University of Arkansas at Little Rock, Little Rock, AR 72204; [2]Division of Chemistry, National Center for Toxicological Research, 3900 NCTR Road, Jefferson, AR 72079. **PREDICTION OF TOXIC EQUIVALENCY FACTORS USING ARTIFICIAL NEURAL NETWORKS**

Kenya Powell, Susan Baker, Rose M. McConnell, and Walter E. Godwin, School of Mathematical & Natural Sciences, University of Arkansas at Monticello, Monticello, AR 71656. **CONDUCTIVE POLYMERS: SYNTHESIS OF FURAN-PYRROLE CO-POLYMERS**

Susan Baker, Kenya Powell, Rose M. McConnell, and Walter E. Godwin, School of Mathematical & Natural Sciences, University of Arkansas at Monticello, Monticello, AR 71656. **CONDUCTIVE POLYMERS: SYNTHESIS OF FURAN-THIOPHENE CO-POLYMERS**

Emily Rickman and Robyn Hannigan, Department of Chemistry and Program for Environmental Science, P. O. Box 419, Arkansas State University, State University, AR 72467. **PHOSPHATE CHEMISTRY OF THE TAUPO VOLCANIC ZONE, NEW ZEALAND**

Marie E. King, Jack T. King, and Stephen K. Boss, Department of Geosciences, University of Arkansas, 113 Ozark Hall, Fayetteville, AR 727017. **BEDROCK GEOLOGY OF FAYETTEVILLE QUADRANGLE, WASHINGTON COUNTY, ARKANSAS**

Karen S. McDonald, Biology Department, University of Central Arkansas, Lewis Science Center, 201 Donaghey Ave., Conway, AR 72035. **A PALEOECOLOGICAL RECONSTRUCTION OF THE IMO FORMATION FROM THE MISSISSIPPIAN EAR AT THE PEYTON CREEK ROAD CUT IN NORTH CENTRAL ARKANSAS**

Larry R. Hilburn, Jesse W. Parrack, and Lynita M. Cooksey, Department of Biological Sciences, Arkansas State University, P. O. Box 599, State University, AR 72467. **THE MEMBERS OF THE *ANOPHELES QUADRIMACULATUS* (DIPTERA: CULICIDAE) COMPLEX OF SIBLING SPECIES PRESENT IN NORTHEAST ARKANSAS**

Kelly Loftin[1], Donna Shanklin[2], Doug Petty[3], John Turner[3], and Bruce Steward[4], [1]University of Arkansas Cooperative Extension Service, Environmental and Natural Resources Section, P. O. Box 391, Little Rock, AR 72204; [2]University of Arkansas Cooperative Extension Services, Environmental and Natural Resources Section, P. O. Box 3468, Monticello, AR 71656; [3]Miller County, University of Arkansas Cooperative Extension Service, 400 Laurel, Suite 319, Texarkana, AR 72204; [4]Bayer Pursell LLC, 6700 Corporate

Drive, Suite 200, Kansas City, MO 64120. **EVALUATION OF CYFLUTHRIN AND IMIDACLOPRID AS INDIVIDUAL MOUND TREATMENTS AGAINST IMPORTED FIRE ANTS**

Jamie L. Reck, Suzanne Coco, and Ann V. Paterson, Department of Natural Sciences, Williams Baptist College, P. O. Box 3565, Walnut Ridge, AR 72476. **FACTORS THAT AFFECT SHORT RANGE MOVEMENT IN THE ARKANSAS BROWN TARANTULA (*APHONOPELMA HENTZI*)**

Erin Sizemore and David Dussourd, Department of Biology, University of Central Arkansas, Conway, AR 72035. **TRENCH OR DIE: WHY DO MANY SOYBEAN LOOPERS FAIL TO TRENCH**

Michael D. Warriner and T. Evan Nebeker, Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762. **INSECT DIVERSITY IN A HYBRID *POPULUS* PLANTATION AND ADJACENT BOTTOMLAND HARDWOOD FOREST**

Tammy V. Ash, David L. Feldman, Jerry L. Farris, Department of Biological Sciences, Arkansas State University, P. O. Box 599, State University, AR 72467. **AN ASSESSMENT OF THE 303D-LISTED STRAWBERRY RIVER, ARKANSAS, WITH RESULTING MANAGEMENT IMPLICATIONS**

Shannon L. Pinkston, Cynthia N. Mugi, and Ann V. Paterson, Department of Natural Sciences, Williams Baptist College, P.O. Box 3565, Walnut Ridge, AR 72476. **FACTORS AFFECTING GROWTH AND DEFORMITIES IN TADPOLES: COMPARING RIVER WATER TO DECHLORINATED TAP WATER**

Daryl E. Jones and Thomas E. Nupp, Fisheries & Wildlife Biology Program, Arkansas Tech University, Russellville, AR 72801. **ANALYSIS OF ARKANSAS DEER HARVEST**

John S. Choinski, Jr., Clay Hendrix and Julie Voegele, Department of Biology, University of Central Arkansas, Conway, AR 72035. **EFFECTS OF UV-B RADIATION ON LEAF PIGMENT SYNTHESIS IN BLACK JACK OAK**

R. Meeker and K. C. Larson, Department of Biology, University of Central Arkansas, Conway, AR 72035. **FRAGMENTATION IN A SOUTHERN OAK-HICKORY FOREST: IMPACTS ON SPECIES RICHNESS AND INVASIBILITY**

Jason Walker and K. C. Larson, Department of Biology, University of Central Arkansas, Conway, AR 72035. **MORPHOLOGICAL PLASTICITY IN TWO TYPES OF LONICERA IN RESPONSE TO LIGHT AVAILABILITY**

D. DeLynn Hearn Holleman, Josh King, and Steven W. Rune, Department of Biology, University of Central Arkansas, Conway, AR 72035-0001. **APOPTOTIC INDUCTION IN THE INTESTINAL EPITHELIUM OF THE MARINE SNAIL *APLYSIA CALIFORNICA* AND THE SPRAGUE-DAWLEY RAT**

D. R. Pierce[1] and K. E. Light[2], [1]Department of Health Sciences, University of Central Arkansas, Conway, AR 72035; [2]College of Pharmacy, University of Arkansas for Medical Sciences, Little Rock, AR 72205. **A SINGLE ETHANOL EXPOSURE KILLS DEVELOPING RAT CEREBELLAR PURKINJE CELLS IN A RELATIVELY RAPID MANNER**

ORAL PRESENTATIONS

Saturday, April 14, 2001
Mathematics
Location: Room 126, Lewis Science Center

Time	Topic
8:00	Mary Branton-Housley, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **APPROXIMATING SCHRÖDINGER POTENTIALS USING DARBOUX TRANSFORMATIONS**
8:15	Chad Fendt, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **SCHRÖDINGERS EQUATION AND POTENTIALS USED TO MODEL α-DECAY**
8:30	Danny Arrigo and Fred Hickling Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **DARBOUX TRANSFORMATIONS FOR A CLASS OF HEAT EQUATION WITH A SOURCE TEAM**
8:45	Bryan Gipson and Garth Johnson, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **ON THE VARIABLE WAVE SPEED EQUATION: PART I - THE DARBOUX TRANSFORMATION**
9:00	Bryan Gipson and Garth Johnson, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **ON THE VARIABLE WAVE SPEED EQUATION: PART II - ADMISSIBLE WAVE SPEEDS**
9:15	BREAK
9:30	Sarah Jacobs, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **DARBOUX TRANSFORMATION AND WAVE EQUATION SYSTEMS**
9:45	Brandon S. Lindley, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **TIME INDEPENDENT SCHRÖDINGER POTENTIALS**
10:00	J. Bruce Johnson[1] and Seth Armstrong[2], [1]Department of Chemistry and Physics, Arkansas State University, State University, AR 72467; [2]Department of Computer Science and Mathematics, Arkansas State University, State University, AR 72467. **A NEW METHOD FOR ANALYSIS OF ION CHANNEL DWELL TIMES**
10:15	Danny Arrigo and Fred Hickling, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **SYMMETRY ANALYSIS OF A WAVE EQUATION AND A SYSTEM EQUIVALENT**
10:30	David R. Peterson, Department of Mathematics, University of Central Arkansas, Conway, AR 72035. **RESONANCE CURVES IN A MULTI-HOLED OCARINA**

Vertebrate Zoology
Location: Room 132, Lewis Science Center

Time	Topic
8:00	David H. Jamieson[1], Pete Rust[2], and Stan Trauth[3], [1]Arkansas

State University-Newport, Department of Biological Sciences, 7648 Victory Boulevard, Newport, AR 72112; [2]Minnesota DNR, Fisheries Division, 5351 North Shore Drive, Duluth, MN 55804; [3]Arkansas State University, Department of Biological Sciences, P. O. Box 599, State University, AR 72467. **FOOD HABITS OF THE OUACHITA DUSKY SALAMANDER, *DESMOGNATHUS BRIMLEYORUM* (CAUDATA: PLETHODONTIDAE), IN ARKANSAS**

8:15 Robyn R. Konvalinka[1], Stanley E. Trauth[1], Malcolm L. McCallum[2], Ben A. Wheeler[2], Hilary Worley[1], and David Saugey[3], [1]Department of Biological Sciences, 7648 Victory Boulevard, Arkansas State University, State University, AR 72467-0599; [2]Environmental Sciences Program, Arkansas State University, State University, AR 72467; [3]Jessieville-Winona Ranger District, Ouachita National Forest, P. O. Box 189, Jessieville, AR 71949. **MICROHABITAT UTILIZATION OF AN ABANDONED MINE SHAFT BY BROODING FEMALES OF THE WESTERN SLIMY SALAMANDER, *PLETHODON ALBAGULA* (CAUDATA: PLETHODONTIDAE)**

8:30 Malcolm McCallum[1] and Stanley E. Trauth[2], [1]P. O. Box 847, Environmental Sciences Program, Arkansas State University, State University, AR 72467; [2]P. O. Box 599, Department of Biological Sciences, Arkansas State University, State University, AR 72467. **PERFORMANCE OF WOOD FROG (*RANA SYLVATICA*) TADPOLES ON THREE SOYBEAN MEAL B CORN MEAL RATIONS**

8:45 Malcolm McCallum[1] and Stanley E. Trauth[2], [1]P. O. Box 847, Environmental Sciences Program, Arkansas State University, State University, AR 72467; [2]P. O. Box 599, Department of Biological Sciences, Arkansas State University, State University, AR 72467. ***PSEUDACRIS STRECKERI ILLINOENSIS* 2000-2001 BREEDING CHORUSES AND NOTES ON CONSERVATION NEEDS**

9:00 BREAK

9:15 David Saugey[1], B. Sasse[2], and J. D. Wilhide[3], [1]United States Forest Service, P. O. Box 189, Jessieville, AR 71949-0189; [2]Arkansas Game and Fish Commission, 2 Natural Resources Drive, Little Rock, AR 72205; [3]Department of Biological Sciences, P. O. Box 599, Arkansas State University, State University, AR 72467-0599. **NOTES ON THE DISTRIBUTION AND ECOLOGY OF THE BRAZILIAN FREE-TAILED BAT (*TADARIDA BRASILIENSIS CYNOCEPHALA*) IN ARKANSAS**

9:30 Jeremy Lynn Jackson, J. D. Wilhide, and Roger Buchanan, Department of Biological Sciences, Arkansas State University, State University, AR 72467. **SWIMMING ABILITY OF ADULT BATS**

9:45 Lann M. Wilf, J. D. Wilhide, and Drew Reed, Department of Biological Sciences, Arkansas State University, State University, AR 72467. **ROOSTING ECOLOGY OF THE SOUTHEASTERN BAT (*MYOTIS AUSTRORIPARIUS*) AND SPECIES COMPOSITION OF BAT POPULATIONS IN DELTA NATIONAL FOREST, MISSISSIPPI**

10:00 Michelle L. Caviness and Douglas A. James, Department of Biological Sciences, University of Arkansas, Fayetteville, AR 72701. **BATS OF THE WESTERN OZARKS**

10:15 BREAK

10:30 David W. Clark, Leah D. Lucio, Steffany White, Annalea K. Bowers, and Gary A. Heidt, Department of Biology, University of Arkansas at Little Rock, Little Rock, AR 72204. **A SURVEY OF RECENT ACCOUNTS OF THE MOUNTAIN LION IN ARKANSAS**

10:45 Annalea K. Bowers, Leah D. Lucio, David W. Clark, and Gary A. Heidt, Department of Biology, University of Arkansas at Little Rock, Little Rock, AR 72204. **EARLY HISTORY OF THE WOLF, BLACK BEAR, AND MOUNTAIN LION IN ARKANSAS**

11:00 D. Blake Sasse, Arkansas Game and Fish Commission, 2 Natural Resources Drive, Little Rock, AR 72205. **STATUS OF PET MOUNTAIN LIONS (*PUMA CONCOLOR*) IN ARKANSAS**

11:15 Jennifer H. Herner-Thogmartin[1], Kimberly G. Smith[2], and Michael E. Cartwright[3], [1]Arkansas Cooperative Fish and Wildlife Research Unit, Department of Biological Sciences, University of Arkansas, Fayetteville, AR 72701; [2]Department of Biological Sciences, university of Arkansas, Fayettevile, AR 72701; [3]Arkansas Game and Fish Commission, P. O. Box 729, Calico Rock, AR 72519. **PERCEIVED DAMAGE BY ELK IN THE ARKANSAS OZARKS**

11:30 Renn Tumlison and Anna Smith, Department of Biology, Henderson State University, Arkadelphia, AR 71999. **NEW RECORDS OF THE WOODCHUCK (*MARMOTA MONAX*) IN SOUTHWESTERN ARKANSAS**

Botany & Plant Biology
Location: Room 133, Lewis Science Center

Time Topic

8:00 Gary E. Tucker, FTN Associates, Ltd., 3 Innwood Circle, Suite 220, Little Rock, AR 72211. **HISTORY OF ARKANSAS BOTANY TO 1950**

8:15 James H. Peck[1], C. Theo Witsell[2], and Thomas L. Foti[2], [1]Biology Department, University of Arkansas at Little Rock, 2801 South University Ave., Little Rock, AR 72204; [2]Arkansas Natural Heritage Commission, 1500 Tower Building, 323 Center St., Little Rock, AR 72201. **ARKANSAS FIELD BOTANY BIBLIOGRAPHY UPDATE (1988-2000)**

8:30 Johnnie L. Gentry, University of Arkansas Herbarium, University of Arkansas, Fayetteville, AR 72701. **THE ARKANSAS VASCULAR FLORA PROJECT**

8:45 George P. Johnson, Biological Sciences, Arkansas Tech University, Russellville, AR 72801. **THE ORCHIDACEAE OF ARKANSAS**

9:00 BREAK

9:15 Johnnie L. Gentry, University of Arkansas Herbarium, University of Arkansas, Fayetteville, AR 72701. **SOLANACEAE OF MESOAMERICA**

9:30 James H. Peck, Department of Biology, University of Arkansas at Little Rock, 2801 South University Ave., Little Rock, AR 72204. **SURVEY OF *SALVINIA* (SALVINIACEAE) IN EASTERN ARKANSAS**

9:45 David Williams and Edith Hardcastle, University of Arkansas Herbarium, University of Arkansas, Fayetteville, AR 72701. **A STATUS REPORT ON HARPERELLA, *PTLIMNIUM NODOSUM* (APIACEAE) IN ARKANSAS**

10:00 Terry K. McKay[1] and Daniel L. Marsh[2], [1]Ouachita National Forest, 912 Smokey Bear Lane, Glenwood, AR 71943; [2]Henderson State University, Arkadelphia, AR 71999. **A SECOND ARKANSAS POPULATION OF SOUTHERN RUNNING-PINE, *DIPHASIASTRUM DIGITUM* (DILL. EX A. BRAUN) HOLUB REPORTED IN MONTGOMERY COUNTY ON THE OUACHITA NATIONAL FOREST**

10:15 BREAK

10:30 Jason A. Haley and Daniel L. Marsh, Henderson State University, Arkadelphia, AR 71999. **DIVERSITY OF *LAMIUM* (LAMIACEAE) IN ARKANSAS, INCLUDING OCCURRENCES OF *LAMIUM HYBRIDUM* AND FLOWER COLOR FORMS**

10:45 April Chamblee and Janet Lanza, Biology Department, University of Arkansas at Little Rock, 2801 South University, Little Rock, AR 72204. **PROPAGATION AND INTRODUCTION OF NATIVE WILDFLOWERS AT PINNACLE MOUNTAIN STATE PARK**

11:00 Hong Li Wang, Department of Biology, University of Arkansas at Little Rock, 2801 South University, Little Rock, AR 72204. **ASSIMILATE TRANSPORT IN WHEAT PLANTS: INSIGHTS FOR IMPROVEMENT OF CROP YIELD**

11:15 K. C. Larson, S. Fowler, and Jason Walker, Department of Biology, University of Central Arkansas, Conway, AR 72035. **LACK OF POLLINATORS LIMITS FRUIT SET IN THE EXOTIC *LONICERA JAPONICA***

Aquatic Ecology & Ecotoxicology
Location: Room 168, Lewis Science Center

Time Topic

8:00 Thetsu Mon and Russell Nordeen, University of Arkansas at Monticello, School of Mathematical and Natural Sciences, P.O. Box 3480, Monticello, AR 71656. **PLASMID ANALYSIS OF BACTERIA THAT METABOLIZE THE DETERGENT IGEPON**

8:15 Gary L. Emmert, Department of Chemistry and the Program of Environmental Sciences, Arkansas State University, State University, AR 72467. **IMPROVING SENSITIVITY AND SELECTIVITY IN DRINKING WATER ANALYSIS**

8:30 Renn Tumlison, Department of Biology, Henderson State University, Arkadelphia, AR 71999. **DISCOVERY OF A POSSIBLE MUTUALISTIC RELATIONSHIP BETWEEN TADPOLES AND A GREEN ALGAE**

8:45 Laura Hudson and Thomas M. Buchahan, Department of Biology, Westark College, Fort Smith, AR 72913. **LIFE HISTORY OF THE RIVER SHINER, *NOTROPIS BLENNIUS* (CYPRINIDAE), IN THE ARKANSAS RIVER OF WESTERN ARKANSAS**

9:00 BREAK

9:15 Jennifer Davis and John Rickett, University of Arkansas at Little Rock, Little Rock, AR 72204. **A SUSPECTED MONOSPECIFIC FISH COMMUNITY IN A HYPERACIDIC LAKE**

9:30 Michael Berumen and Morgan Pratchett, Honors Department, Fulbright College of Arts and Sciences, University of Arkansas, Fayetteville, AR 72701. **DIET AND CONDITION OF BUTTERFLYFISH IN HABITATS WITH VARYING CORAL COVER AND COMPOSITION**

9:45 D. L. Feldman[1], J. L. Farris1, C. D. Milam[1], M. T. Moore[2], S. J. Smith[2], and C. M. Cooper[2], [1]Ecotoxicology Research Facility, Arkansas State University, State University, AR 72467; [2]USDA-ARS National Sedimentation Laboratory, Oxford, MS 38655. **SEASONAL VARIATION OF BIOTIC AND ABIOTIC FACTORS THAT CHARACTERIZE AGRICULTURAL DRAINAGE DITCHES**

10:00 Randall Staley and Ronald L. Johnson, Arkansas State University, Department of Biology, State University, AR 72467. **IDENTIFICATION OF FLORIDA LARGEMOUTH BASS ALLELES IN HATCHERIES AND RESERVOIRS IN ARKANSAS**

10:15 BREAK

10:30 Elizabeth Murray[1], Tom Foti[2], Henry Langston[3], Jody Pagan4, Charles Klimas[5], Arkansas Multi-Agency Wetland Planning Team, [1]2 Natural Resources Dr., Little Rock, AR 72205; 2Arkansas Natural Heritage Commission; [3]Arkansas State Highway and Transportation Department; [4]USDA Natural Resource Conservation Service; [5]Klimas and Associates. **HYDROGEOMORPHIC CONTROLS ON WETLAND FUNCTIONAL DIVERSITY IN ARKANSAS**

10:45 Benjamin A. Wheeler[1] and Stan E. Trauth[2], [1]Environmental Sciences, P.O. Box 847, Arkansas State University, State University, AR 72467; [2]Biological Sciences Department, P.O. Box 599, Arkansas State University, State University, AR 72467. **STATUS OF THE OZARK HELLBENDER: EVIDENCE FOR THE NEED OF MANAGEMENT STRATEGIES**

11:00 John D. Rickett[1] and E. P. (Perk) Floyd[2], [1]University of Arkansas at Little Rock, Little Rock, aR 72002; [2]U.S. Public Health Service (ret.), 2423 E. Woodson Lateral, No. 35, Hensley, AR 72065. **THE MACROBENTHIC COMMUNITY OF FERGUSON LAKE, SALINE COUNTY, ARKANSAS**

General & Inorganic Chemistry
Location: Room 170, Lewis Science Center

Time Topic

8:00 David M. Chittenden and Julie D. Chittenden, Department of Chemistry and Physics, Arkansas State University, State University, AR 72467. **AN EMPIRICAL MODEL OF THE VARIATION IN CONCENTRATION OF METAL IONS DURING A PRECIPITATION EVENT**

8:15 Wally Cordes, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701. **STRUCTURAL FEATURES OF NEUTRAL RADICAL MOLECULAR METALS**

8:30 Genevive Brown and John P. Graham, Department of Physical Science, Arkansas Tech University, Russellville, AR 72801. **THE ELECTRONIC STRUCTURE OF MANGANESE, IRON AND COBALT NITROSYL METALLOPORPHYRINS**

8:45 L. A. thornton, Jr.[1], M. Draganjac[1], and A. W. Cordes[2], [1]Department of Chemistry and Physics, Arkansas State university, State University, AR 72467; [2]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701. **SYNTHESIS OF A RUTHENIUM-TETRA(THT)DICHLORIDE COMPOUND: POTENTIAL PRECURSOR FOR MODELS OF THE ACTIVE SITE FOR HDS OVER LAURITE**

9:00 Amanda Wroble, Scotty Sproles, M. Draganjac, and Paul M. Nave, Department of Chemistry and Physics, Arkansas State University, State University, AR 72467. **SYNTHESIS AND CHARACTERIZATION OF A RUTHENIUM-THIOXANE COMPLEX**

9:15 BREAK

9:30 Chad Chastain, Robert Engelken, Justin Meyer, Richard Tanner, Barrett Brown, Anil Baral, and Gustavo Rehder, Optoelectronic Materials Research Laboratory, Arkansas State University, P.O. Box 1740, State University, AR 72467. **DEPOSITION OF MOLYBDENUM, TUNGSTEN, AND OTHER OXIDE FILMS BY SPRAY PYROLYSIS AND ELECTROCHEMICAL METHODS**

9:45 Justin Meyer, Robert Engelken, Chad Chastain, Richard Tanner, Barrett Brown, Anil Baral, and Gustavo Rehder, Optoelectronic Materials Research Laboratory, Arkansas State University, P.O. Box 1740, State University, AR 72467. **POWDER SPRAY DEPOSITION OF INDIUM SULFIDE MIXED FILMS**

10:00 Barrett Brown, Robert Engelken, Richard Tanner, Chad Chastain, Justin Meyer, Anil Baral, and Gustavo Rehder, Optoelectronic Materials Research Laboratory, Arkansas State University, P.O. Box 1740, State University, AR 72467. **ELECTRODEPOSITION OF DIFFICULT-TO-PLATE METALS, SPECIFICALLY MOLYBDENUM AND NICKEL-MOLYBDENUM ALLOY FILMS**

10:15 Richard Tanner[1], Robert Engelken[1], Anil Baral[1], Justin Meyer[1], Chad Chastain[1], Barret Brown[1], Gustavo Rehder[1], and Clayton Workman[2], [1]Optoelectronic Materials Research Laboratory, Arkansas State University, P.O. Box 1740, State University, AR 72467; [2]Microelectronics-Photonics Program, 222 Physics Building, University of Arkansas, Fayetteville, AR 72701. **CHROMIUM AND CHROMIUM OXIDE ELECTRODEPOSITION FROM ELECTROLYTES OF TRIVALENT CHROMIUM SALTS**

10:30 BREAK

10:45 Reagan Baber and Edmond W. Wilson, Jr., Department of Physical Science, Hardy University, Searcy, AR 72149-0001. **MOISTURE ANALYSIS USING THERMOMETRIC TITRATIONS**

11:00 Melanie J. Beazley, Richard D. Rickman, and Jon Russ, Department of Chemistry, Arkansas State University, State University, AR 72467. **CARBON ISOTOPE COMPOSITION OF LIVING AND FOSSIL LICHEN**

11:15 Pam Ramage[1], Scott Reeve[1], Michael Dvorak[2], and Greg Gillispie[2], [1]Department of Chemistry and Physics, Arkansas State University, 118 S. Caraway Road, State University, AR 72467; [2]DTI, 2201 A. 12th St. N, Fargo, ND. **A NOVEL HPLC DETECTOR: GENERATING ON-THE-FLY FLUORESCENCE LIFETIMES CONCURRENTLY AT MULTIPLE EMISSION WAVELENGTHS**

11:30 Alan Ford and Scott Reeve, Department of Chemistry and Physics, Arkansas State University, State University, AR 72467. **NON-COMMERCIAL SOFTWARE FOR ANALYZING AND INTERPRETING ROTATIONALLY RESOLVED MOLECULAR SPECTRA**

Physics & Astronomy
Location: Room 172, Lewis Science Center

Time	Topic
8:00	Christine A. Byrd[1], Stephen A. Nicoletti[1], W. J. Braithwaite, and Edwin S. Braithwaite[2], [1]Department of Physics & Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204; [2]Department of Science and Mathematics, Cedarville University, Cedarville, OH 45314. **USING INFLIGHT KAON AND PION DECAYS TO BOOTSTRAP EFFICIENCY VS ENERGY FOR STAR'S MAIN TPC, USING THE RELATIVISTIC HEAVY ION COLLIDER AT BNL**
8:15	Stephen A. Nicoletti[1], Christine A. Byrd[1], W. J. Braithwaite[1], and Edwin S. Braithwaite[2], [1]Department of Physics & Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204; [2]Department of Science and Mathematics, Cedarville University, Cedarville, OH 45314. **SEPARATING KAONS AND PIONS BY INFLIGHT DECAY IN STAR'S MAIN TPC USING 130 GEV/NUCLEON DATA FROM THE RELATIVISTIC HEAVY ION COLLIDER AT BNL**
8:30	Kyland Holmes and Pradip Bandyopadhyay, Department of Physics, Hendrix College, 1600 Washington Avenue, Conway, AR 72032. **LIF:MG, CU,P RADIATION DOSIMETER: A STUDY OF LUMINESCENCE AND SENSITIVITY**
8:45	Cody Hopkins and Pradip Bandyopadhyay, Department of Physics, Hendrix College, 1600 Washington Avenue, Conway, AR 72032. **THE ROLES OF COPPER IMPURITY IN THE PHOTO-STIMULATED LUMINESCENCE FROM KBR SINGLE CRYSTALS X-IRRADIATED AT 77 K**
9:00	C. Emery[1], D. W. Bullock[1], Z. Ding[1], M. Filipkowski[1], V. P. LaBella, M. Mortazavi[2], G. Salamo[1], [1]Physics Department, University of Arkansas, Fayetteville, AR 72701; [2]Physics Department, University of Arkansas at Pine Bluff, Pine Bluff, AR. **ELECTRON SPIN SCATTERING ACROSS A P-TYPE GaAs(110) STEP USING A FERROMAGNETIC-METAL STM TIP**
9:15	BREAK
9:30	Wendy Kiehl, Cynthia Sides, and Franklin D. Hardcastle, Department of Physical Sciences, Arkansas Tech University, Russell, AR 72801. **THERMAL LENS DETECTION OF CHROMOPHORES IN AQUEOUS SYSTEMS**
9:45	Jeff Robertson, Tut Campbell, Benji Myers, and Bret Taylor, Department of Physical Science, Arkansas Tech University, 1701 N. Boulder, Russellville, AR 72801. **SUPEROUTBURST AND SUPERCYCLES IN SUPERHUMPING CATACLYSMIC VARIABLE STARS**
10:00	Matthew A. Tilley, Bao-An Li, Andrew T. Sustich and Bin Zhang, Department of Chemistry and Physics, P.O. Box 419, Arkansas State University, State University, AR 72467-0419. **THERMODYNAMIC PROPERTIES OF NEUTRON-RICH MATTER**
10:15	Bao-An Li and Matthew A. Tilley, Department of Chemistry and Physics, P.O. Box 419, Arkansas State University, State University, AR 72467-0419. **URANIUM-URANIUM COLLISIONS AT ULTRA-RELATIVISTIC ENERGIES**
10:30	Andrew T. Sustich, Bao-An Li, Bin Zhang, Amanda Evans, and Matt Tilley, Arkansas State University, Department of

Chemistry and Physics, P.O. Box 419, Arkansas State University, State University, AR 72467-0419. **PROBING THE ISOPSIN DEPENDENCE OF THE NUCLEAR EQUATION OF STATE**

45 Bin Zhang[1], C. M. Ko[2], Bao-An Li[1], Siwei Lin[2], Subrata Pal[2], 1Department of Chemistry and Physics, Arkansas State University, P.O. Box 419, State University, AR 72467-0419; [2]Cyclotron Institute and Physics Department, Texas A&M University, Mail Stop 3366, College Station, TX 77843-3366. **A MULTI-PHASE TRANSPORT STUDY OF RELATIVISTIC NUCLEAR COLLISIONS**

Early History of the Wolf, Black Bear, and Mountain Lion in Arkansas

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Abstract

During the nineteenth century settlement of Arkansas, the red wolf (*Canis rufus*), black bear (*Ursus americanus*), and mountain lion (*Puma concolor*) were not only the three largest and most dangerous predators, they also stirred the imaginations of explorers and settlers. References to these species appeared prominently in the journals of early explorers such as George W. Featherstonhaugh (1844) and Frederick Gerstaecker (1854), and their presence inspired voluminous collections of stories and tall tales. Black bears were so common that a large trade developed in pelts, oil, and other body parts, and Arkansas became commonly known as "The Bear State." Wolves and mountain lions also were common and were despised for their suspected predation on livestock and their threat to human life. As a result, the General Assembly of the Arkansas Legislature enacted laws that provided bounties for killing these animals. The species were overexploited, and all three nearly were extirpated from the state by the 1920s-1930s. A stable bear population has now been restored (due to a restoration program in the White River National Wildlife Refuge and re-stocking programs in the Interior Highlands undertaken by the Arkansas Game and Fish Commission), the red wolf is considered to be extinct from the state, and the status of the mountain lion is uncertain.

"The chase in the United States is moreover rapidly on the decline; for the American hunter spares nothing, and for some time, particularly since the day when skins were first paid for in hard dollars, a war of extermination has been waged against the poor stags and bears; – so that the hunter who, some five years hence, shall visit these realms, will scarcely find his expectations of sport realized, unless he is prepared either to content himself with small game, or to penetrate to the Rocky Mountains and explore the territory of the Indians." – *Frederick Gerstaecker, 1854*

Introduction

Arkansas' largest and best-known predators during historical times were the red wolf (*Canis rufus*), black bear (*Ursus americanus*); and mountain lion (*Puma concolor*). All three species occurred statewide. The ocelot (*Felis pardalis*) also was found in the extreme southwestern part of the state. In fact, the type locality was given as Arkansas when the ocelot was first described in 1855 (Hall, 1981). However, this species was extirpated very early and probably never occurred in large numbers. Whereas it is possible that some early reports about wildcats really were reports about ocelots, it is doubtful that the ocelot was a major predator in the state (Sealander and Heidt, 1990).

Because of their size and supposed ferocity, the former three species have received a great deal of attention, usually negative, from human inhabitants. This study reviews the history of the three species and their frequent interactions with humans during the past two centuries. It also provides a brief summary of their presumed current status.

Early Explorations

The first inhabitants of the area now known as Arkansas included the Bluff Dwellers and the Mound Builders who are believed to have occupied the land thousands of years before the first Europeans arrived. The region later became home to many Native American tribes including the Caddo, Quapaw, and Osage. The land that is now Arkansas was untouched by Europeans until the Spanish and French began their explorations during the sixteenth and seventeenth centuries.

One of the first Europeans to travel through the territory was the Spanish explorer Hernando de Soto. In 1541 he and his men entered from the east (near Helena), moved to the Northeast, then back to Hot Springs. Historians believe that they probably traveled as far south as the Red River on their quest for gold. De Soto recorded the earliest written descriptions of the vast wilderness and abundant wildlife in the area, and his journals sparked the distinction Arkansas would later gain of being a "sportsman's paradise" (Lawrence, 1991).

Over 100 years later, in 1682, Louis XIV of France sent the French explorer Sieur de La Salle to claim all the land along the Mississippi River and named the region "Louisiana" in honor of the king. La Salle's lieutenant, Henri de Tonti, later founded Arkansas Post, which became the first permanent European settlement in the territory (Table 1).

The French reigned until 1762 when the Treaty of Fontainbleau gave Spain control of much of the Louisiana

Table 1. Early Explorers of the 1500s - 1800s

Explorer	Year	Location Explored
Hernando de Soto	1541	Helena; Eastern AR.; Hot Springs; Red River
Joliet and Marquette	1673	Mouth of the Arkansas River
LaSalle and de Tonti	1682	Memphis/Helena; Quapaw City; Mouth of the Arkansas
Henri de Tonti	1686	Established Arkansas Post
La Harpe	1721	Lower Arkansas River
Dunbar and Hunter	1804	Ouachita River
Schoolcraft	1818-1819	St. Francis and White River, Parts of the Ozarks
Nuttall	1819	Arkansas River; Red River
Featherstonhaugh	1834	White River; Little Red River; Little Rock
Gerstaecker	1839-1842	Mississippi Delta; Fourche LaFave River; Ozarks

Sources: Dougan (1994), Lawrence (1991), and Sutton (1998)

Territory, including Arkansas. In 1800 the Treaty of San Ildefonso returned the territory to France. Then, in 1803 the United States purchased the Louisiana Territory from France and took formal possession a year later. Arkansas remained a part of the Louisiana Territory until 1812 when it became part of the Missouri Territory. The Arkansas Territory was separated from the Missouri Territory in 1819, and Arkansas Post served as the capitol until 1821 when Little Rock was designated as the permanent capitol. In 1825 much of the western part of the Arkansas Territory was severed by the Conway Line, which separated Arkansas from Oklahoma. Between 1820 and 1835 the population of the Territory increased from approximately 15,000 people to 50,000, most of whom were homesteaders settled along rivers and streams. After much political dispute, in 1836 Arkansas became the 25th state in the Union. The population of the state continued to grow, and by 1860 it had reached 435,000 (Dougan, 1994).

Before several detailed explorations were undertaken in the first half of the 1800s, there were numerous transitory visits by early explorers (Table 1). The three major explorers whose journals provided the most details were Thomas Nuttall, George W. Featherstonhaugh, and Frederick Gerstaecker (Table 1).

American naturalist Thomas Nuttall accompanied several scientific expeditions to the Mississippi and Missouri valleys, and in 1819 his travels brought him to the Arkansas Territory that he described as "one vast trackless wilderness of trees." Nuttall was interested primarily in plants, geology, and the natives of the area; however, he commented on the predators he observed along the Arkansas River, noting, "Wildcats of two kinds, both striped and spotted as well as panthers, bears, and wolves (black and gray), are in considerable abundance in this country" and, "Panthers are said to be abundant in the woods of the Red River nor are they uncommon on the banks of the Arkansa" (Lottinville, 1999).

English geologist George William Featherstonhaugh was one of the many travel-writers to visit the Arkansas Territory (Featherstonhaugh, 1844). In 1834 he traveled from Poplar Bluff, Missouri to the White River and then headed southwest, continuing toward the Little Red River and on to Little Rock. His explorations took him through the bottomlands of the Petite Mammelle River and Mammelle Mountain where he noted "gangs of savage wolves that range about by night." After leaving Little Rock, Featherstonhaugh encountered other travelers near the Saline River where they shared stories of large numbers of panthers, wolves, and bears that inhabited the area. He then traveled to the "Hot Springs of the Washita" where he notes, "...all roads of every kind terminate at the Hot Springs; beyond them there is nothing but the unbroken wilderness." Featherstonhaugh planned to continue on to the Mexican frontier but encountered difficulties in his search for a guide. The local hunters were unwilling to miss out on the prime bear hunting season, stating "When the bears are fat, they can surrender a good skin and from twenty to twenty-five gallons of oil." In addition, Featherstonhaugh offered to pay a guide more than the guide could make bear hunting, but the zeal for the hunt outweighed the financial gain, so the potential guides refused.

Throughout his journeys, Featherstonhaugh recorded many anecdotes from the settlers that he met along the way. The following example proved why so many of them feared the panther and other predators: "One unfortunate man ... had been attacked [by a panther] ... the man choked the beast, and retained strength enough to reach his home, where he died soon after."

One of the most prolific writers among the early travelers was the German explorer Frederick Gerstaecker. He traveled in Arkansas for two extended periods: May 1839 to February 1840, and January 1841 to July 1842. He was very enthusiastic about his home in the New World and frequently commented on the beauty and magnificence of the area, as well as the abundant wildlife and hunting opportunities available in the state.

During his first visit, Gerstaecker lived as a backwoodsman in the swamps of the Mississippi Delta (St. Francis County mostly) where he hunted and worked for local farmers in exchange for lodging. On the second trip, he traveled west of Little Rock in the vicinity of the Fourche LaFave River. He also took a side trip into the Ozarks where he described a terrorizing encounter with a bear that killed his hunting companion.

References to the territories three most feared predators appear throughout Gerstaecker's published journals (Gerstaecker, 1854). During his first journey he noted, "Although I heard the howls of several wolves, I did not mind them, but enjoyed a sound sleep. In order to avoid the bears and panthers, I had climbed up a tree. ...I heard the howling of wolves and once the roar of a panther in the distance" (Gerstaecker, 1854).

Bounty Laws

Depredation of livestock and fear of personal attack fostered perceptions held by early settlers concerning the threatening nature of large predators. Many settlers suffered heavy losses when their cattle, hogs, and colts fell prey to wolves and panthers. Tales of human attacks became widespread, and out of desperation people often barricaded their homes against these predators. Accounts by travel writers during this time period also helped to reinforce these fears. Wolves and panthers became known as ruthless killers and as a result bounty laws were enacted which encouraged the mass removal of these animals. From 1816 to 1921 a series of legislative acts were formulated to encourage the killing of wolves and panthers, which ultimately played a significant role in their demise (Table 2).

Species Accounts

Red wolf (*Canis rufus*)

The red wolf is larger and more robust than the coyote. Its muzzle, ears, nape, and outer surfaces of the legs are tawny. The remainder of the pelage is a mixture of cinnamon-buff and tawny interspersed with gray and black above (often giving rise to a description of the animal being gray). A black color phase occurs where the animal is predominately black except for a white pectoral spot. Red wolves weigh between 16-41 kg (35-90 lb) (Gipson, 1976; Sealander and Heidt, 1990).

As Arkansas was being settled, red wolves ranged throughout the state and were apparently quite numerous. They could be found singly or in packs. Wolves of any kind have been the source of terror throughout recorded history, and Arkansas settlers and explorers have been no exception (e.g., Thomas, 1972; Allen, 1989b). People not only feared for their lives, they also attributed much of their livestock loss to wolves. Consequently, wolves were killed when encountered and, as seen in Table 2, have been the subjects of a number of bounty laws through the years (Holder, 1951; Sutton, 1998).

As settlements grew during the 1800s, the numbers of wolves decreased. By the turn of the century wolf populations had significantly diminished, particularly in eastern Arkansas. The decline of wolf populations continued during the first two decades of the past century. During the 1930s coyotes apparently started expanding into the state and hybridization began to occur (Holder, 1951; Sealander and Heidt, 1990).

Wolf populations, however, continued to exist in the Ozark Mountains of northwest Arkansas and in parts of the Gulf Coastal Plain. In the early 1940s it was estimated that 40-100 wolves still were present in Sharp County. In Washington County, 32 were trapped in 1943 and 1944. During this same time period, 32 wolves were trapped in Miller and Little River counties, and 2 to 10 were trapped in other southwestern counties of the Gulf Coastal Plain. In the winter of 1942-43, nine wolves were trapped in Pulaski County (Holder, 1951). Continued trapping and killing and

Table 2. A History of Statewide Bounty Laws

1816 Missouri territorial legislature enacted bounty laws designed "to encourage the killing of wolves, panthers, and wildcats."

1819 Act of 1816 repealed

1838 An Act to encourage the killing of wolves in the state of Arkansas. Act included:

1. Bounty of $3.00 from county for wolf scalp
2. County magistrate to burn or destroy scalp
3. Master receives provisions for wolves taken by slaves
4. Penalty for cheating, $4.00
5. Form of certificate

1843 Section 1 amended to give county discretion over bounty

1885 Act 44, An Act to Amend -- added wildcat and panther scalps

$5.00 wildcat
$8.00 wolf
$10.00 panther

1915 Establishment of Arkansas Game and Fish Commission

1917 Act 133 -- gave AG&FC authority to protect and regulate hunting of game and furbearers

1919 Act 269 "An Act to Amend Act 44 of the Acts of 1885"

1. Set statewide bounties rather than county
   $5.00 wildcat
   $10.00 wolf
   $25.00 panther
2. Penalty for stealing increased, 45 counties exempted

1921 Act 146 -- exempted two additional counties

1921 Act 198 -- 22 counties exempt from paying any bounties

increased hybridization caused the red wolf to be extirpated from Arkansas by the early 1970s (Gipson and Sealander, 1976; Gipson et al., 1974, 1975).

Mountain Lion (*Puma concolor*)

The mountain lion is a large, powerfully built cat with a long tail (slightly more than one-third of the total length). These animals range in size from 1500-2743 mm (59.1-108.0 in) and weigh from 36-103 kg (79.4-227.0 lb); females are smaller than males. The pelage is uniformly pale brown to reddish brown above and dull white below (Sealander and Heidt, 1990).

During the early history of Arkansas, the mountain lion or panther was found statewide, but was probably more numerous in the remote upland regions of the Ozark and Ouachita Mountains. The panther was the terror of settlers, and many stories, probably exaggerated, were told of harrowing experiences of cat encounters (Holder, 1951; Thomas, 1972; Allen, 1989a; Sutton, 1998).

By 1900, most mountain lions had been killed or driven to remote areas, and it was thought that by 1920 they had been extirpated from the state. In addition to hunting pressure, the reduction of the white-tailed deer herd (which had dwindled to less than 300 animals) may also have played a role in the decrease of the mountain lion (Young and Goldman, 1946). Due to restoration projects, the deer population had increased by the late 1940s, and soon after-ward a mountain lion was killed in Montgomery County (Sealander, 1951). In the 1950s and 1960s, sightings and observations of sign increased (Lewis, 1969, 1970), and a second animal was killed in Ashley County (Noble, 1971). Sealander and Gipson (1973) summarized 63 mountain lion records from 1945 to 1972 and concluded that due to the increasing deer population, a small population of mountain lions existed in the state. The last mountain lion killed in the state was in Logan County in 1975 (Sutton, 1998).

McBride et al. (1993) concluded there were no reproducing lions in the state after conducting an extensive field study. Reports of sightings or sign have persisted, however, and currently at least four mountain lions have been documented (Witsell et al., 1999; Clark et al., unpubl. data). The origin of these animals is not known, although there are over 100-150 captive animals currently in Arkansas (Sasse, 2001), and free-ranging animals might possibly have originated from that source.

Mountain lions in Arkansas originally were designated as *P. concolor coryi*, the endangered Florida panther. However, Culver et al. (2000), using mitochondrial DNA, have placed all North American mountain lions into one subspecies, *P. c. couguar.*

Black Bear (*Ursus americanus*)

The black bear is large and heavily built, measuring 1270-1980 mm (50-78 in) and weighing 100-227 kg (220-500 lb). The pelage is deep glossy black to cinnamon-brown; there may be a white patch on the pectoral area (Sealander and Heidt, 1990).

At the time of the early exploration of Arkansas, black bears were found throughout the state and were extremely common. Bears played an important role in the lives of Indians providing them with clothing, food, and ornaments (teeth and claws). As settlers began inhabiting the state, bears were economically important for the same reasons as well as for the utilization of bear grease. This grease or oil was highly prized for cooking in that it did not become rancid as quickly as butter (Featherstonhaugh, 1844). Thousands of barrels of bear oil/grease were shipped annually to ports such as New Orleans. It is said that Oil Trough (Independence County) received its name from the fact that commercial hunters stored bear grease in troughs made of hollow logs before shipment down the White River (Sealander and Heidt, 1990). Due to this commercial trade, thousands of bears were killed annually during the first half of the 19th century. The bear trade was so important that until 1923, Arkansas was unofficially known as "The Bear State" (Holder, 1951; Sealander and Heidt, 1990; Sutton, 1998). As would be expected from such a large and potentially dangerous animal, bear stories have been extremely numerous (e.g., Thomas, 1972; Allen, 1988).

With the exception of the lower White River bottoms and the Ouachita Mountains, bears had been largely exterminated from Arkansas at the turn of the 19th century. By 1910 the population in the Ouachita Mountains also was scarce. Holder (1951) estimated that there were only 40-50 bears remaining in the state in the early 1950s. More than half of these were in and around the White River National Wildlife Refuge, and the remaining were scattered in the Ouachita and Ozark Mountains.

During 1959, the Arkansas Game and Fish Commission began a highly successful restocking program in the Ozark and Ouachita mountains (Smith et al., 1990). It is now estimated that there are over 3500 bears in the state and the AG&FC conducts an annual hunting season (R. Eastridge, AG&FC, pers. comm.).

Literature Cited

Allen, D. W. (ed.) 1988. Turnbo's tales of the Ozarks: bear stories. Arkansas Research, Conway, Arkansas. 148 pp.

Allen, D. W. (ed.) 1989a. Turnbo's tales of the Ozarks: panther stories. Arkansas Research, Conway, Arkansas. 132 pp.

Allen, D. W. (ed.) 1989b. Turnbo's tales of the Ozarks: wolf stories. Arkansas Research, Conway, Arkansas. 131 pp.

Culver, M., W. E. Johnson, J. Pecon-Slattery, and **S. J. O'Brien.** 2000. Genomic ancestry of the American puma (*Puma concolor*). J. Hered. 91:186-197.

Dougan, M. B. 1994. Arkansas odyssey: the saga of Arkansas from prehistoric times to present. Rose Publishing Company, Inc., Little Rock, Arkansas. 684 pp.

Featherstonhaugh, G. W. 1844. Excursion through the slave states, from Washington on the Potomac, to the frontier of Mexico; with sketches of popular manners and geological notices. Harper, New York. 168 pp.

Gerstaecker, F. 1854. Wild sports in the far west. G. Routledge & Co., New York. 396 pp.

Gipson, P. S. 1976. Melanistic *Canis* in Arkansas. Southwestern Nat. 21:124-126.

Gipson, P. S., and **J. A. Sealander.** 1976. Changing food habits of wild *Canis* in Arkansas with emphasis on coyote hybrids and feral dogs. Am. Midl. Nat. 95:249-253.

Gipson, P. S., J. A. Sealander, and **J. E. Dunn.** 1974. The taxonomic status of wild *Canis* in Arkansas. Syst. Zool. 23:1-11.

Gipson, P. S., I. K. Gipson, and **J. A. Sealander.** 1975. Reproductive biology of wild *Canis* (Canidae) in Arkansas. J. Mamm. 56:605-612.

Hall, E. R. 1981. The mammals of North America, 2nd ed. 2 vols. John Wiley and Sons, New York. 1181 pp.

Holder, T. H. 1951. A survey of Arkansas game. Federal Aid Publ., Project 11-R. Arkansas Game and Fish

Comm., Little Rock, Arkansas. 155 pp.

awrence, B. 1991. The early American wilderness as the explorers saw it. Paragon House, New York. 245 pp.

ewis, J. C. 1969. Evidence of mountain lions in the Ozarks and adjacent areas, 1948-1968. J. Mamm. 50:371-372.

ewis, J. C. 1970. Evidence of mountain lions in the Ozark, Boston, and Ouachita Mountains. Proc. Oklahoma Acad. Sci. 70:182-184.

ottinville, S. (ed.) 1999. A journal of travels into the Arkansas territory during the year 1819. Univ. of Arkansas Press, Fayetteville, Arkansas. 361 pp.

IcBride, R. T., R. M. McBride, J. L. Cashman, and D. S. Maehr. 1993. Do mountain lions exist in Arkansas? Proc. of the Ann. Conf. of the Southeastern Assoc. of Fish and Wildlife Agencies. 47:394-402.

Noble, R. E. 1971. A recent record of the puma (*Felis concolor*) in Arkansas. Southwestern Nat. 16:209.

Sasse, D. B. 2001. Status of pet mountain lions (*Puma concolor*) in Arkansas. J. Arkansas Acad. Sci. 55:(in press).

Sealander, J. A. 1951. Mountain lion in Arkansas. J. Mamm. 32:364.

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

Sealander, J. A., and **P. S. Gipson.** 1973. Status of the mountain lion in Arkansas. Proc. Arkansas Acad. Sci. 27:38-41.

Smith, K. G., J. D. Clark, and **P. S. Gipson.** 1990. History of black bears in Arkansas: over-exploitation, near elimination, and successful reintroduction. Proc. of the Tenth Eastern Workshop on Black Bear Restoration and Management. 10:5-14.

Sutton, K. 1998. Arkansas wildlife: a history. Univ. Arkansas Press, Fayetteville, Arkansas. 317 pp.

Thomas, R. E. 1972. Authentic Ozarks stories of big varmints: bears, wolves, panthers. Dox Books, Little Rock, Arkansas. 48 pp.

Witsell, T., G. A. Heidt, P. L. Dozier, T. Frothingham, and **M. Lynn.** 1999. Recent documentations of mountain lion (*Puma concolor*) in Arkansas. J. Arkansas Acad. Sci. 53:157-158.

Young, S. P., and **E. A. Goldman.** 1946. The puma, mysterious American cat. Am. Wildl. Inst. 385 pp.

An Empirical Model for the Variation in Concentration of Metal Ions during a Precipitation Event

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Abstract

The concentration of a pollutant in an air mass and the concentration of that pollutant in a series of rain water samples from a single event within that air mass, fluctuate during the course of the event. This the result of scavenging, diffusion, and advection processes. A simple mathematical model, containing only a scavenging term has had limited success in describing changes of concentration in rain water. To date, no attempt has been made to include diffusion or advection terms in the model. In this study, a two factor model was developed after determining that (1) the exponential scavenging term is dependent upon the amount of precipitation that has fallen rather than time elapsed and (2) that the magnitude of the diffusion/advection term is inversely proportional to the precipitation rate. Coefficients for the variables in the two terms [ψ_{av} and (bC_f), respectively] were determined by the best fit of concentration curve derived from the model equation to experimental points. Time series from 24 rain events samples collected during 1987-88 and during the spring of 1998 were analyzed. The values of ψ_{av} were remarkably constant during both periods, but the two groups of ψ_{av} were different. The values of (bC_f) correlated moderately well with the concentrations of ions in the samples.

Introduction

The modeling of a time series of a single rain for the concentrations of solutes in rain water has proved to be a difficult problem because of the number of factors that determine those concentrations. Slinn (1977) developed a kinetic equation for the change in airborne particle concentration,

$$\partial X/\partial t = -(V\bullet\nabla)X + \nabla\bullet(K\bullet\nabla X) - \psi X + G + L \qquad (1)$$

where X is the airborne concentration (mgL^{-1}) of particles or constituents of the particles in a polluted air mass, V is the wind velocity, and ψ is the rate constant for the scavenging of the species, X, from the air mass. The first term is the advection term, the second is the diffusion term, the third is the scavenging term, and the fourth and fifth represent other gains and losses, respectively.

Equation (1) was simplified and broken down (Slinn, 1975) to treat separately the particles attached to cloud water and the unattached (free) particles, $X_{total} = X_c + X_f$. Modifying slightly his equations, we arrive at

$$\partial X_f/\partial t = -\psi_f X_f + \nabla\bullet(K\bullet\nabla X_f) - aX_f \qquad (2)$$

$$\partial X_c/\partial t = -\psi_c X_c + \nabla\bullet(K\bullet a\nabla X_f) + aX_f \qquad (3)$$

where a is the rate of attachment of cloud particles to water droplets.

A model was presented (Beverland and Crowther, 1991) which assumed that the scavenging term of equation (1) was the only significant factor early in a time series. Concentration data from within-event sampling of rain water provided information on the effect of scavenging and advective processes on the wet deposition of acidic species. High resolution sampling (every 0.5 mm of precipitation) was used to determine time series for nitrate and sulfate ion concentrations. Within events, falling concentrations were observed for the first 2 - 3 mm of rain, when scavenging processes are dominant. The scavenging term can be expressed as a simple first order term

$$X_c(r,t) = X_c(r,0)\, e^{-\psi(r)t} \qquad (4)$$

where $X_c(r,0)$ is the concentration of particles of radius, r, within the initial rain sample of the time series, and X(r,t) is the particle concentration at time, t, after the commencement of the time series. Since $\psi(r)$ varies slowly with r, it was approximated by ψ_{av}, the average scavenging efficiency for particles of all sizes. The varying particle, sulfate, and nitrate concentrations were modeled by a series of exponential terms dependent on t. The model simulation was restarted after any period of increased X(t). It was assumed that these increases were due to an advection source. The period between the onset of an increase in concentration and the restart could not be modeled.

Modeling of sulfate and nitrate concentration time series curves is complicated by local sources of these ions. The oxidation of SO_x and NO_x during the event may be significant sources of these ions. The kinetic rate equations for the oxidations would have to be included in the model. The complication of a chemical reaction source can be avoided if analysis is limited to time series for the common metal ions: Mg^{2+}, Ca^{2+}, Na^+, and K^+.

The Beverland-Crowther model was expanded by adding a term which incorporates the changes of ionic concentration in rain water due to the diffusion and minor advection of free particles in clouds. It was assumed that (1) ψ_{av} remained constant throughout the event, (2) diffusion and minor advection were sources or sinks of free ions which become attached to cloud water throughout the event, (3) diffusion of cloud water of concentration X(0) to the air column above the collection site was negligible compared to other sources, (4) metal ions were distributed uniformly in the cloud volume, (5) diffusion of cloud water was negligible, and (6) a major removal or supply of ions by advection was rare. The diffusion rate would depend on free particle concentration gradients which would be affected by the amount of precipitation, $\Delta\Pi$, that had left the cloud. Substituting the concentrations of any metal ion, j, in samples of cloud water (collected as rain water), $C_{c,j}$

$$\partial C_{c,j} = -\psi_{av} (C_{c,j})\, \partial t + (bC_{f,j})\, \partial t \qquad (5)$$

where b is a combination of the operators in the first and second terms of equation (1). Solely for the sake of simplicity, $(bC_{f,j})$ was treated as a linear function of the total amount of precipitation which had been collected. An approximation for the integration of equation (5) over the time period Δt is possible for small values of Δt and by substituting equation (4) into equation (5)

$$C_{c,j}(t_2) = C_{c,j}(t_1) \exp(-\psi_{av} \Delta t) + (bC_{f,j}) \Delta t \qquad (6)$$

It is just as likely that $\Delta C_{c,j}$ due to scavenging is a function of the amount of precipitation fallen, $\Delta\Pi$, during time Δt. Equation (6) may be rewritten

$$C_{c,j}(t_2) = C_{c,j}(t_1) \exp(-\psi_{av} \Delta\Pi) + (bC_{f,j}) \Delta t \qquad (6)$$

where Δt is the time elapsed during the fall of $\Delta\Pi$ mm of rain. In this expression Δt is also understood to be $\Delta t/\Delta\Pi = 1/P$ (the inverse of the precipitation rate).

As either equation (6) or equation (7) could be used to construct the model time series curve for the events analyzed in this study, regression analysis was used to determine whether Δt or $\Delta\Pi$ was the better predictor for $C_{j,c}$ (t_2 or π_2) during the time early in the rain event when the scavenging factor is predominant.

Regression fits of the first three to five samples in the time series of seven rain events indicated that either Δt or $\Delta\Pi$ was an adequate predictor in the exponential portion of the concentration curves. The R^2 for both predictors were the same for five samples. The R^2 for Δt was greater in one and in the other (with a highly variable precipitation rate), R^2 for $\Delta\Pi$ was greater. It is obvious from the later portion of Figure 1 that the diffusion/minor advection factor, more important at that time, varies with the inverse of the precipitation rate which appears in disguise in equation (7) as Δt, the time elapsed during a segment of precipitation $\Delta\Pi$ (or $\Delta t/\Delta\Pi = 1/P$). We chose to use equation (7) to model the concentrations of the metal ions.

Methods

Sample Collection and Analysis.--The sampling site for the 1987-88 samples was an area near downtown Jonesboro, AR and, for the 1998 samples, an area of the Arkansas State University campus in eastern Jonesboro. Both sites were free of overhead obstructions. The collectors consisted of polycarbonate funnels of 15 and 25 cm diameters. Samples of 1 - 5 mm of rainfall were collected in 1987- 88 and of 0.30 - 1.31 mm in 1998 and fed into polycarbonate receivers. The samples were immediately transferred to polycarbonate bottles, filtered through 0.45 µm micropore filters, and either analyzed within 24 h of collection or frozen to await analysis by atomic absorption or atomic emission spectroscopy.

Empirical Fitting of Model Concentrations to Experimental Data.--For each metal ion, model $C(j,c,\Pi)$ values were calculated for every 0.1 mm of rainfall for 1987-88 samples and for every 0.05 mm for 1998 samples. The actual concentrations of the first rain water sample was used as the model's $C(j,c,\pi_1)$. The coefficients, (bC_f) and ψ_{av}, in equation (7) were determined by a trial and error assignment of values until the deviation of calculated points from experimental points (s) was minimized by the following method.

1 A first estimate of ψ_{av} was made from the slope of the first 3 - 5 points in the time series in a plot of the concentrations against amount of rain fallen, so that numerical integration of the 0.1 mm segments along the model curve for each sample should yield $\int_{\pi 1}^{\pi 2} C_{model}\, \partial\Pi = C_{sample}\Delta\Pi$

2 The initial and final values for (bC_f) were estimated from the values necessary to bring the exponential curve up to the experimental concentrations. The intermediate values of this parameter, $(bC_f)_i$, are calculated from $[(bC_f)_{initial} (\Pi_i - \Pi_{initial}) + (bC_f)_{final} (\Pi_{final} - \Pi_i)] / (\Pi_{final} - \Pi_{initial})$.

3 $\Delta t/\Delta\Pi$ for each model segment of the calculated time series was estimated from interpolating between the samples' average inverse rainfall rate,

$(\Delta t/\Delta\Pi)_k$ (see Figure 1). The uncertainty of the estimate is small if the sample sizes are small and/or if the rainfall rate is constant.

4 The values of the three parameters [ψ_{av}, $(bC_f)_{initial}$, and $(bC_f)_{final}$] were adjusted until Σs was minimized and the following constraints are met as closely as possible.

The final fit must satisfy several constraints.

1 The first order (concentration independent) scavenging rates of the four metal ions should be the same:
ψ_{av} (Mg) ~ ψ_{av} (Ca) ~ ψ_{av} (K) ~ ψ_{av} (Na)

2 The concentration of an ion, j, in the rain water samples should be proportional to the concentration of that ion attached to cloud water at the time of collection:
$b_jC_{f,j} \propto C_{c,j}$ and $b_1C_{f,1}/b_2C_{f,2} = C_{c,1}/C_{c,2}$

3 For all points, $\int_{\pi 1}^{\pi 2} C_{model}\,\partial\Pi = C_{sample}\Delta\Pi$

Results

A good fit was obtained for model equation concentrations with experimental data for Mg^{2+} and Ca^{2+} in 24 of the 26 time series rain events. The fits for the Na^+ and K^+ occasionally proved less satisfactory, so discussion will concentrate on the former two species. All constraints listed above were well met for the fits, but the correlation coefficients for (bC_f) with C_c were somewhat disappointing, 0.5 and 0.6 for Mg^{2+} and Ca^{2+}, respectively.

Figures 1 and 2 present the fit for a complex event of 1988 and for two simple events from 1998, respectively. Table 1 lists the mean ψ_{av}, the median of the initial values of (bC_f), and median values for (bC_f), the change in (bC_f) between two consecutive model points for both the 1987-88 and 1998 samples. If three outliers are removed from the list of 1987-88 values of ψ_{av}, the average value becomes 0.35±0.08.

Table 1: Empirical Values of Constants in Equation (7)

Year	ψ_{av}	Median $(bC_f)_0$ (mg mm L^{-1} min^{-1})		Median $\Delta(bC_f)$ (mg L^{-1} min^{-1})	
		Mg	Ca	Mg	Ca
1987-88	0.41±0.018	0.020	0.059	+2.0 x 10^{-6}	+1.4 x 10^{-5}
1998	1.4 ±0.1	0.12	0.40	-4.7 x 10^{-5}	0.0 x 10^{-5}

Discussion

In most cases, it was possible to derive a good fit from a model that considers scavenging and diffusion/minor advection as factors in determining the concentration of Mg^{2+} and Ca^{2+} in a time series of rain water samples. The assumption of a linear change in (bC_f) with time elapsed during the event appears to be valid. The magnitude of the diffusion effect should decrease as the concentration gradient is reduced as free ions leave the cloud during the rain event, i.e. diffusion should yield negative values of (bC_f). Since half of the (bC_f) are positive and half negative, this factor is probably a combination of diffusion and continuous small magnitude advection terms.

Increases in sample ionic concentrations during an event are usually caused by diffusion and small magnitude advection that outweigh the scavenging effect later in the time series during periods of low precipitation rate. Sudden, large magnitude additions of ions were observed in only 2 events (see Figure 2) and sudden drops in ionic concentration were not observed at all. Thus it can be assumed that

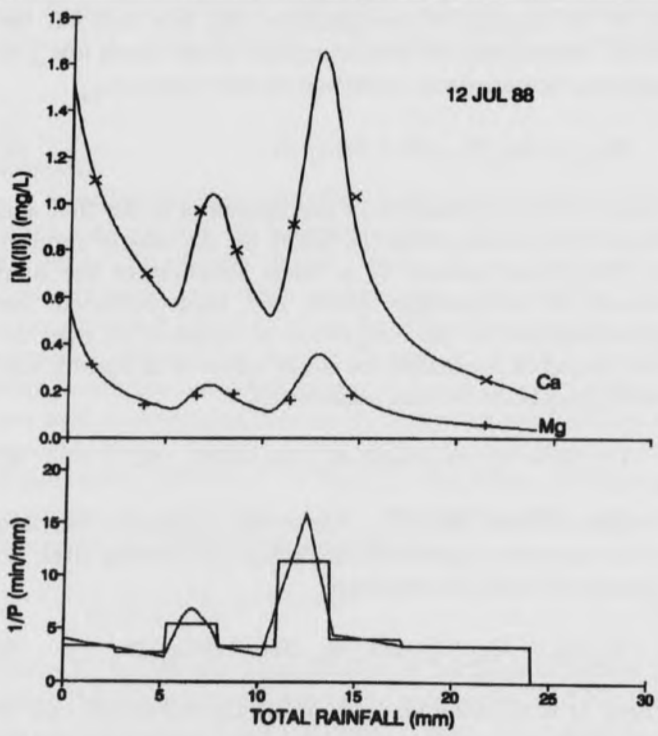

Fig. 1. Variation of concentration with amount of precipitation fallen and the rate of precipitation in a complex event. Upper plot: Fit of model concentration of Mg^{2+} and Ca^{2+} (line) to data points (x and +, respectively) Lower plot: Estimation of $(\Delta t\Delta\Pi)_i$ (curved line) from the amount of rain water collected in individual samples (bar chart).

m jor advective additions are rare.

The ψ_{av} values were unexpectedly constant during the months of sampling in 1987-88 and for the 5 samples t en in Spring 1998. However the values for the two g ups are very different.

This study shows that the concentration of metal ions in a me series for a single rainfall can be modeled by a kinetic equation of two terms. The first term is the well-known fi t order exponential term. The second, a term describing th effects of diffusion and constant low-magnitude advection, is probably a complex combination of terms but it can be effectively approximated by assuming a simple linear c ange in the term with time from the onset of the event.

The major disadvantage of this model is that it is not possible to assign a physical interpretation to the individual values of ψ_{av}. Perhaps a study of the meteorological conditions during rain events will lead to such a physical interpretation.

Literature Cited

Beverland, I. J. and **J. M. Crowther.** 1991. On the interpretation of event and sub- event rainfall chemistry. Environ. Pollut. 15: 163-174.

Slinn, W. G. N. 1975. Precipitation scavenging: some problems, approximate solutions, and suggestions for future research *in* Precipitation Scavenging-1974. CONF-741014, ERDA Symposium Series, Washington, D.C. 60 pp.

Slinn, W. G. N. 1977. Some approximations for the wet and dry removal of particles and gases from the atmosphere. Wat. Air Soil Pollut. 7: 513-543.

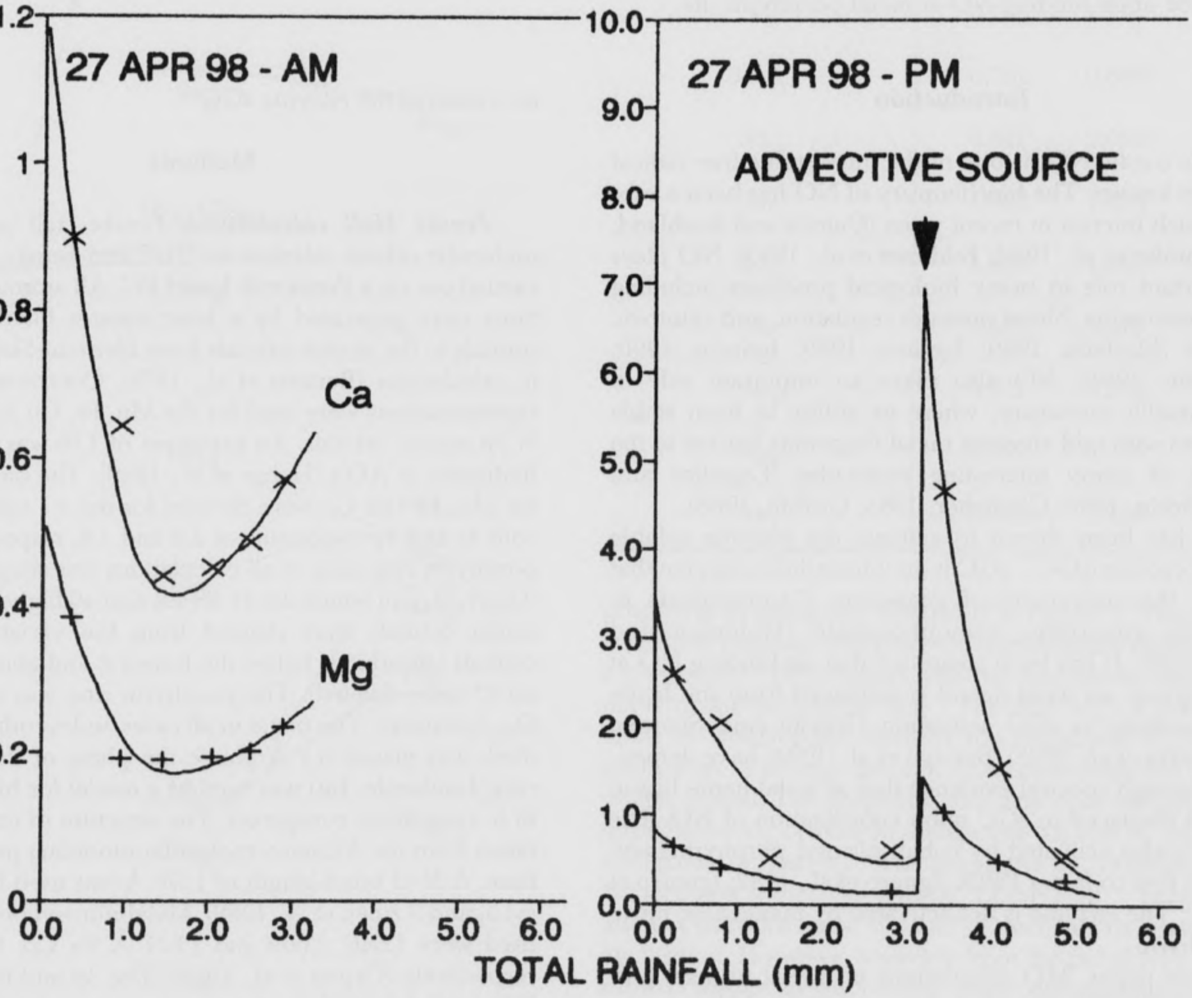

Fig. 2. Fit of model concentration of Mg^{2+} and Ca^{2+} (line) to data points (x and +, respectively). Left plot: Scavenging controls concentration early and diffusion/minor advection control late. Right plot: Scavenging controls concentration at all times except for a sudden advective addition of ions.

Molecular Orbital Studies of Nitrosyl Metalloporphyrin Complexes

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Abstract

Molecular orbital calculations are applied to the study of the structure and bonding of nitrosyl metalloporphyrin complexes. The Fenske-Hall approximate molecular orbital method and the Amsterdam Density Functional (ADF) method are used. The calculations provide qualitative and quantitative explanations for the observed structural differences between the nitrosyl porphyrin complexes of iron, manganese, and cobalt. It is proposed that the energy of the highest occupied molecular orbital (HOMO) of these complexes is primarily responsible for the observed structural differences. The interaction between the nitrosyl ligand and metal d_{z^2} orbital results in an antibonding orbital that is occupied in the complexes of Fe and Co, but unoccupied in the Mn complex. Bending of the metal-N-O linkage in complexes of Fe and Co results in stabilization of this orbital and consequently a more stable configuration for the complex. In addition, the binding affinity of these complexes for a sixth ligand is influenced by the energy and occupation of this largely metal-based orbital. The conclusions drawn from these calculations may provide evidence for the mechanism of activation of the enzyme soluble guanylyl cyclase, which is activated upon binding NO at metal porphyrin site.

Introduction

Nitric oxide, NO, is one of the most stable free radical molecules known. The biochemistry of NO has been a subject of much interest in recent years (Culotta and Koshland, 1992; Stamler et al., 1992; Feldman et al., 1993). NO plays an important role in many biological processes including neurotransmission, blood pressure regulation, and cytotoxic processes (Marletta, 1989; Ignarro, 1989; Ignarro, 1990; Garthwaite, 1991). NO also plays an important role in organometallic chemistry, where its ability to form stable complexes with odd electron metal fragments has led to the synthesis of many interesting molecules (Legzdins and Richter-Addo, 1988; Gladfelter, 1985; Griffith, 1968).

NO has been shown to activate the enzyme soluble guanylyl cyclase (sGC). sGC is an intracellular enzyme that catalyses the conversion of guanosine 5'-triphosphate to 3',5'-cyclic guanosine monophosphate (Waldman and Murad, 1987). It has been suggested that on binding NO at a heme group, an axial ligand is displaced from the heme group resulting in sGC activation (Traylor and Sharma, 1992; Dierks et al., 1997). Burstyn et al. (1994) have demonstrated through spectral evidence that an axial heme ligand is indeed displaced in sGC upon coordination of NO. The enzyme is also activated by cobalt nitrosyl porphyrins and the metal free co-factor PPIX (Ignaro et al., 1982; Ignarro et al., 1984). The enzyme is not activated by manganese nitrosyl porphyrin.

In this paper, MO calculations on metal nitrosyl porphyrin complexes of iron, manganese, and cobalt are presented. The principal focus of the paper will be that of the role of different metal centers in influencing the structure of the complexes and the binding affinity for a ligand trans to NO. The calculations lend support to the current models of activation of the enzyme sGC.

Methods

Fenske Hall calculations.--Fenske-Hall approximate molecular orbital calculations (Hall and Fenske, 1972) were carried out on a Pentium® based PC. All atomic basis functions were generated by a least squares fit of Slater-type orbitals to the atomic orbitals from Herman-Skillman atomic calculations (Bursten et al., 1978). Contracted double ζ representations were used for the Mn, Fe, Co 3d, and C, O, N 2p atomic orbitals. An exponent of 1.16 was used for the hydrogen 1s AO's (Hehre et al., 1969). The basis functions for Mn, Fe and Co were derived for the +1 oxidation state with 4s and 4p exponents of 2.0 and 1.8, respectively. The porphyrin ring used in all calculations was simple porphine ($C_{20}N_4H_{12}$) in which the 31 lowest and 40 highest lying molecular orbitals were deleted from the variational set of orbitals (all orbitals below the lowest π and above the highest π* were deleted). The porphyrin ring was idealized for D_{4h} symmetry. The metal in all cases, unless otherwise specified, was placed 0.1 Å above the plane of the porphyrin ring. Imidazole (Im) was used as a model for histidine (His) in 6- coordinate complexes. The structure of imidazole was taken from the Alchemy molecular modeling program database. A N-O bond length of 1.176 Å was used for the nitrosyl ligand (Orpen et al., 1989). Metal-nitrosyl bond distances used were 1.646, 1.669 and 1.651 Å for Co, Fe, and Mn, respectively (Orpen et al., 1989). The 3σ and 6σ orbitals of NO were deleted from the set of variational orbitals.

Density functional calculations.--Density functional calculations were carried out on a Cray YMP supercomputer using the Amsterdam Density Functional program (Baerends et al., 1973). Double-ζ basis sets were used for C,

N. ,nd H of the porphyrin ring. A triple-ζ basis was used for N ,nd O of NO, and Mn, Fe and Co. The $1s^2$ configurati s of C, N and O and the $1s^2$, $2s^2$, $2p^6$ configurations of M Fe and Co were treated as core. All calculations were ca ied out with Becke (1988) and Perdew (1986) non-local cc ections. All bond distances and angles were those used in he Fenske-Hall calculations.

Results

The Metal-Porphyrin Interaction.--A brief summary of th Fenske-Hall picture of the metal porphyrin interaction is gi en here in order to identify the important frontier molecu ar orbitals used in the discussion of 5- and 6- coordinate complexes. The principal interactions involved in metal-

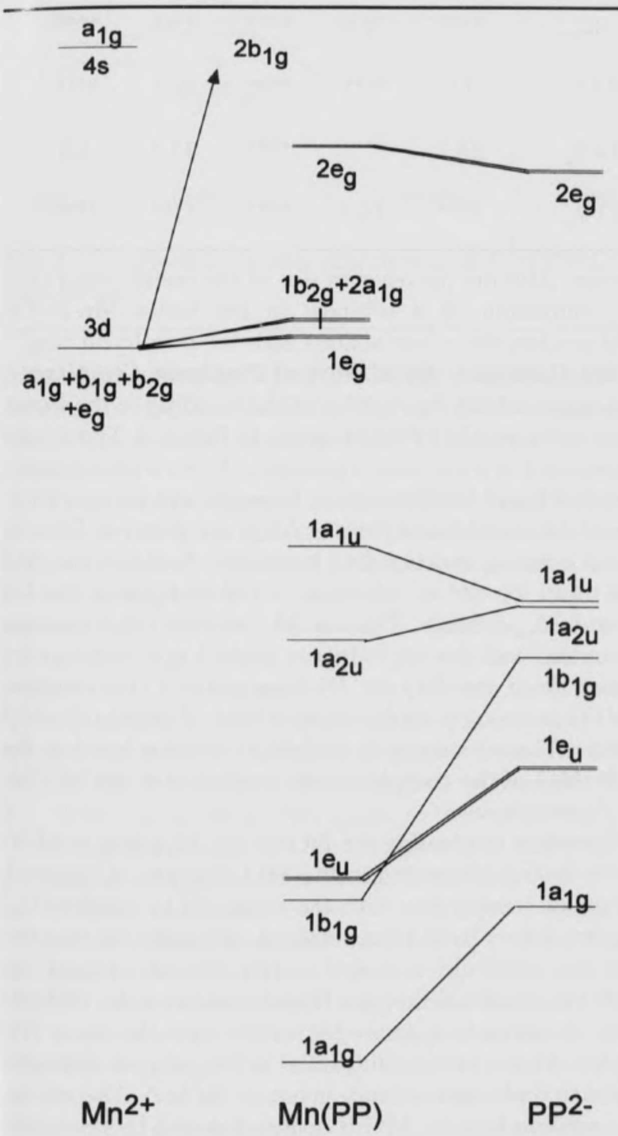

Fig. 1. A molecular orbital description of the Mn - porphyrin interaction

Table 1: Mulliken populations of frontier MOs in metal porphyrin complexes

	Mn	Fe	Co
Porphyrin a_{1g}	1.535	1.532	1.536
Porphyrin e_u (total)	3.276	3.264	3.252
Porphyrin b_{1g}	1.301	1.321	1.326
Porphyrin $2e_g$ (total)	0.378	0.280	0.190
Metal total	6.559	7.653	8.758
Metal total d	5.448	6.449	7.510
$3d_{z^2}$	0.126	0.101	1.017
$3d_{x^2-y^2}$	0.701	0.680	0.675
$3d_{xy}$	1.017	2.000	2.000
$3d_{xz}$	1.802	1.859	1.909
$3d_{yz}$	1.802	1.859	1.909
4s	0.342	0.370	0.449
$4p_x$	0.372	0.378	0.384
$4p_y$	0.372	0.378	0.384
$4p_z$	0.025	0.028	0.031

porphyrin bonding are illustrated in Figure 1. The molecular orbital diagram describes the combination of Mn^{2+} with a porphyrin^{2-} (PP^{2-}) ligand with the manganese atom in the plane of the porphyrin ring. The Mn $3d_{x^2-y^2}$ orbital, the lobes of which point towards the porphyrin N atoms, is pushed up in energy through interaction with the b_{1g} porphyrin orbital. The porphyrin also acts as an electron donor through the a_{1g} orbital (to manganese 4s) and e_u orbitals (to manganese p_x and p_y). The porphyrin $2e_g$ orbitals (Lowest Unoccupied Molecular Orbital (LUMO) of porphyrin^{2-}) interact with the metal d_{xz} and d_{yz} orbitals in a backbonding fashion. However, donation from the porphyrin $1e_g$ (not shown) results in an overall slight destabilization of the metal-based e_g (d_{xz},d_{yz}) orbitals. The HOMO of MnPP is a singly occupied, essentially non-bonding, metal based orbital (b_{2g}). The LUMO of manganese porphyrin is the largely Mn $3d_{z^2}$ based non-bonding a_{1g} orbital. The electronic structure of iron porphyrin is similar; the HOMO is

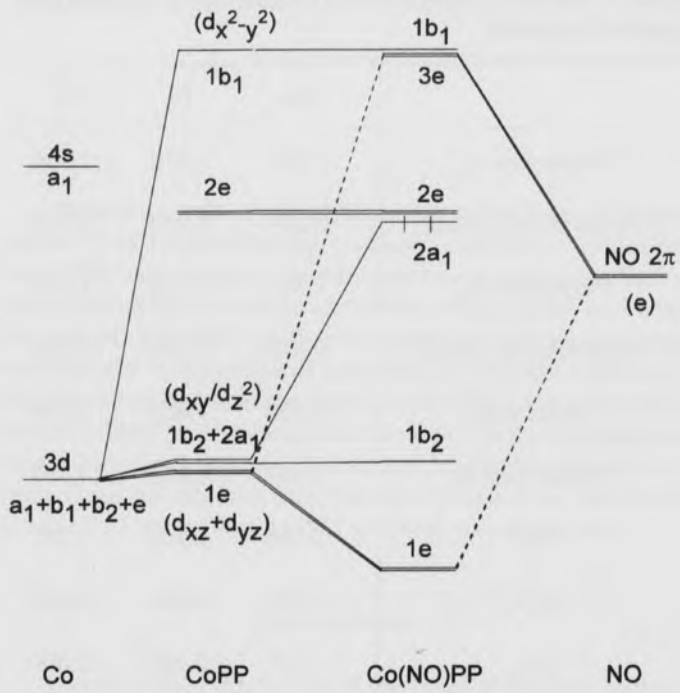

Fig. 2. A molecular orbital description of Co(PP)NO, linear NO

Table 2. Percent character and energy of valence MOs of Co(PP)NO, θ=180° (**** <1%)

	2e	2e	$1b_2$	$1a_1$	$1b_1$
Energy (eV)	-9.36	-9.29	-8.32	-6.11	-3.43
Co $3d_z^2$	4.9	****	****	42.7	1.6
Co $3d_{x^2y^2}$	****	****	****	****	59.1
Co $3d_{xy}$	****	****	98.9	****	****
Co $3d_{xz}$	62.1	****	****	20.4	****
Co $3d_{yz}$	****	72.6	****	****	****
NO 5	1.0	****	****	6.3	****
NO 2_x	23.3	****	****	11.3	4.0
NO 2_y	****	18.9	****	****	****

a doubly occupied metal-based non-bonding b_{2g} orbital, and the LUMO is a nonbonding metal based a_{1g} orbital. In Co porphyrin the HOMO is a singly occupied a_{1g} orbital, and the LUMO is a porphyrin-based $2e_g$ orbital. Due to the closeness in energy of the metal-based valence MOs (e_g, a_{1g}, b_{2g}) of these complexes, no attempt is made to deduce a ground state configuration from these results. The ground state of iron porphyrin is largely believed to be $^3A_{2g}$, corresponding to the configuration $(d_{xy})^2(d_{z^2})^2(d_{xz},d_{yz})^2$ (Sontum and Case, 1983). The $(d_{xz},d_{yz})^4(d_{xy})^2$ configuration ($^1A_{1g}$) predicted by the Fenske-Hall calculations is not unreasonable considering the similarity in energy of the metal frontier orbitals and the level of approximation inherent to these calculations.

Mulliken populations for some of the frontier orbitals of M^{2+} (M=Mn, Fe, Co) and PP^{2-} in the complexes MPP are given in Table 1. Clearly the additional electrons in the series MnPP, FePP, CoPP reside on the metal center. The variation of π and σ-interactions of the porphyrin with Mn, Fe, and Co is interesting: The degree of metal to porphyrin-$2e_g$ backbonding decreases from Mn-Fe-Co despite the increasing number of metal based electrons available for bonding. This can be attributed to the increasing energetic gap between the metal $d\pi$ orbitals and porphyrin $2e_g$ orbitals as the valence d orbital energy of successive metals decreases. Also the decrease in size of the metal center (relative contraction of d orbitals) in the series Mn-Fe-Co should weaken the π interactions with the porphyrin ring.

Five Coordinate Metal Nitrosyl Porphyrin Complexes.-- A molecular orbital description of the bonding in the linear nitrosyl complex Co(PP)NO is given in Figure 2. The results are presented in a fragment approach, shown as the interaction of CoPP and NO fragments. Energies and percent characters of the metal-based frontier MOs are given in Table 2. There is a strong backbonding interaction between the NO 2π ($\pi*$) and Co $d\pi$ (e), resulting in stabilization of the Co $3d_{xz}$ and $3d_{yz}$ orbitals. The Co $3d_{xy}$ orbital ($1b_2$) remains nonbonding, and the $3d_z^2$ ($1a_1$) is pushed up in energy by donation from the NO 5σ (N lone pair). The resultant HOMO is a strongly antibonding orbital, of mainly Co $3d_z^2$ character. There exists no formal NO - metal σ bond as the $1a_1$ HOMO of the complex is the antibond of the NO 5σ-Co d_z^2 interaction.

The effect of bending the NO in the XZ plane to M-N-O (θ) = 140° is illustrated in the MO diagram of Figure 3. For ease of comparison with the linear NO complex, C_{4v} symmetry labels have been retained, although the symmetry of the molecule is now C_s. The Co $3d_z^2$ based $1a_1$ HOMO is stabilized through backdonation to the NO $2\pi_x$ orbital, an interaction symmetry forbidden in the linear NO complex. This is clearly illustrated in the percent character of valence molecular orbitals given in Table 3. The energy of the antibonding $1a_1$ MO is further lowered by decreased interaction with the NO 5σ orbital. These effects are accompanied by a decrease in NO $2\pi_x$-Co d_{xz} overlap (Table 4).

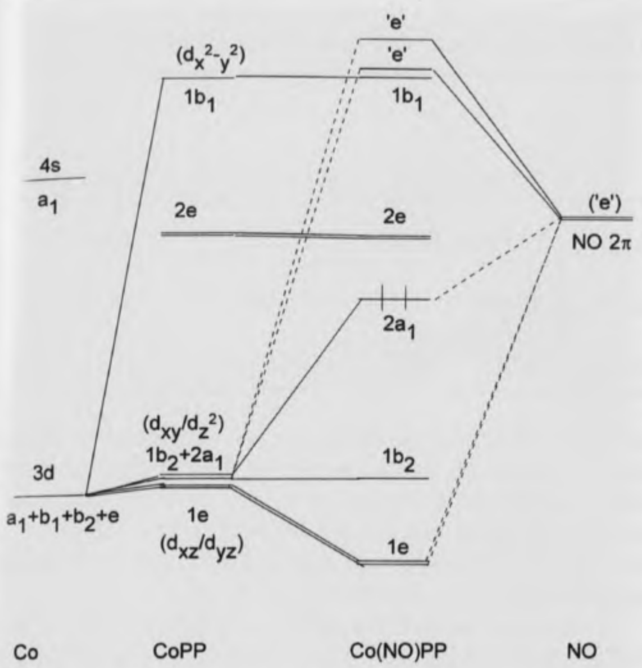

Fig. 3. A molecular orbital description of Co(PP)NO, NO bent (θ=140°)

Table 3. Percent character and energy of valence MOs of Co(PP)NO, θ=140° (**** <1%)

	2e	2e	$1b_2$	$1a_1$	$1b_1$
Energy (eV)	-9.93	-9.93	-8.69	-5.68	-3.59
Co $3d_z{}^2$	****	****	****	64.5	1.6
Co $3d_{x^2-y^2}$	****	****	****	****	62.1
Co $3d_{xy}$	****	****	98.8	****	****
Co $3d_{xz}$	64.5	****	****	****	****
Co $3d_{yz}$	****	64.4	****	****	****
NO 5	****	****	****	4.3	****
NO 2_x	****	****	****	4.3	****
NO 2_y	****	23.8	****	****	****

Also the decrease in NO 5σ - Co $d_z{}^2$ overlap results in a decrease in stabilization of the NO 5σ - Co bonding molecular orbital (not shown, an increase in energy of ~0.85 eV is observed).

Considerable changes in the Mulliken populations for the Co dπ, NO 2π and Co $d_z{}^2$ orbitals are observed on bending (Table 3). The Co $d_z{}^2$ Mulliken population decreases on bending by ~0.36 due to $d_z{}^2 \rightarrow$ NO $2\pi_x$ back-bonding and decreased NO 5σ $\rightarrow d_z{}^2$ σ donation. The populations of the Co d_{xz} and d_{yz} orbitals increase by 0.32 and 0.14 respectively. The change in d_{xz} population is attributed to the decrease in d_{xz} - NO $2\pi_x$ overlap on bending the nitrosyl and the newly introduced donation from the NO 5σ orbital. The NO 5σ population is seen to increase slightly (by ~0.05) on bending. This is due to the competing effects of decreased overlap with the Co $d_z{}^2$ orbital and the newly introduced interaction with Co d_{xz}. The change of +0.16 in the Mulliken population of the NO $2\pi_x$ orbital results from the back-bonding interaction with Co $d_z{}^2$, countering the decrease in donation from the Co d_{xz}. The increase in Mulliken population of the Co d_{yz} orbital may at first seem odd as the Co d_{yz} - NO $2\pi_y$ overlap is relatively unperturbed on bending NO (Table 4). However, we can attribute the change to the increased electron density on NO because of increased back-donation to the $2\pi_x$ orbital and decreased donation from the 5σ orbital. The decrease in population of the NO $2\pi_y$ orbital is consistent with the reduced donation from Co d_{yz}. These results are qualitatively consistent with those derived from extended Hückel calculations on five coordinate organometallic metal nitrosyls (Hoffmann et al., 1974; Mingos, 1973).

A Walsh diagram for the valence molecular orbitals in CoPP(NO) on bending the nitrosyl ligand is given in Figure 4. On changing the Co-N-O angle from 180 to 120 degrees, we observe considerable stabilization of the $1a_1$ HOMO and destabilization of the Co dπ based 1e orbitals. This is accompanied by a corresponding increase in HOMO-LUMO gap from 0.28 eV to 1.50 eV as the LUMO (porphyrin $2e_g$) is essentially invariant in energy with θ. It is interesting to note that in this transformation from formal NO^+ (θ=180°) to formal NO^- (θ=120°), we observe a flow of charge from metal to nitrosyl (Table 6). The difference in charge between linear NO and bent NO (θ=120°) is, however, only -0.128 e. Although consistent with the formal $NO^+ \rightarrow NO^-$ direction of charge flow, the charges also suggest that the best description for NO, bent or linear, is an approximately neutral ligand. Contour plots, taken in the XZ plane, of the Co d_{xz} and $d_z{}^2$ - NO interactions in bent (θ=140°) CoPP(NO) are given in Figure 5. The rehybridization of NO $2\pi_x$ / NO 5σ and Co d_{xz}/ Co $d_z{}^2$ are clearly evident. Figure 6 compares the interactions between NO and M in the bent and linear complexes M(PP)NO.

The degree of bending observed in a given complex will depend upon the relative effect of the above interactions

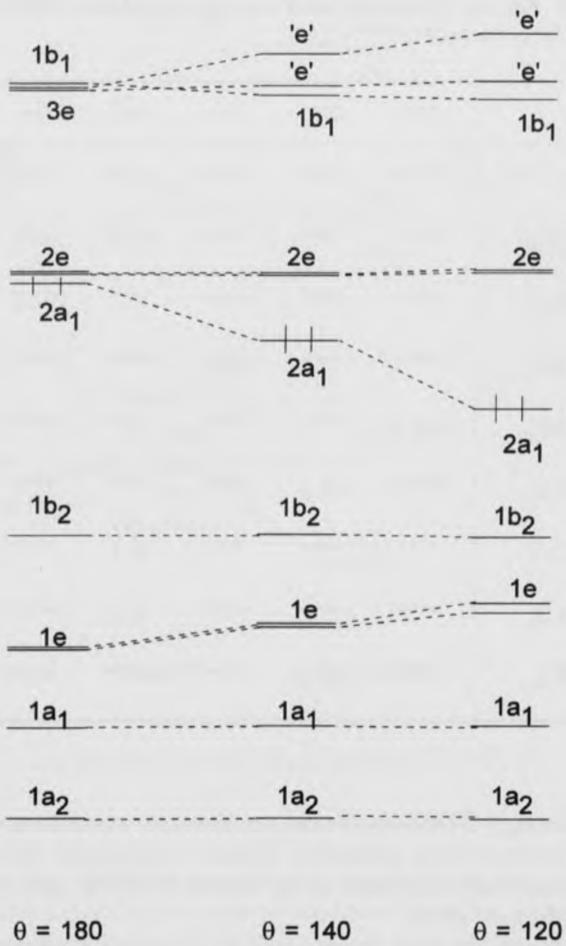

Fig. 4. Walsh diagram for the variation of frontier orbital energies of Co(PP)NO with θ

on the total energy of the complex. In the Walsh diagram of Figure 4, it is clear that the Co(PP)NO HOMO ($1a_1$) energy changes more rapidly with Co-N-O angle than the energy of the Co dπ (1e) orbitals. However, the dπ orbitals contain 4 electrons and consequently might be expected to contribute more to the total energy of the complex than the $1a_1$ HOMO. These factors will counter each other in determining the optimal Co-N-O angle.

It is also plausible for the Co-NO to bend at different dihedral angles to the XZ plane. The effect of bending the Co-NO at various dihedral angles to the XZ plane was investigated. No significant energetic difference between the different conformations was observed. The principal metal based valence MO's are essentially invariant with dihedral angle. No evidence was observed to suggest any direct interaction between the NO ligand and porphyrin ring at any dihedral angle. This is consistent with experiment, which

Table 4. Fenske-Hall calculated overlaps between Co and NO orbitals for linear and bent NO in CoPP(NO)

	NO 5σ	NO $2\pi_x$	NO $2\pi_y$
	Linear / Bent	Linear / Bent	Linear / Bent
Co $3d_z{}^2$	0.130 / 0.111	0.000 / 0.059	0.000 / 0.00
Co $3d_{xy}$	0.000 / 0.053	0.092 / 0.063	0.000 / 0.00
Co $3d_{yz}$	0.000 / 0.000	0.000 / 0.000	0.092 / 0.09

has shown the dihedral angle to vary considerably among similar systems, and a low barrier to rotation has been previously predicted (Hoffmann et al. 1974). For this discussion, the nitrosyl ligand will always be bent in the XZ plane as this simplifies the molecular orbital description by minimizing rehybridization of the M dπ orbitals.

A molecular orbital description of Fe(PP)NO (Fe-N-O = 140^o) is given in Figure 7. The $1a_1$ metal based HOMO is stabilized through interaction with the NO $2\pi_x$ orbital, as observed in Co(PP)NO. However, in the case of Fe, the HOMO is only singly occupied. Consequently, stabilization of this orbital would be expected to have a lesser effect on the total energy of the complex relative to the stabilization of the HOMO of Co(PP)NO. Hence, it is predicted that the destabilization of Fe dπ orbitals will be more influential in determining the degree of bending than the corresponding orbitals in Co(PP)NO. Consequently, a larger value of θ is expected for Fe(PP)NO relative to Co(PP)(NO). This is consistent with experiment, which shows Co-N-O = 135^o and Fe-N-O = 149^o in Co(TPP)NO (Scheidt and Hoard, 1973) and Fe(TPP)NO (Scheidt and Frisse, 1974), respectively. It is noted that the HOMO of Fe(PP)NO lies closer to the porphyrin e_g orbitals than that of CoPP(NO), largely due to the higher energy of the Fe 3d orbitals relative to the 3d orbitals of Co. This results in a smaller HOMO-LUMO gap (at 140^o) for FePP(NO) (0.37eV) compared to CoPP(NO) (0.76eV). Although calculations on the linear NO complex of Fe were non-convergent (due to accidental degeneracy of porphyrin e_g and $a_1(d_z{}^2)$ during SCF cycles), calculations on Fe(PP)NO at 140^o and 180^o were performed with deletion of the porphyrin e_g LUMO orbitals. This deletion allows the calculation to converge readily but eliminates backdonation from Fe to the porphyrin ring. Consequently, data from these calculations cannot be directly compared to the previous calculations. However, comparison of calculations in which the porphyrin e_g LUMO is deleted at M-N-O = 140^o and 180^o does reveal similar trends in frontier orbital populations to those observed for Co(PP)NO. As in the Co complex, the population of Fe $d_z{}^2$ decreases, accompanied by an

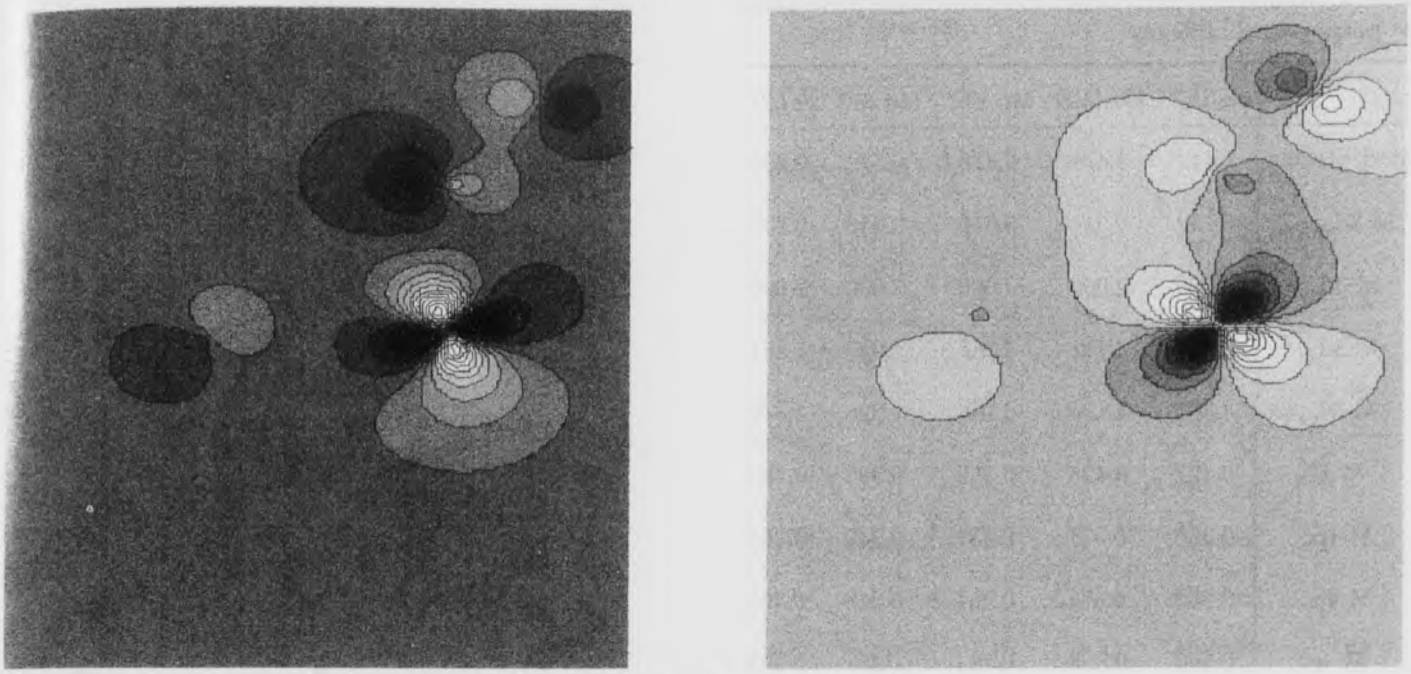

Fig. 5. Contour plots of the d_z2-NO and d_{xz}-NO interactions in bent Co(PP)NO

increase in the metal dπ populations, on bending the nitrosyl.

A molecular orbital diagram of Mn(PP)NO is given for Mn-N-O = 180° and Mn-N-O = 140° in Figure 8. The HOMO of Mn(PP)NO is a non-bonding metal based b_2 orbital (d_{xy}). The d_z^2 based $1a_1$ orbital is unoccupied, and therefore no stability is gained by introducing a NO2π - d_z^2 interaction on bending of the nitrosyl ligand. Therefore we predict bending of the nitrosyl ligand to be unfavorable, resulting in the destabilization of the metal dπ based e orbitals and reduced NO 5σ - Mn d_z^2 overlap.. The change in σ bonding is suggested to be the primary deterrent to bending in the Mn complex as decreased Mn d_{xz} - NO $2\pi_x$ overlap is compensated by mixing of the Mn d_z^2 orbital with d_{xz}, resulting in no significant change in energy of the dπ based e orbitals. The decrease in energy of the $1a_1$ d_z^2 / NO 5σ antibonding LUMO on bending is accompanied by a change of +0.73 eV in the energy of the largely NO 5σ based NO-Mn d_z^2 bonding MO. It is interesting to note that the Mn d_z^2 Mulliken population increases on bending. This may be attributed to NO 2π → d_z^2 donation, the opposite of the backdonation observed in the Fe and Co complexes. The Mn d_{xz} Mulliken population decreases on bending. Hence, electron density is effectively shuttled from the d_{xz} to d_z^2 orbital on bending NO, the opposite direction to that observed for the Fe and Co complexes.

Six-Coordinate Complexes.--Considering the above analysis of pentacoordinate metal porphyrin nitrosyls, the effect of a sixth ligand, trans to NO, can be readily discussed. A molecular orbital description of Mn(NO)PP(Im) (linear NO, Im = imidazole) is given in Figure 9. The occupied Mn 3d-based molecular orbitals are relatively unperturbed by the presence of imidazole. Imidazole acts primarily as a sigma donor ligand, with essentially no back-bonding ability. The Mn d_z^2 based a_1 orbital acts as an acceptor orbital for the imidazole N lone pair, resulting in stabilization of imidazole and destabilization of the virtual a_1 orbital. A net formal bond order of 1 is observed, and the HOMO-LUMO gap is unchanged. This interaction is favorable, stabilizing the Im lone pair and avoiding filled-filled orbital interactions while producing an 18-electron complex. Consequently, we would expect MnPP(NO) to form a stable bond to imidazole and similar ligands.

On interaction of Fe(PP)NO with imidazole, the singly occupied, largely d_z^2 based a_1 HOMO of Fe(PP)NO would be pushed up in energy, decreasing the HOMO-LUMO gap. This filled - half filled interaction would result in stabilization of the imidazole N lone pair, along with destabilization of the a_1 Fe(PP)(NO)(Im) HOMO. A formal bond order of 0.5 is predicted, consistent with the experimentally observed long Fe-(1-methyimidazole) bond in Fe(TPP)(NO)(1-MeIm) of 2.18 Å. (Scheidt and Piciulo, 1976).

Co(PP)NO is an 18-electron complex. Reaction of Co(PP)NO with imidazole would result in a filled-filled Co(PP)NO a_1-Im lone pair interaction. The largely d_z^2

Table 5. Mulliken populations in five-coordinate metal nitrosyl porphyrin complexes

	Co 180°	Co 140°	Mn 180°	Mn 140°	Fe140°
M3d +NO2π	1.842	1.478	0.488	0.579	0.936
M $3d_{x2-y2}$	0.752	0.717	0.640	0.648	0.703
M $3d_{xy}$	2.000	2.000	2.000	2.000	2.000
M $3d_{xz}$	1.391	1.712	1.185	1.027	1.381
M $3d_{yz}$	1.391	1.526	1.185	1.228	1.419
M 4s	0.422	0.428	0.353	0.363	0.403
M $4p_x$	0.380	0.373	0.351	0.346	0.366
M $4p_y$	0.380	0.375	0.351	0.348	0.369
M 4p	0.568	0.398	0.184	0.176	0.269
M d total	7.376	7.433	5.498	5.482	6.439
M total	9.126	9.007	6.737	6.715	7.846
NO 5σ	1.630	1.683	1.553	1.584	1.630
NO $2\pi_x$	0.630	0.791	0.728	0.793	0.796
NO $2\pi_y$	0.630	0.474	0.728	0.682	0.552
M3d +NO2π	8.636	8.698	6.954	6.957	7.787

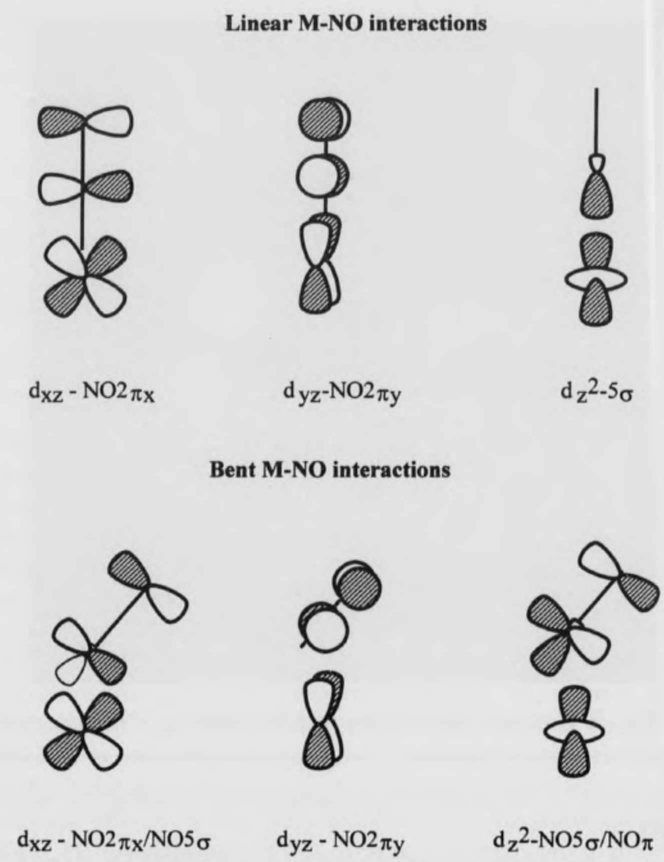

Fig. 6. Metal - nitrosyl bonding interactions in bent and linear M(PP)NO.

based antibonding a_1 HOMO of Co(PP)NO would be further destabilized by σ-donation from a trans ligand. No net bonding results (a formal bond order of 0, 20e complex); Co(PP)NO would not be expected to bind a sixth ligand.

These observations suggest that binding of NO to metalloporphryin complexes of Fe or Co will weaken or destroy bonding to a trans-σ-donor ligand. Binding of NO to a manganese metalloporphyrin complex will not significantly weaken a Mn-(trans-σ- donor) interaction. The proposed mechanism of activation of sGC by labilization of a distal ligand on binding NO is consistent with the above calculations and the observation of activation by Fe and Co nitrosyl porphyrins and the lack of activation by Mn nitrosyl porphyrins.

Total Energy Variations of M(PP)NO with M-N-O Angle.--Density functional calculations were performed to study the effect of M-N-O bending on the total energy of the complexes of interest. The Fenske-Hall results presented above suggest different degrees of bending for NO for Mn, Fe, and Co porphyrin nitrosyls. However, undermining these conclusions are two problems inherent to approximate Hartree-Fock methods. First, as approximations are made in calculation of the Fock matrix, the calculations are not truly variational. Therefore total energy comparisons are not

Table 6. Variation of charge distribution in Co(PP)NO with Co-N-O angle

θ	180°	140°	120°
Co	-.123	-.008	0.100
NO	0.156	0.111	0.028
Porphyrin	-0.033	-0.103	-0.128

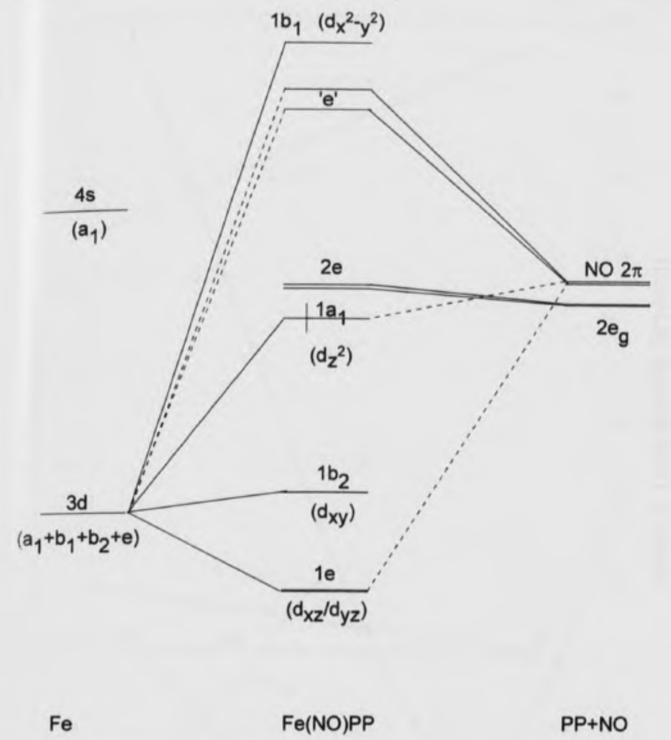

Fig. 7. A molecular orbital description Fe(PP)NO with θ = 140°.

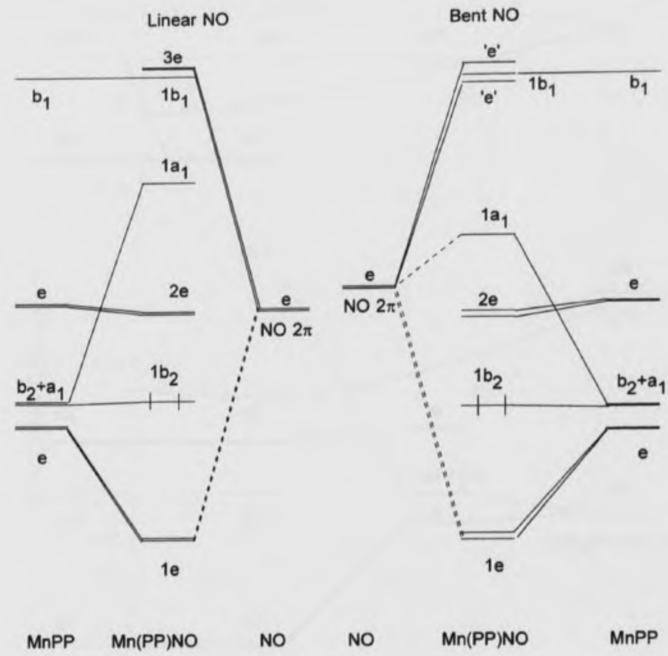

Fig. 8. Molecular orbital descriptions of Mn(PP)NO, NO bent and linear.

valid. Second, the arguments based upon the number of electrons stabilized and degree of stabilization may not be compelling. As the total energy is not simply the sum of the energies of occupied orbitals, this argument is open to criticism. Full energy minimization calculations on these metal porphyrin nitrosyl complexes would be prohibitively expensive due to the large number of functions and low (C_s) symmetry. Hence a series of single-point calculations at various M-N-O angles were carried out for the complexes M(PP)NO, M=Mn, Fe, and Co. Figure 10 shows the variation of total energy of the complexes M(PP)NO (M = Mn, Fe, Co) with M-N-O angle determined from a series of single point ADF calculations at the Becke-Perdew level. The porphyrin was idealized to D_{4h} symmetry, and the metal porphyrin complexes were given C_s symmetry (NO bent in the XZ plane). In each case, as in the Fenske-Hall calculations presented above, the metal was placed 0.10 Å above the plane of the porphyrin ring. The Co, Fe, and Mn complexes have energy minima at ~128°, 144°, and 180° respectively. The trend in optimal M-N-O angle is consistent with the Fenske-Hall results presented above.

The experimentally determined values θ, 135°, 149°, and ~176° for Co(TPP)NO (Scheidt and Hoard, 1973), Fe(TPP)NO (Scheidt and Frisse, 1975), and Mn(TPP)NO (Scheidt and Hoard, 1973) (TPP=tetraphenylporphyrin), respectively, indicate that the degree of bending is slightly overestimated in the ADF calculations. The agreement with experiment is, however, surprisingly good considering the approximations made in these calculations.

Figure 11 shows the variation of the energies of the $1a_1$ and 1e MOs with θ in Co(PP)NO. The variation of the $1a_1$ (HOMO) energy with θ is similar to that calculated by the Fenske-Hall method. The energetic variation of the Co $3d_{xz}$-based MO is consistent with the decrease in overlap between the NO $2\pi_x$ - Co d_{xz} orbitals on decreasing θ. The Co $3d_{yz}$-based MO is relatively invariant with θ, which is consistent with little or no change in overlap between NO $2\pi_y$ and Co d_{yz}. This differs somewhat from the Fenske-Hall results, where both the Co d_{xz} and d_{yz} changed considerably in energy with θ. The difference most probably arises from basis set effects and the fact that the net charge transfer between Co and NO on bending is considerably smaller in the ADF calculations.

The variation of NO charge with θ, including charges on the N and O atoms of NO, is illustrated in Figure 12. It is noted that the changes in the NO charge are dominated by changes in the charge on the N atom. This complements the description given earlier of the principal bonding changes with θ being controlled by the NO 5σ and NO 2π orbitals, both of which are largely based on the NO nitrogen

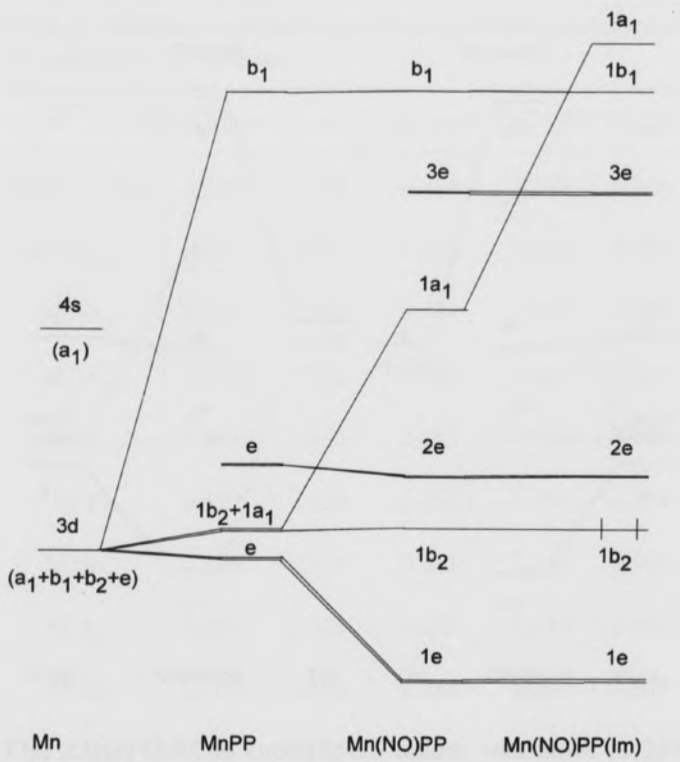

Fig. 9. A molecular orbital description of Mn(PP)(NO)Im.

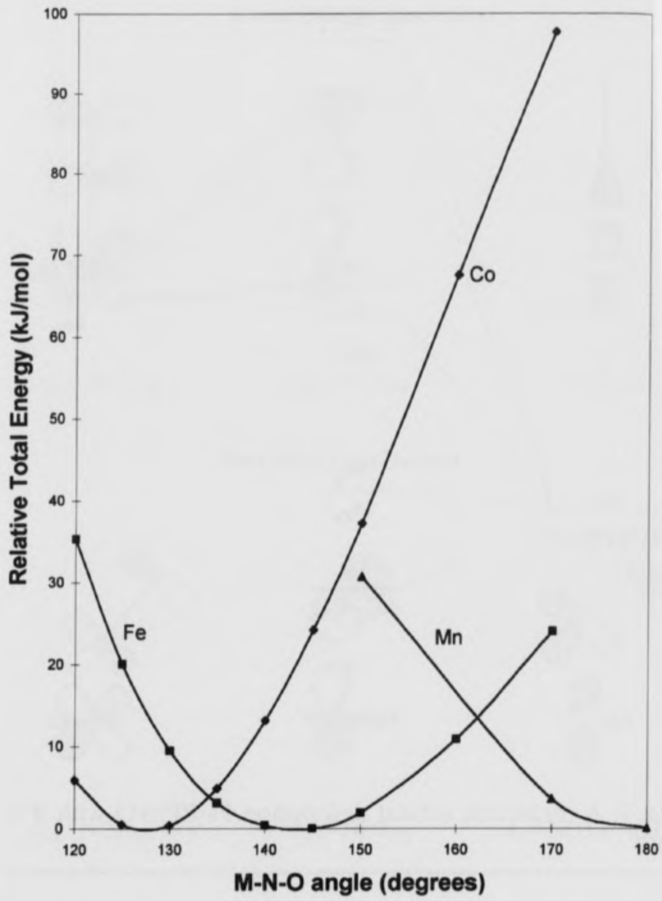

Fig. 10. Variation of total energy of M(PP)NO (M = Mn, Fe, Co) with M-N-O angle.

atom. On bending, the NO ligand increases in total negative charge; this is consistent with the formal $NO^+ \rightarrow NO^-$ transformation. The calculated charge variations are very small and suggest, as noted before, that the best description of NO at any M-N-O angle in these complexes is that of an essentially neutral ligand.

Conclusions

The mechanism of activation of the enzyme sGC is believed to be related to the labilization of a His ligand trans to NO in a metal porphyrin group of the enzyme. The enzyme is activated by Fe and Co, but not by Mn. The results presented here suggest that labilization of the His residue is due to the localization of electron density in a metal d_z^2/NO 2π based orbital on going from Mn to Fe to Co. Further consistent with this is the observation that Fe(PP)(CO)(His) does not activate the enzyme. Fe(PP)CO is isoelectronic with Mn(PP)NO, and hence the a_1 (d_z^2) orbital is unoccupied. It is also predicted that Co(PP)CO, isoelectronic with Fe(PP)NO, would labilize a trans His ligand. The degree of bending of the nitrosyl ligand is dependent on the relative energy and occupation of the metal-based d_z^2 and $d\pi$ frontier orbitals. Our calculations predict a linear NO in MnPP(NO) and a bent NO in Fe(PP)NO and Co(PP)NO with M-N-O = 145° and 128°, respectively. These predictions are in good agreement with experimental values for M(TPP)NO complexes. The relative activation of the enzyme is also predicted to be greatest for Co(PP)NO, where 2 electrons reside in the antibonding a_1 HOMO.

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Literature Cited

Baerends, E. J., D. E. Ellis, and **P. Ros.** 1973. Self consistent molecular Hartree-Fock-Slater calculations. I. Computational procedure. Chem. Phys. 2:41-51.

Becke, A. D. 1988. Density functional exchange-energy

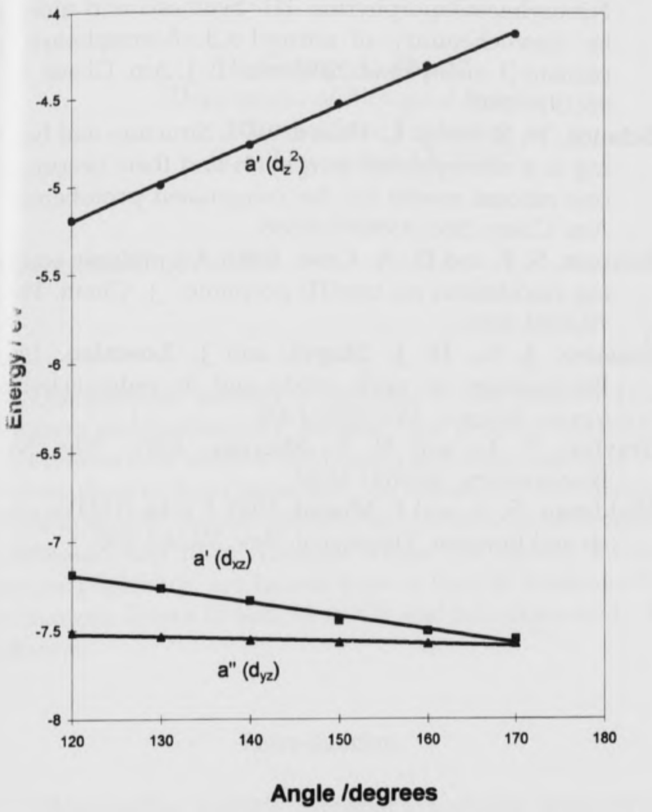

Fig. 11. Energy variation of metal based frontier MOs with Co-N-O angle in Co(PP)NO

approximation with correct asymptotic behavior. Phys. Rev. A38, 3098-3100.

Bursten, B. E., J. R. Jensen, and **R. F. Fenske.** 1978. An Xa optimized atomic orbital basis. J. Chem. Phys. 68, 3320-3321.

Burstyn, J. N., T. G. Spiro, S. Hu, and **A. E. Yu.** 1994. Resonance Raman spectroscopy of soluble guanylyl cyclase reveals displacement of distal and proximal heme ligands by NO. J. Am. Chem. Soc. 116: 4117-4118.

Culotta, E. and **D. E. Koshland.** 1992. NO news is good news. Science 258:1862-1865.

Dierks E. A., S. Hu, A. E. Yu, T. G. Spiro, and **J. N. Burstyn.** 1997. Demonstration of the role of scission of the proximal histidine-iron bond in the activation of soluble guanylyl cyclase through setalloporphyrin substitution studies. J. Am. Chem. Soc. 119: 7316-7323.

Feldman, P. L., O. W. Griffith, and **D. J. Stuehr.** 1993. The surprising life of nitric oxide. C&EN, December 20: 26-38.

Garthwaite, J. 1991. Glutamate, nitric oxide and cell-cell signaling in the nervous system Trends. Neurosci. 14: 60-67.

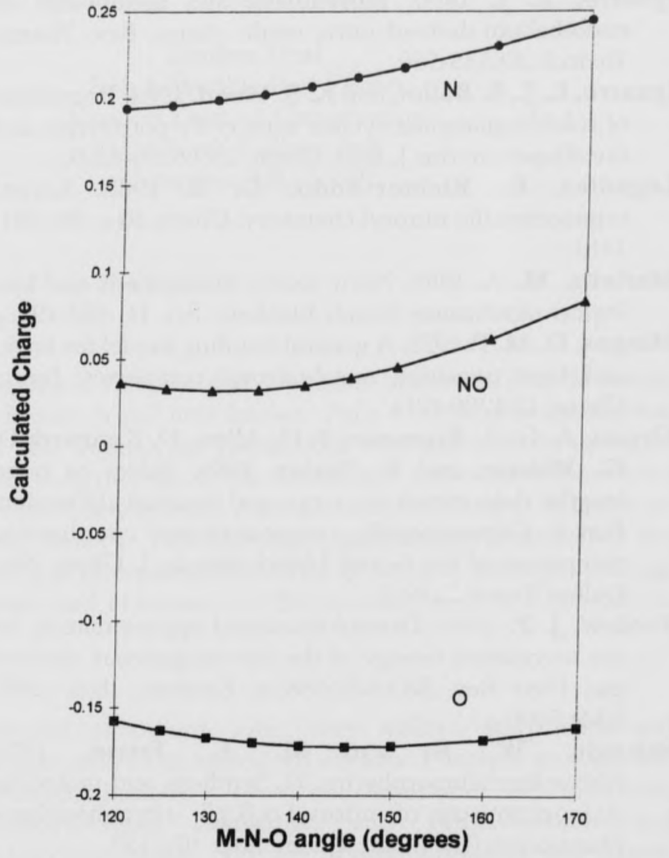

Fig. 12. Variation of NO charges with M-N-O angle in Co(PP)NO

Gladfelter, W. L. 1985. Nitrosyl and Nitrido Metal Clusters Adv. Organomet. Chem. 24: 41-85.

Griffith, W. P. 1968. Organometallic nitrosyls. Adv. Organomet. Chem. 7: 211-239.

Hall, M. B. and **R. F. Fenske.** 1972. Electronic structure and bonding in methyl- and perfluoromethyl (pentacarbonyl)manganese. Inorg. Chem. 11: 768-775.

Hehre, W. J., R. F. Stewart, and **J. A. Pople.** 1969. Self-Consistent Molecular-Orbital Methods. I. Use of Gaussian Expansions of Slater-Type Atomic Orbitals. J. Chem. Phys. 51: 2657-2665.

Hoffmann, R., M., M. L. Chen, M. Elian, A. R. Rossi, and **D. M. P. Mingos.** 1974. Pentacoordinate nitrosyls. Inorg. Chem. 13:2666-2675.

Ignaro, L. J., K. S. Wood, and **M. S. Wolin.** 1982. Activation of purified soluble guanylate cyclase by protoporphyrin IX Proc. Natl. Acad. Sci. U.S.A. 79, 2970.

Ignarro, L. J. 1989. Heme-dependent activation of soluble guanylate cyclase by nitric oxide: regulation of enzyme activity by porphyrins and metalloporphyrins. Semin.

Hematol. 26: 63-76.

Ignarro, L. J. 1990. Biosynthesis and metabolism of endothelium-derived nitric oxide. Annu. Rev. Pharm. Toxicol. 30:535-560.

Ignarro, L. J., B. Ballot, and **K. S. Wood.** 1984. Regulation of soluble guanylate cyclase activity by porphyrins and metalloporphyrins J. Biol. Chem. 259:6201-6207.

Legzdins, P.; Richter-Addo, G. B. 1988. Recent organometallic nitrosyl chemistry. Chem. Rev. 88: 991-1010.

Marletta, M. A. 1989. Nitric oxide: biosynthesis and biological significance Trends Biochem. Sci. 14: 488-492.

Mingos, D. M. P. 1973. A general bonding model for linear and bent transition metal-nitrosyl complexes. Inorg. Chem. 12:1209-1211.

Orpen, A. G., L. Brammer, F. H. Allen, O. Kennard, D. G. Watson, and **R. Taylor.** 1989. Tables of bond lengths determined by x-ray and neutron diffraction. Part 2. Organometallic compounds and coordination complexes of the d- and f-block metals. J. Chem. Soc. Dalton Trans. S1-S83.

Perdew, J. P. 1986. Density-functional approximation for the correlation energy of the inhomogeneous electron gas. Phys Rev. B33:8822-8824. Erratum. Ibid. 1986. B34: 7406.

Scheidt, W. R. and **M. E. Frisse.** 1975. Nitrosylmetalloporphyrins. II. Synthesis and molecular stereochemistry of nitrosyl-α,β,γ,δ -tetraphenylporphinatoiron (II). J. Am. Chem. Soc. 97:17-21.

Scheidt, W. R. and **P. L. Piciulo.** 1976. Nitrosylmetalloporphyrins. III. Synthesis and molecular stereochemistry of nitrosyl-α,β,γ,δ-tetraphenylporphinato (1-methylimidazole)iron(II). J. Am. Chem. Soc. 98:1913-1919.

Scheidt, W. R. and **J. L. Hoard.** 1973. Structure and bonding in a nitrosylcobalt porphyrin and their bearing on one rational model for the oxygenated protoheme. J. Am. Chem. Soc. 95:8281-8288.

Sontum, S. F. and **D. A. Case.** 1983. Xα multiple scattering calculations on iron(II) porphine. J. Chem. Phys. 79:2881-2892.

Stamler, J. S., D. J. Singel, and **J. Loscalzo.** 1992. Biochemistry of nitric oxide and its redox-activated forms. Science. 258:1898-1902.

Traylor, T. G. and **V. S. Sharma.** 1992. Why NO? Biochemistry, 31:2847-2849.

Waldman, S. A. and **F. Murad.** 1987. Cyclic GMP synthesis and function. Pharmacol. Rev. 39:163-196.

Distribution and Status of *Ophiogomphus westfalli* (Odonata: Gomphidae) in Missouri and Arkansas

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Abstract

Ophiogomphus westfalli is endemic to the Interior Highlands (Ozark Plateaus and Ouachita Mountains), in Missouri, Arkansas and southeastern Kansas. First described in1985, its life history is still little known. Prior to 1997, this species was known from only six sites in Missouri and 10 in Arkansas. From late May through late July in both 1999 and 2000 we surveyed 49 sites, three of them twice each, on Missouri Ozark streams in order to further clarify the distribution and relative abundance of this dragonfly. Adults, nymphs and/or exuviae were found at 23 sites. Literature and museum searches bring to 72 locations in Missouri and 10 in Arkansas where this species has been found. Small to moderate-sized populations, restricted to the Interior Highlands, are known from at least 82 locations. Therefore, it is recommended that its global and Missouri rankings be changed from G2 and S2 to G3 and S3, respectively. Distribution and abundance of this species needs further study in Arkansas.

Introduction

Ophiogomphus westfalli (Westfall's snaketail dragonfly) was described by Cook and Daigle (1985) from specimens collected in Arkansas and Missouri. It characteristically inhabits second- to fifth-order streams throughout the Interior Highlands (Fig. 1). Nymphs typically burrow in sand/gravel substrates. Upon emergence, the teneral individuals move away from the stream into nearby clearings, such as old fields, until their bodies harden and the reproductive systems mature. Here, they perch on low vegetation. Mature males return to the stream where they characteristically perch on gravel bars, streamside emergent vegetation or dead twigs. Males also periodically patrol at the head of clearly delineated riffles, watching for females returning to the water for mating and subsequent oviposition (Needham et al., 2000; Dunkle, 2000). The species is currently classified globally as G2 and in Missouri and Arkansas as S2.

Description of the Area.--The Interior Highlands are a broad geographic region lying within Arkansas, Missouri, extreme eastern Oklahoma and southeastern Kansas. The Highlands were formed by uplifting, folding and faulting processes during the Pennsylvanian Period, approximately 300 mya. Elevation ranges from 80 to over 900 m. The Highlands include two divisions, the larger northern Ozark Plateaus Physiographic Province and the smaller southern Ouachita Mountains Province (Robison and Buchanan, 1988).

The Ozark Plateaus are characterized by rugged, flat-topped mountains, long, deep valleys, steep cliffs and ledges, and clear, spring-fed streams. Principle geologic formations include Ordovician limestone and dolomite, Pennsylvanian sandstone, and Pennsylvanian and Ordovician shales. Soils are primarily residual, and vegetation is mostly upland hardwood forests of white oak, red oak and hickory (Robison and Buchanan, 1988). While limestone and dolomite often impart great alkalinity to the water, a wide range of both alkalinity and water hardness has been recorded.

The Ouachita Mountains are a series of long, narrow ridges with east-west axes. The ridges are separated by wide valleys, each drained by a river or stream. Principle geologic formations in this province are Paleozoic sedimentary sandstone and shale ranging in age from Cambrian or Ordovician through Pennsylvanian, which were warped, twisted and folded under tremendous pressure. Soils are derived from shale and sandstone, with recent alluvium in the bottomlands of the main rivers. Shortleaf pine, upland hardwood and bottomland hardwood forests predominate (Robison and Buchanan, 1988). Water hardness, alkalinity and pH all tend to be lower in Ouachita streams than in those of the Ozark Plateaus.

Methods

Forty-nine sites on Missouri Ozark streams were surveyed for adult Westfall's snaketails and associated odonate species, three of them twice. Sampling was conducted from late May through late July in both 1999 and 2000. Locations were typically first selected from maps, based upon stream size and accessibility. Approximately two to three hours were devoted to the visual search for dragonflies at each site. Stream banks, gravel bars and nearby open areas (e.g. old fields) were examined along and to either side of an axis approximating 400 m along the stream bed. Typically, one voucher specimen was collected of each species observed. Sight identifications were occasionally made for netted specimens which were subsequently released. Populations of *Opiogomphus westfalli* were considered to be small if only one or two, or moderate if several (five+), adult individuals were observed within the search area. At 45 of the 49 sites and at the same time adults were collected, nymphs and associated aquatic macroinvertebrates were collected by Turtox Indestructible™ dip net. Specimens from this study are deposited in the Aquatic Macroinvertebrate and Adult Odonata Collections of the Arkansas State University Museum of Zoology.

All known sources of records were canvassed. Individual collectors who provided records are Tim Vogt, Illinois State Museum; John Belshe, Central Missouri State University; Randy Sarver, Missouri Department of Natural Resources; and Jane Walker and Joe Smentowski. A Missouri Department of Conservation state-wide survey of dragonflies added several records. The University of Missouri Enns Entomology Museum contains specimens. In Arkansas, a concentrated effort made by approximately 30 members of the Dragonfly Society of the Americas yielded 65 adult *O. westfalli* from a 1 km reach during a six-hour period along the South Fork of the Spring River near Hardy on 2 June 1990.

Results and Discussion

Earliest records of *Ophiogomphus westfalli* identified it as *Ophiogomphus rupinsulensis.* Williamson's (1932) specimens from the Current River in 1930 were confirmed as *O. westfalli* by Cook and Daigle (1985). Grabau (1955) recorded a very small nymph of *O. rupinsulensis* from the Meramec River. We could not relocate this specimen in the Enns Entomology Museum collection, therefore its identification could not be verified. Harp and Rickett's (1977) records of *O. rupinsulensis* for Arkansas are for this species, as well. Their later records for snaketails (Harp and Rickett, 1985) use the correct name for the species, however. Beckemeyer and Huggins (1997) tentatively identified a nymph from Cherokee County, Kansas, as *O. rupinsulensis.* This specimen is probably *O. westfalli,* as its location is quite near the known range for this species but several hundred km from the known range of *Q. rupinsulensis.*

In this study, adults, nymphs and/or exuviae were recorded at 23 of the 49 sites surveyed (Table 1). Literature and museum searches brought to 72 locations in Missouri and 10 in Arkansas where this species has been found (Figure 1, Table 2). A complete list of associated odonate species and preliminary results of the aquatic macroinvertebrate survey were reported by Harp and Trial (2000). Many new locations resulted from corrected identifications of *O. westfalli* nymphs (originally identified as *Emetogomphus designatus*) in MDC benthic samples housed in the Enns Entomology Museum. Several additional records resulted from the MDC state-wide survey of dragonflies. Locations sampled, numbers of *O. westfalli* recorded and an evaluation of the habitat suitability for this dragonfly are summarized by river basin.

Elk River Basin.--*Ophiogomphus westfalli* was found at four of the five sites surveyed. Adults were recorded on Big Sugar Creek, while nymphs were found in DNR samples from Indian and Mikes creeks. Low numbers were found, but the population appears to be widespread in this river basin. Stream turbidity was low, gradient was adequate and the substrate was appropriate for this species. The Elk River mainstem and other tributaries may support this dragonfly and need to be searched.

Spring River Basin.--The target species was recorded at five of eight sites. Moderate numbers were present in upper Shoal Creek but not at two sites downstream. Center Creek, from which nymphs were collected in 1961 (Cook and Daigle, 1985), is now quite turbid and was not sampled. The lower reaches of Spring River in Missouri show degradation from silt, making the stream more turbid than *O. westfalli* prefers. Nitrogen and phosphorus are increasing the algal blooms, which can shade lower water levels and increase biochemical demand (BOD) as these algae die. Nymphs were collected from Spring River and Shoal Creek by the MDC in 1964- 65. *O. westfalli* populations appear to be widespread but with low numbers.

White River Basin.--The populations are widespread (eight of 10 sites) but generally low in numbers. Moderate numbers were found at Flat Creek. Bryant Creek, the North Fork of White River and James River also had adults, nymphs and/or exuviae in low numbers. Adverse impacts include organic runoff and solid waste in Beaver, Bull, Roark and Swan creeks. Cattle also impact Swan Creek. As yet, these impacts apparently are not too severe, since a few *O. westfalli* adults were observed at Swan and Bull creeks. Adults were reported from Beaver Creek in 1982. Overall, populations appear to be healthy in this basin.

Black River Basin.--Several streams support small populations of *O. westfalli* (15 of 28 sites and 19 of 33 samples). This species does not appear to tolerate continuously cold streams (heavily influenced by springs), and this seems to contribute to a patchy distribution in this basin.

Small populations are widely scattered in the South Fork of Spring River above its confluence with the West Fork. The junction of these two streams was surveyed twice, since upstream populations of the South Fork are known and good populations exist on the South Fork further down-

Fig. 1. *Ophiogomphus westfalli* locations.

Table 1. Missouri *Ophiogomphus westfalli* sample locations and voucher specimens collected.

Stream	County	Location	Year	Adult	Nymph	Exuviae
Elk R Basin						
Big Sugar Cr	McDonald	St Hwy 90	1999	♂,♀ in wheel	0	0
Indian Cr	McDonald	St Hwy 76	1999	0	0	0
Spring R Basin						
Spring R	Lawrence	St Hwy 97	1999	0	0	0
Shoal Cr	Newton	MDC Cherry Comer Access	1999	0	0	0
Shoal Cr	Newton	MDC Smack-out Access	1999	0	NBS*	NBS
Shoal Cr	Newton	MDC Jolly Access	1999	1♂, 5S**	0	0
White R Basin						
Roaring R	Barry	MDC Roaring R Cons Area	1999	0	0	0
James R	Stone	above MDC Hooten Town Access	1999	1♂	0	0
Flat Cr	Barry	MDC Lower Flat Cr Access	1999	1♂, 1♀ 5S	1	3
Roark Cr	Taney	Branson, Roark Valley Rd	1999	0	0	0
Bull Cr	Taney	US Hwy 160	1999	1♀	1	0
Swan Cr	Taney	Co Hwy AA	1999	2S	0	1
Beaver Cr	Taney	St Hwy 76	1999	0	0	0
Bryant Cr	Ozark	MDC Warren Bridge Access	1999	0	0	1
Bryant Cr	Ozark	St Hwy 95	1999	1S	2	0
No F White R	Douglas	Jct St Hwy 14/181	2000	2S	0	0
Black R Basin						
W&S F Spr R	Howell	100 m S of St Hwy 142	1999	0	0	0
			2000	0	NBS	NBS
Wm F Spr R	Ozark	St Hwy 19	1999	0	0	0
Eleven Pt R	Oregon	MDC Greer Crossing Access	1999	0	0	0
	Oregon	St Hwy 99	2000	0	NBS	NBS
	Howell	Co Hwy W	1999	0	0	0
Jacks Fork	Shannon	MDC Buttin Rock Access	1999	1♂	0	0
Rocky Cr	Shannon	MDC Rocky Cr Cons Area	1999	0	0	0
Rogers Cr	Carter	MDC Peck Ranch Cons Area	1999	0	0	0
Black R	Reynolds	MDC Lesterville Access	2000	0	0	0
W F Black R	Reynolds	MDC Centerville Access	1999	0	0	0
St Francis R Basin						
St Francis R	Wayne	MDC Coldwater Access	2000	0	0	0
	Madison	Co Hwy C	2000	0	0	0
	Madison	MDC Millstream Grdns Cons Area	2000	0	0	0
	St Francois	Co Hwy H	2000	0	0	0
Twelvemile Cr	Madison	Co Hwy C	2000	0	0	0
Castor R Basin						
Castor R	Madison	Co Hwy V	2000	1♂, 6S	0	0

Table 1. continued

Osage R Basin						
Little Sac R	Polk	St Hwy 215	1999	0	0	0
Pomme de Terre	Polk	St Hwy 32	1999	0	0	0
Niangua R	Dallas	MDC Charity Access	1999	1♂	0	0
Gasconade R Basin						
Gasconade R	Pulaski	lkm dnstrm MDC Schlicht Spr Acc	2000	1♂	0	0
	Laclede	MDC Anna M Adams Access	2000	1♂	0	0
Osage Fork	Laclede	MDC Hull Ford Access	2000	0	0	0
	Laclede	MDC Drynob Access	2000	5S	0	0
Big Piney R	Phelps	Co Hwy J	2000	2S	0	0
	Texas	St Hwy 32	2000	4S	0	0
	Texas	MDC Boiling Springs Access	1999	0	NBS	NBS
Roubidoux Cr	Pulaski	MDC Roubidoux Cr Cons Area	2000	0	0	0
Meramec R Basin						
Meramec R	Crawford	Meramec St Park	1999	1S	NBS	NBS
			2000	1♂, 5S	0	0
Bourbeuse R	Gasconade	MDC Tea Access	2000	0	NBS	NBS
	Gasconade	1.5km upstream of St Hwy 19	2000	0	0	0
	Gasconade	MDC Mint Spring Access	2000	0	0	0
Big R	Jefferson	MDC Merrill Horse Access	2000	0	0	0
	St Francois	MDC Leadwood Access	2000	0	0	0

* NBS=No benthic sample
** S=Sight ID only, no voucher specimen

stream, in Arkansas. The species was found neither time. The Warm Fork of Spring River was organically enriched and had much solid waste, conditions apparently not favored by *O. westfalli.*

Three sites were surveyed on the Eleven Point River. No snaketails were found, probably because of the heavy influence of numerous springs.

Current River and its tributaries support small populations (nine of 11 collections). Many of the tributaries are too small, and springs are common in this basin, resulting in few individuals at any given site. Single adults were seen at several Nature Conservancy lands. These are adjacent to Current River, which may be the source of these individuals.

The West Fork of Black River and its tributaries, though small, support a moderately large population of *O. westfalli* (two of three stations, five of six samples). A series of four MDC benthic samples collected from 1969-84 at one station contained 26, 21, 9 and 1 nymphs, respectively. While one adult was collected at an upper MDC site, none was found at a location downstream of the MDC sites in 1999. It is not known whether the above-pattern of collections reflects a real decline in the population. The Middle and East forks were not investigated during this study because of limited time. MDC benthic samples from Brushy and Strother creeks, both tributaries of Middle Fork, contained nymphs in the early 1980s. No snaketail adults or nymphs were found in Black River at the MDC Lesterville Access during the 2000 survey. Lead mining and gravel removal probably severely limit the snaketail population in the lower West Fork and mainstem Black River.

St. Francis River Basin.--No individuals were found on the mainstem or a major tributary, Twelvemile Creek, despite intense searching at five sites. The upper stream is strongly impacted by organic pollution, while the middle and lower reaches are impacted by lead mine drainage. One 1968 MDC benthic sample from Big Creek, a tributary of the lower St. Francis River, contained a single nymph. A snaketail population may still be there. Otherwise, no records of this species exist for this basin.

Castor River Basin.--The single site sampled on the mainstem had a moderate number of adults. The gradient was suitable and the water was clear. Farther downstream, turbidity and organic enrichment increased, while gradient decreased. Whitewater River had inadequate current with high turbidity at the two access points visited, and no samples were taken. Farther upstream this river was too small.

Osage River Basin.--Most of the streams have marginal habit for the nymphs. Gradients are generally too low and

Table 2. Known locations for *Ophiogomphus westfalli* in Arkansas.*

Stream	County	Location	Year	Adult	Nymph
Black R Basin					
S F Spring R	Fulton	10km W of Hardy	1981	1♀	
			1984	1♂, 1♀	
			1986	1♀	1
			1990	65	
			1991	1♂, 2♀	
			1993	2♂, 1♀	
Janes Cr	Randolph	St Hwy 90	1985		1
Strawberry R	Sharp	US Hwy 167	1976		1
			1990	a few	
	Izard	St Hwy 354	1988		2
White R Basin					
Long Cr	Carroll	Denver	1981		3
Caddo R Basin					
Caddo R	Montgomery	St Hwy 240	1978		1
			1980		1
		Rd (TAR?) 177	1981	4♂	
			1984	4♂, 1♀	
		Rd 8	1983	1♀	
Ouachita R Basin					
S F Saline R	Saline	1km N of Nance	1974		1
			1976		1
		US Hwy 70	1975		1

*With the exception of the Caddo R adults, all specimens are cataloged as voucher specimens in the ASUMZ. Collectors include GL Harp, PA Harp, R McDaniel, S Moulton, HW Robison, G Susanke and members of the Dragonfly Society of the Americas. The Caddo R adult records are from Cook and Daigle (1985).

the substrate contains too much silt or clay. Organic enrichment and concomitant turbidity were observed in this study. No snaketails were found on the Little Sac River. Although there is one 1975 MDC nymphal record from the Pomme de Terre River, none were found in this survey, and based on the observations of this study, the species probably no longer exists on the Pomme. Single individuals were recorded from four total collections on the Niangua and Little Niangua rivers and Wet Glaize Creek.

Gasconade River Basin.--This basin may support the largest, healthiest populations of the snaketail (15 of 18 locations, 21 of 24 samples). This species occurs along a 270 km reach of the mainstem of the Gasconade River (two sites during this study, six MDC sites). Moderate numbers of adults were also seen at two locations on the Osage Fork. MDC benthic samples from the Osage and Woods forks also contained nymphs.

The snaketail is widely distributed in the Big Piney River from west of Licking to its confluence with the Gasconade River. During this study, individuals were found at two of three sites. None was found at MDC Boiling Spring Access, probably because of the spring influence. An MDC site at the mouth of the Big Piney contained nymphs in 1974 and 1976.

No snaketails were found in the aerial survey or dip net sample at the single site on Roubidoux Creek. This stream is heavily influenced by springs.

Maries River Basin.--One DNR benthic sample taken from a site in 1971 and one MDC benthic sample taken from another site in 1975 contained 1-2 nymphs. Streams in this basin are too small where habitat otherwise favorable to snaketails occurs. Farther downstream, gradient is too low and the water is too turbid. An individual was collected in 2001, but the population in this basin is probably declining.

Meramec River Basin.--Moderate populations exist in his basin (14 of 19 locations, 17 of 22 collections). Moderate numbers were found on Meramec River within Meramec State Park, and one of us (L T) found individuals at two sites approximately 60 km upstream, as well. Other investigators have found this dragonfly in Meramec River tributaries. Courtois Creek supports moderate populations (two sites). Adults are reported for Indian and Little Indian creeks and one nymph from Goose Creek.

Two MDC benthic samples from the Bourbeuse River in 1962 contained nymphs. However, aerial surveys at three sites and dip net samples at two of those sites failed to find the species in 2000. Increased soil erosion and resulting turbidity are suspected to be the primary reason for the decline. Although there is a gravel-rock substrate, most of it is covered with a layer of silt up to 8-10 cm thick.

Big River supports a small population of snaketails, but only in the upper reaches, which are not impacted by lead mining. This species has been found periodically at MDC Bootleg Access from 1981-2000. It was not found downstream, at two locations, during this study. The population in this river may be in decline.

Distribution in Arkansas.--More data for this species have come from one site on the South Fork of Spring River west of Hardy than from any other single site. Periodically, various members of the Dragonfly Society of the Americas have collected this snaketail on the Caddo River around Amity and Glenwood. Otherwise, a few scattered records for Strawberry River at Evening Shade and nymphs from the Saline River exist (Table 2). The distribution and abundance of this species needs to be studied.

Primary Factors Influencing Distribution.--In general, *O. westfalli* is likely to be found along any undisturbed second- to fifth-order Ozark or Ouachita stream which is not heavily influenced by springs. At least moderate current and well-defined riffles are required, as are relatively clear water and sand-gravel substrate. In light of the wide range of alkalinity and pH values in Ozark streams and their relatively low values in Ouachita streams, where soils are primarily shale and sandstone, these parameters appear to be of secondary importance. Principle environmental perturbations in this snaketail's range appear to be related to agricultural activity. Clear cutting for pastures or tree harvesting increases runoff, resulting in decreased photosynthesis and concomitant diminished dissolved oxygen in the stream. Siltation decreases the available oxygen in the substrate, where the nymphs reside. Nitrogen and phosphorus enrichment from agricultural activity or municipalities increases the frequency and severity of algal blooms. These blooms can shade the lower water levels and, at their demise, can increase the BOD. Another limit to the distribution of *O. westfalli* results from lead and zinc mine drainage. This dragonfly is apparently intolerant of these heavy metals.

Associated Odonata Species.--Several species of Odonata were found in association with *O. westfalli* (Harp and Trial, 2000). Some of these (e.g. *Plathemis lydia*) are associates because they are species adapted to a broad spectrum of habitats. During this study, however, it became evident to one of us (GLH) that the occurrence of one species, *Gomphus ozarkensis*, closely paralleled that of *O. westfalli.* These species share several characteristics. For example, they are both stream-dwelling dragonflies of Family Gomphidae and are endemic to the Interior Highlands. Both species have short flight seasons and have synchronized spring emergence. Some differences are also known. *Gomphus ozarkensis* emerges about two weeks earlier than *Q. westfalli*, while the latter flies approximately three weeks later. For example, O. *ozarkensis* may first emerge from mid-April (Ouachita Mountains) to mid-May (Missouri Ozark Plateaus), but on the South Fork of Spring River 10 km west of Hardy, where this species has been studied extensively, it typically first emerges around 6-10 May and flies until late June (Susanke and Harp, 1991). At this site *O. westfalli* appears about two weeks later and flies until mid- to late July. Additionally, while away from the stream, *O. ozarkensis* characteristically perches on bare ground, whereas *O. westfalli* perches on low vegetation. How these species co-exist is an interesting and potentially important question to answer for the effective management of both species.

Future Monitoring.--Unless a major perturbation disturbs a large part of the Interior Highlands, *O. westfalli* populations should continue to be healthy. The distribution of this species in several river basins is poorly known and more sampling is needed. Monitoring can most effectively be implemented at locations known to have sizeable populations, such as Meramec River in Meramec State Park, and at locations where the population may be in decline, such as in the Osage River Basin. Surveys at five-year intervals should be adequate to monitor this species.

Conclusions

Small to moderate-sized populations of *Ophiogomphus westfalli*, restricted to the Interior Highlands, are known from 82 locations, 72 of which are in Missouri. Therefore, it is recommended that its global and Missouri rankings be changed from G2 and S2 to G3 and S3, respectively. Distribution and abundance of this species in Arkansas needs further study.

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Literature Cited

Beckemeyer, R. J. and **D. G. Huggins.** 1997. Checklist of Kansas Dragonflies. Kansas Sch. Nat. 43:3-16.

Cook, C. and **J. J. Daigle.** 1985. *Ophiogomphus westfalli* spec. nov. from the Ozark Region of Arkansas and Missouri, with a key to the *Ophiogomphus* species of eastern North America (Anisoptera: Gomphidae). Odonatologica 14:89-99.

Dunkle, S. W. 2000. Dragonflies through binoculars: a field guide to dragonflies of North America. Oxford Univ. Press. 266 pp.

Grabau, M. C. 1955. A taxonomic study of the naiads of Missouri dragonflies (Odonata-Anisoptera). MS Thesis, Univ. of Missouri. 116 pp.

Harp, G. L. and **J. D. Rickett.** 1977. The dragonflies (Anisoptera) of Arkansas. Proc. Arkansas Acad. Sci. 31:50-54.

Harp, G. L. and **J. D. Rickett.** 1985. Further distributional records for Arkansas Anisoptera. Proc. Arkansas Acad. Sci. 39:131-135.

Harp, G. L. and **L. Trial.** 2000. Distribution and status of *Ophiogomphus westfalli* in Missouri and Arkansas. Missouri Dept. Conserv. Rept. 26 pp. + appendices.

Needham, J. G., M. J. Westfall, Jr. and **M. L. May.** 2000. Dragonflies of North America. Scientific Publishers, Gainesville, Florida. 939 pp.

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

Susanke, G. R. and **G. L. Harp.** 1991. Selected biological aspects of *Gomphurus ozarkensis* (Westfall) (Anisoptera: Gomphidae). Advances in Odonatology. 5:143-151.

Williamson, E. B. 1932. Dragonflies collected in Missouri. Occasional papers of the Museum of Zoology, Univ. Michigan, Ann Arbor. No. 240. 40 pp.

Perceived Damage by Elk in the Arkansas Ozarks

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Abstract

Wildlife managers in Arkansas are faced with managing a growing population of Rocky Mountain elk (*Cervus elaphus nelsoni*) that has extended its range to incorporate private lands near the Buffalo National River (BNR) in northcentral Arkansas. This range expansion has created conflicts between private landowners and wildlife management personnel. To document the extent of damage and assess attitudes of landowners with elk on their land, interviews were conducted with landowners who contacted us or the Arkansas Game and Fish Commission about problems with elk. A survey also was created and sent to landowners who live near the BNR in Boone and Newton counties and who may have elk on their land. Ten of 18 respondents with elk on their land reported having a problem with nuisance activity. Landowners indicated that most damage was to pastures, hay crops, and food plots. Damage appeared to occur more often in summer, when elk home ranges were smallest, than in other seasons. Landowners incurring damage from elk had a strong negative opinion. Continued research into effective management practices should be conducted to properly manage this growing population of elk and reduce conflicts between elk and Arkansas landowners.

Introduction

Rocky Mountain elk were introduced to Newton County, Arkansas, between 1981 and 1985 (Arkansas Game and Fish Commission [AGFC], unpubl. data). Infrared censuses conducted on the Buffalo National River (BNR) corridor and surrounding private lands indicated this population had grown from 112 animals in 1985 to an estimated 312 animals in winter of 1993-1994 (AGFC, unpubl. data). The present population may number as many as 450 elk (AGFC, unpubl. data).

Arkansas' elk herd inhabits 91,000 ha of the BNR as well as some state-owned lands (Cartwright, 1997). A portion of this growing herd has left the boundaries of state and federal land and ventured onto adjacent private lands. The estimated total elk range in northcentral Arkansas may be as large as 315,000 acres. Wildlife managers are now faced with a growing herd of elk that has the potential to cause significant conflicts between private landowners and the elk. These conflicts may increase as the perceived amount of damage due to elk increases (Craven et al., 1992).

Nuisance complaints by Arkansas' private landowners began in 1990. Since then, nuisance activity reported includes damage to pastures, hay crops, fences, fruit trees, food plots for white-tailed deer (*Odocoileus virginianus*), and human harassment (AGFC, unpubl. data). These nuisance activities have the potential to strain the relationship between landowners and the AGFC (Gabrey et al., 1993).

Landowner perception of the extent of damage due to wildlife is important because it influences landowner attitudes about wildlife in general (Conover, 1994). Factual data regarding number of elk, range conditions, and extent of damage (Olsen, 1943), as well as information pertaining to attitudes of landowners with elk on their land can be used to help manage this growing elk population and reduce conflicts between elk and private landowners. We investigated attitudes of landowners with elk on their land and documented reported damage/nuisance occurrences to assess Arkansas landowner perceptions of elk damage.

Methods

In the summer of 1997, 160 surveys were sent to Conservation District Cooperators who owned land near the BNR and within the current elk range in Boone and Newton counties. Conservation District Cooperators are landowners collaborating with the National Park Service to improve their land or land practices for the benefit of wildlife. Questionnaires were modeled after a survey conducted by Gabrey et al. (1993). Landowners were asked to complete the surveys and return them in self-addressed stamped envelopes provided with the questionnaires. The survey consisted of questions regarding the presence of elk on private land, types of damage caused by elk, time of year damage occurred, estimated economic costs, possible solutions to elk problems, and general tolerance of landowners to elk and other wildlife on their land.

In addition, all nuisance or damage complaints reported to the Arkansas Game and Fish Commission from fall 1997 to fall 1998 were documented with landowner interviews and photographs. Photographs taken were of elk signs, such as feces, tracks, hair, and damage thought to be caused by elk. Landowners were asked to estimate economic loss due to damage or nuisance, indicate if they had had problems with elk in the past, and give their general feelings about elk on their land.

To determine if landowner survey answers and interviews could be pooled, we checked for differences in responses using Chi-square statistics. Chi-square statistics were also used to test for seasonal differences.

Results

Landowner survey and interview results could not be pooled because responses to questions about types of damage and seasons in which damage occurred differed ($\chi^2 = 15.7$, $P = 0.02$). Therefore, the survey and interviews were analyzed separately.

Landowner Survey.--We mailed 160 surveys to landowners and had 30 returned as undeliverable. Forty-

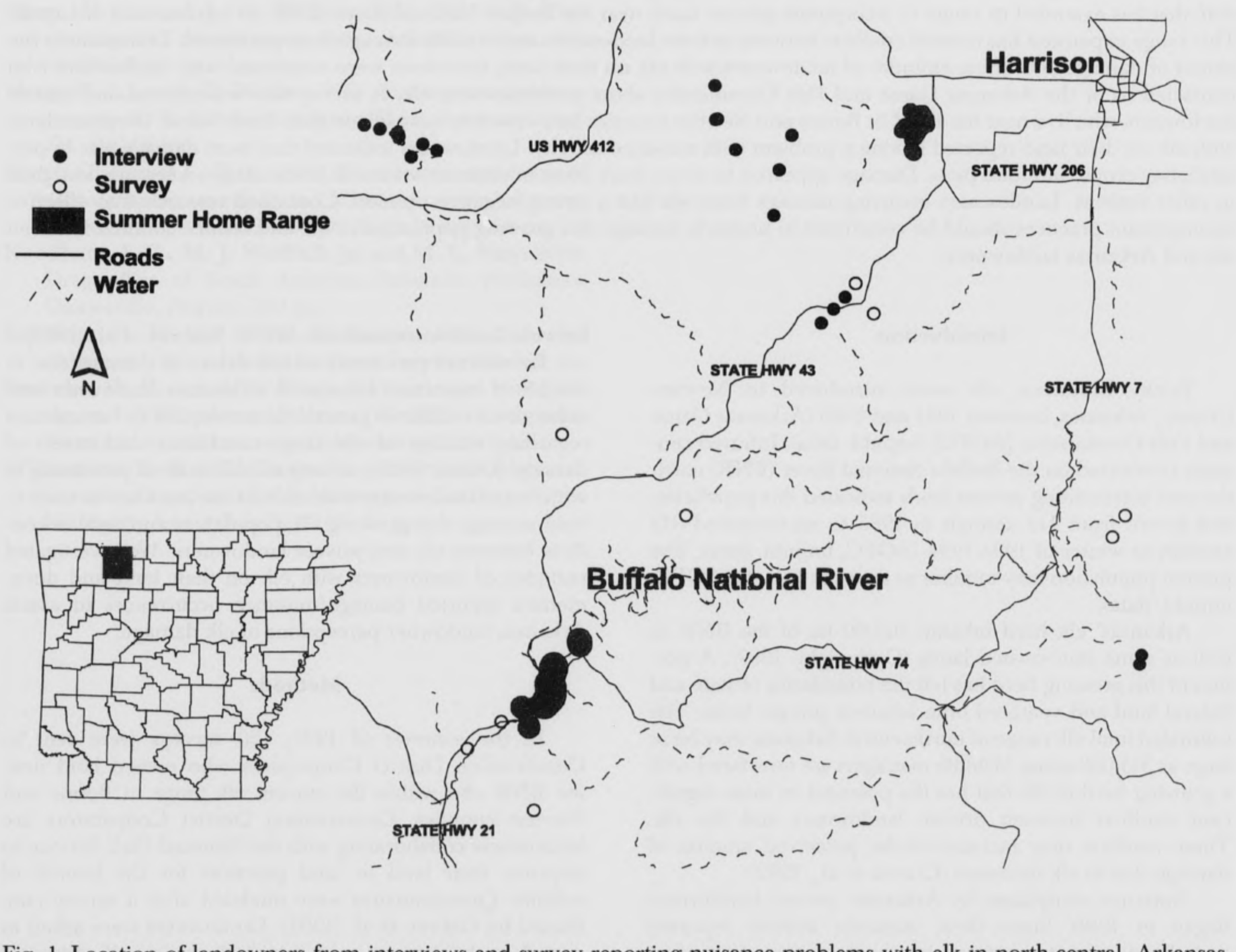

Fig. 1. Location of landowners from interviews and survey reporting nuisance problems with elk in north-central, Arkansas, fall 1997 to fall 1998. Summer home ranges are also included for 4 radio-collared elk. Two animals shared parts of their home range near the Buffalo National River.

even landowners (36%) returned surveys and 45 were eemed usable. Of the 45 usable surveys, 18 landowners eported elk on their land.

• Have you experienced any problems from elk on your and? If yes, please indicate what type of problems occurred nd your estimate of the loss.

Of those landowners reporting elk on their land, 10 had roblems with their presence (Fig. 1). These owners reported damage to pastures, hay crops, fences, gardens, and food plots for white-tailed deer and wild turkeys (*Meleagris gallopavo*). The 2 most commonly reported types of damage were to pastures and hay crops. In both cases, seven out of the ten landowners having problems with elk reported damage to pastures and/or hay crops.

• Please indicate the season the majority of each type of nuisance has occurred.

Damage did not occur more in one season than in any other ($\chi^2 = 3.6$, $P > 0.10$); however, 7 of the 10 landowners having problems with elk reported damage in summer (Fig. 2).

• Have you called AGFC with a complaint about nuisance activities? If yes, when and what was the nuisance complaint reported? Have you used any methods to scare away elk? If yes, what methods were used and were they effective?

Four landowners filed complaints with the AGFC regarding elk damage. Only one landowner reported the use of any methods to deter elk. This landowner reported using noise, human scent, soap, and dogs, none of which were deemed successful.

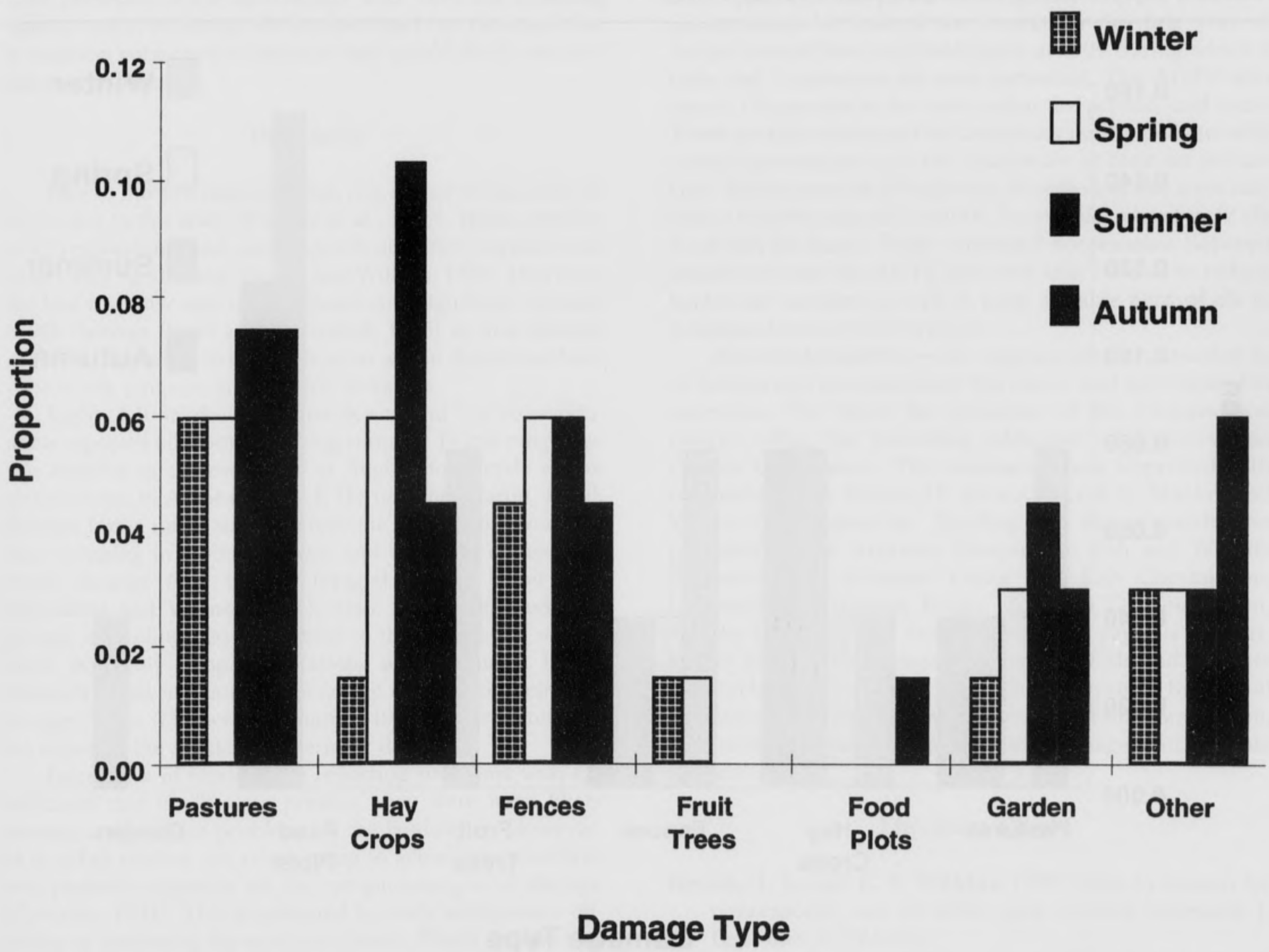

Fig. 2. Arkansas landowner survey results of predominant damage type reported for each season in north-central, Arkansas, fall 1997 to fall 1998.

• What solutions to elk nuisances would you like to see?

Most landowners reported favoring all of the choices given as possible solutions to elk problems. These included a hunting season on elk ($n = 8$), monetary compensation from AGFC for damage due to elk ($n=9$), and trapping and relocation of problem elk ($n=8$).

• What is your best annual estimate of economic loss due to elk?

Eight landowners reported damage costs ranging from \$50–5,000. Five landowners estimated their loss at over \$500, 2 estimated their loss between \$251–500, and 1 estimated his loss between \$51–250.

• How do you feel about having elk on your land?

Eight landowners who had elk on their land said they disliked having elk on their land, 4 were indifferent, and 4 said they enjoyed having elk on their land. Two landowners did not respond to this question.

Nuisance Complaint Interviews.--Ten landowners were personally interviewed regarding damage reported to us or the AGFC (Fig. 1). Reported damage occurred to pastures, hay crops, fences, gardens, fruit trees, wildlife feeders, and food plots for deer and turkey (Fig. 3). Most reported damage occurred to open fields (hay crops, $n=3$; and food plots, $n=4$) in summer ($n=8$) and autumn ($n=5$; Fig. 3). Damage to fences, fruit trees, gardens, and wildlife feeders was easily documented, whereas damage to food plots, pastures, and hay crops was more difficult to assess. However, in all instances of reported damage due to elk, elk sign such as tracks and feces were found. In 8 of 10 incidences of perceived elk damage, we observed elk on the property of the interviewed landowner or monitored a radio-collared elk there.

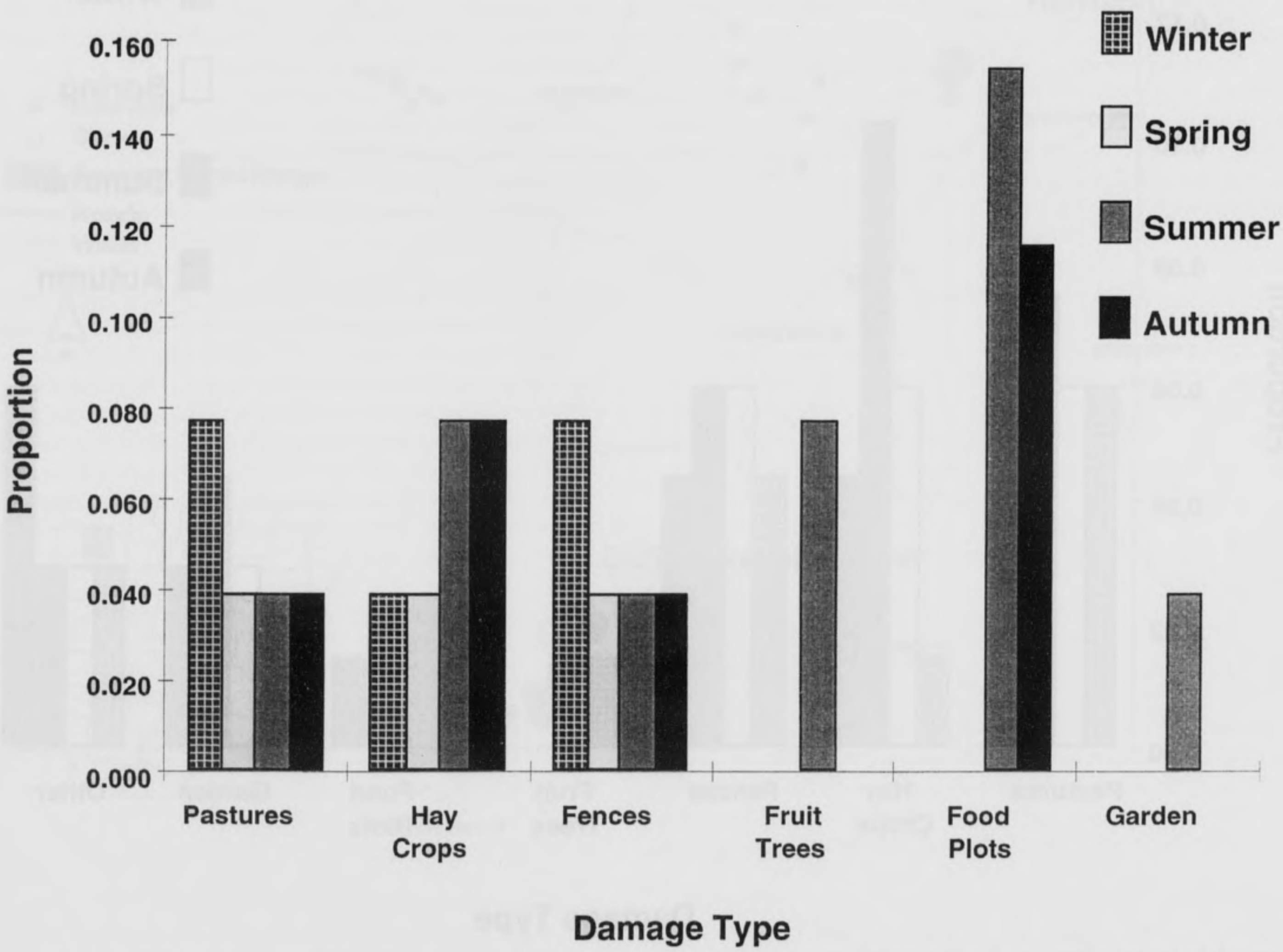

Fig. 3. Arkansas landowner interview results of predominant damage type reported for each season in north-central, Arkansas, fall 1997 to fall 1998.

Landowners had difficulty estimating the costs of reported damage to their property; however, 3 landowners made an attempt. One landowner estimated an annual loss of $4,500 due to elk eating and trampling ≥ 12.14 ha of hay crop. The second landowner estimated elk consumed $200/year of forage meant for cattle. The third estimated $1,600/year for loss of forage in food plots and for loss of corn and protein feed placed in wildlife feeders and intended for deer and turkeys.

Only one landowner reported damage as a first time occurrence, whereas all others reported occurrence of nuisances at least once before. Landowners with elk on their land that were incurring damage had a strong negative opinion about elk. Of the 18 landowners who reported seeing elk on their land, 8 landowners experienced no problems from their presence. Some landowners who were not incurring damage enjoyed seeing elk on their land but reasoned that if numbers continued to increase they would likely perceive elk as a problem.

Discussion

Due to our low response rate, non-response bias may be a concern in this study (Craven et al., 1992). When attributes of respondents and non-respondents differ, variable estimates may be affected (Brown and Wilkins, 1978). However, the low response rate may indicate an insignificant amount of elk damage (Scott and Townsend, 1985) or that damage problems are restricted to a few areas within the private land zone of elk range in northcentral Arkansas.

Eight of 10 landowners interviewed and 7 of 10 respondents reported elk damage during summer. Home range size was smallest in summer (July to August) for female elk on private lands in Arkansas (Fig. 1, Herner-Thogmartin, 1999). Smaller home range size may indicate elk are concentrating their foraging in a smaller area, and therefore committing more damage than if they foraged over a larger area (deCalesta and Witmer, 1994). Also, because elk move in groups, trampling may contribute to the destruction of pastures and hay crops (deCalesta and Witmer, 1994). Telemetry data indicate elk spend the majority of their time in open fields (Herner-Thogmartin, 1999), where landowners reported the greatest concern for damage.

Interviews of landowners reporting problems with elk indicated that if elk were present, they were most likely causing a significant problem for the landowner. However, as in other studies, the relationship to actual loss is unclear and probably depends on the conspicuousness of damage (Conover, 1994). This is indicated by each landowner's difficulty in estimating his economic losses. Plants browsed by elk, deer, and cattle have a similar appearance, which may contribute to the difficulty in estimating damage due to elk (deCalesta and Witmer, 1994).

Cooney (1952) suggested special elk hunts are very effective in reducing damage on private land. Craven et al. (1992) reported that in 1985, 90% of wildlife agencies manipulated hunting seasons and bag limits to mitigate damage problems. In 1925, Utah's State Game Department attempted to relieve their nuisance elk problems by opening a hunting season, fencing haystacks, and paying damages. However, their efforts did not solve the problem and sentiments against elk grew increasingly negative (Olsen, 1943).

In 1998 and 1999 AGFC staff met with complaining landowners in order to receive their input regarding proposed hunting seasons. In fall of 1998, the AGFC held Arkansas' first limited permit elk season. Twenty permits were issued, and 7 cows and 10 bulls were harvested. One of the reasons for this hunt was to reduce perceived nuisance problems on private land. Unfortunately, access to private lands by hunters was limited in this first year. A limited permit hunt was held again in 1999 during which 9 bulls and 7 antlerless elk were harvested. The AGFC also issued 179 permits to be used within the private land zone. These permits were used by landowners or by persons with written permission from the landowner to hunt on private land. Twenty-two elk (7 bulls and 15 antlerless elk) were harvested on private lands. In 2000, harvest decreased to 12 elk from private lands. With continued cooperation between landowners and the AGFC, the state may be able to reduce landowner conflicts as well as keep a viable herd of elk in Arkansas for everyone to enjoy.

ACKNOWLEDGMENTS.—Our appreciation is extended to all landowners who answered this survey and participated in interviews. We thank the personnel of the Conservation District office for providing addresses of Conservation District Cooperators. This manuscript was improved with comments from Robert D. Brown, David S. Maehr, and Wayne E. Thogmartin. Funding for this research was provided by the Arkansas Cooperative Fish and Wildlife Research Unit, Arkansas Game and Fish Commission, University of Arkansas, Rocky Mountain Elk Foundation, and the U. S. National Park Service. This paper is a contribution from 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 cooperating.

Literature Cited

Brown, T. L. and **B. T. Wilkins.** 1978. Clues to reasons for nonresponse, and its effect upon variable estimates. J. Leis. Res. 10:226-231.

Cartwright, M. E. 1997. Return of the elk. Arkansas Wildl. 28:2-4.

Conover, M. R. 1994. Perceptions of grass-roots leaders of the agricultural community about wildlife damage on their farms and ranches. Wildl. Soc. Bull. 22:94-100.

Cooney, R.F. 1952. Elk problems in Montana. J. Range Manag. 5:3-7.

Craven, S. R., D. J. Decker, W. F. Siemer, and **S. E. Hygnstrom.** 1992. Survey use and landowner tolerance in wildlife damage management. Trans. North American Wildl. Nat. Res. Conf. 57:75-88.

deCalesta, D. S. and **G. W. Witmer. 1994**. Elk. Pp. 41-50 *In* S. E. Hygnstrom, R. M. Timm, and G. E. Larson, editors. Prevention and control of wildlife damage, U.S. Department of Agriculture, Washington D. C., USA.

Gabrey, S. W., P. A. Vohs, and **D. H. Jackson.** 1993. Perceived and real crop damage by wild turkeys in northeastern Iowa. Wildl. Soc. Bull. 21:39-45.

Herner-Thogmartin, J. H. 1999. Ecology of an introduced Rocky Mountain elk (*Cervus elaphus nelsoni*) herd in Arkansas. M.S. Thesis, Univ. Arkansas, Fayettevile, AR. 136 pp.

Olsen, O. A. 1943. Big game in multiple land use in Utah. J. Forest. 41:792-797.

Scott, J. D. and **T. W. Townsend. 1985.** Deer damage and damage control in Ohio's nurseries, orchards, and Christmas tree plantings: The growers view, *In* P. T. Bromely, ed, Proc. 2nd East. Wildl. Dam. Cont. Conf. Raleigh, NC.

Life History of the River Shiner, *Notropis blennius* (Cyprinidae), in the Arkansas River of Western Arkansas

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Abstract

The reproductive cycle, food habits, and age and growth of the river shiner, *Notropis blennius* (Girard), in the Arkansas River of western Arkansas were studied from May 1996 through October 1997. Based on gonadosomatic indices and mean ovum diameters of females, tubercle development in males, and the first appearance of young-of-year in samples, the breeding season extended from June through August in both 1996 and 1997. The river shiner is a diurnal, generalist feeder that forages on a wide variety of food items. In all four seasons, detritus dominated the diets of adults and juveniles in terms of volume and frequency of occurrence. Aquatic insects and algae were also important food items. It is a short-lived, *r*-strategist; it has a maximum life expectancy of about two years and has successfully maintained stable populations in the Arkansas River for more than 30 years after the construction of the Arkansas River Navigation System.

Introduction

Life history aspects of many North American minnows inhabiting large rivers are poorly known. The river shiner, *Notropis blennius*, was originally described from the Arkansas River near Fort Smith, Arkansas by Girard (1856). It is a schooling species occurring in large rivers throughout the Mississippi River basin and the Hudson Bay drainage of southcentral Canada (Etnier and Starnes, 1993). The river shiner is common today in the Arkansas and Mississippi rivers of Arkansas where it is usually found in the main channel in moderate current over a sand substrate (Robison and Buchanan, 1988). It avoids quiet backwaters and strong currents. Completion of the Arkansas River Navigation System in 1971 drastically altered the environment of the Arkansas River, but *N. blennius* continues to maintain a large population near its type locality. It is currently the second most abundant cyprinid species, after *N. atherinoides*, in the Arkansas River near Fort Smith more than three decades after the construction of the navigation system.

Practically all available information on the life history of *N. blennius* is from the northern portion of its range. Whitaker (1977) studied food habits in the White River of Indiana, and Becker (1983) provided data on food habits, reproduction, and age and growth in Wisconsin where it is found in river and lake environments. However, there is little ecological information for the river shiner in southern areas of its large range where it is restricted entirely to large rivers. Because it is common in the Arkansas River, the river shiner may play an important role as a forage species for predatory fishes. Knowledge of its life history will contribute to a better understanding of fish community dynamics and may be useful in making certain management decisions. Life history information can also contribute to a better understanding of the important ecological attributes that are responsible for the continued survival and abundance of *N. blennius* after the construction of the navigation system. Our objectives were to describe the reproductive cycle, food habits, and age structure of the river shiner near its type locality in the Arkansas River of western Arkansas.

Materials and Methods

Collections of *N. blennius* were made monthly from May 1996 through April 1997. Because no ripe females were found during this period, bimonthly collections were made from May 1997 through October 1997. These collections were made between the hours of 1200 and 1500 from the Arkansas River approximately 0.8 km downstream from Trimble Lock and Dam of the McClellan-Kerr Navigation System in Crawford County (Sec 31, R31W, T8N) with 9 x 1.5 m nylon seines of 3.2 mm mesh. All sampling was in dikefield habitats adjacent to the navigation channel in slow to moderate current over predominantly sand substrates. To estimate summer daily feeding periodicity, river shiners were also collected at 3-hr intervals over a 24-hr period on 29-30 June 1998. Specimens were preserved in 10% formalin and later transferred to 45% isopropyl alcohol. All specimens were weighed to the nearest 0.01 g and measured to the nearest 1.0 mm standard length (SL). The identity of other species of fishes collected at the study locality was recorded for each sample.

The reproductive cycle was studied primarily by determining periodic changes in the reproductive condition of adult female *N. blennius.* Measurements of ovum diameters and determination of ovary masses were made on specimens collected between May 1996 and October 1997. Ovaries were removed from the fifty largest females (or all

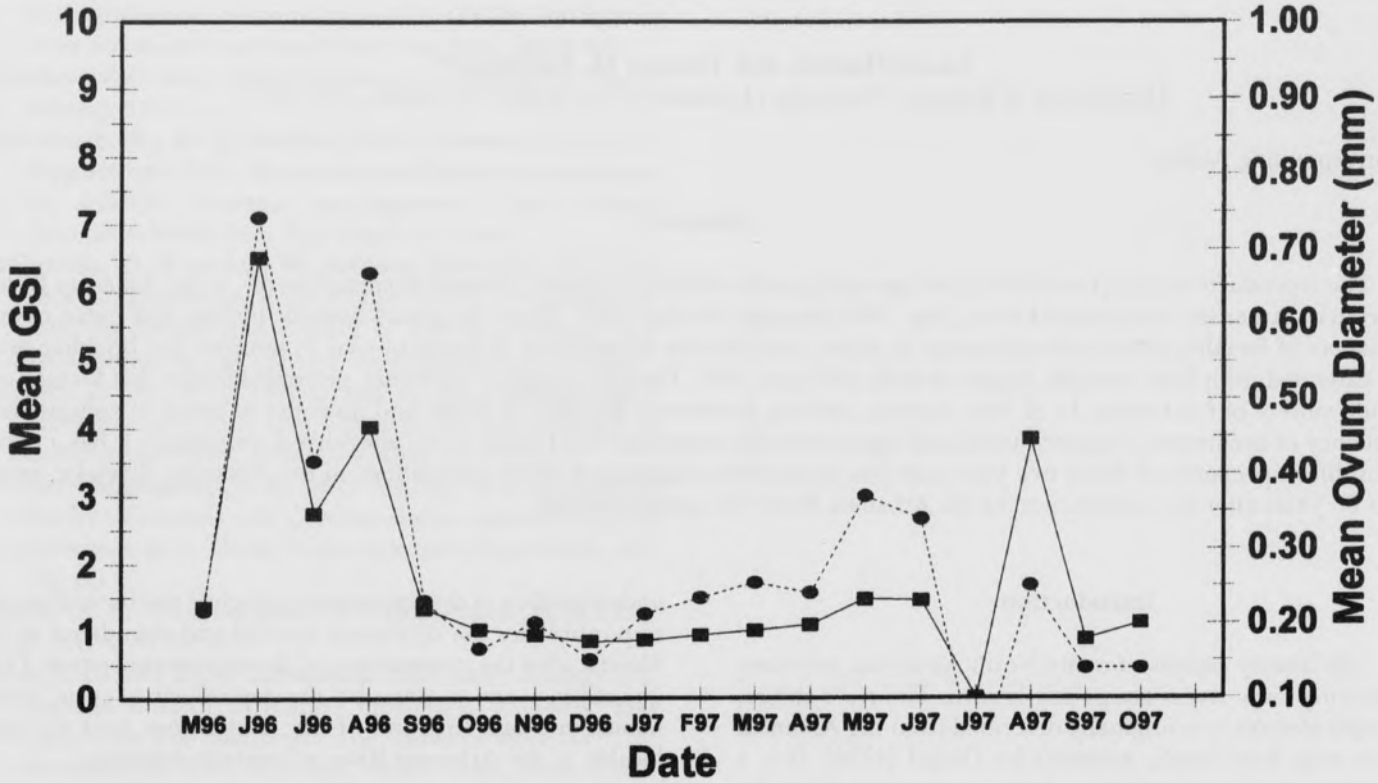

Fig. 1. Mean gonadosomatic index (GSI; rectangles) and mean diameter of larger ova (circles) for *Notropis blennius* from monthly Arkansas River samples in 1996 and 1997.

adult females if fewer than fifty) from each collection, blotted dry on paper towels, and weighed to the nearest 0.01 g. For each collection, female gonadosomatic index (GSI) was calculated, where GSI = ovary mass/ (total body mass - ovary mass) x 100. Mean GSI for each month's sample was calculated by averaging the GSIs of the individual fish. An ocular micrometer was used to measure the largest and smallest ova to the nearest 0.1 mm for each specimen examined. Ten ova from the largest size class of ova present from each individual were used to calculate mean ovum diameter. The mean ovum diameter for the entire sample was also calculated. Fecundity estimates were obtained by direct counts of all ripe ova in the ovaries of reproductively mature females. The reproductive condition of adult male river shiners was determined by the development of tubercles and by gross examination of the testes. Sexually mature males were tuberculate during the breeding season and had enlarged, white testes.

Because *N. blennius* has no distinct stomach, food habits were determined from 474 specimens by examining the contents of the anterior one-third of the s-shaped digestive tract of 50 specimens from each collection made from May 1996 through April 1997. All individuals were examined from samples having fewer than 50 specimens. Gut contents of each fish were removed and identified to the lowest practical taxa using a dissecting or compound microscope, and percent volume of each food item was visually estimated. Counts of individual food items were not possible because *Notropis* species macerate their food (Surat et al., 1982).

Food habit and reproductive data were grouped according to the following seasons: spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February). Morisita's measure of overlap as modified by Horn (1966) was used to determine the degree of diet overlap between males and females, between adults and juveniles, and among seasons for adults. Specimens under 35 mm SL were considered juveniles. In Morisita's index, the overlap coefficient, C, ranges from 0, when samples are completely distinct, to 1, when samples are identical with respect to proportional food categories.

Because there were no discernible annuli on the scales of *N. blennius*, age categories were estimated from length-frequency analyses. Length-frequency histograms were prepared by plotting the numerical frequency for each 1 m size group.

Results

A total of 1,223 individuals of *N. blennius* was collected uring the study. Based on appearance of gonads and, in ıales, occurrence of nuptial tubercles, the smallest sexually ıature individuals of both sexes were approximately 35 ım SL. Gonadosomatic indices and mean ovum diameters ıf female *N. blennius* indicated a reproductive season xtending from June through August in both years of the tudy (Fig. 1). In 1996 mean GSI values peaked in June with a second smaller peak in August; in 1997 a single GSI peak occurred in August. By September of both years, GSI values and mean ovum diameters dropped drastically. Ovaries and ova remained small from September 1996 until May 1997, with ovarian masses averaging 0.8 - 1.0% of the somatic mass during that time. Accelerated ovarian development began by mid-May 1997. Although no females were found with ripe eggs in 1996 or 1997, the change in mean diameters of the largest developing ova present paralleled that of the seasonal GSI values for both years. Five female *N. blennius* taken on 3 August 1998 possessed ripe ova. Those females, which ranged from 50 to 69 mm SL, contained from 97 to 667 ripe eggs. Nuptial tubercles were developed in male river shiners from May to October in 1996 and 1997. The tubercles occurred only along the rays of the pectoral fins. This tubercle pattern closely resembled that reported for Tennessee and Missouri specimens (Etnier and Starnes, 1993; Pflieger, 1997), but differed substantially from the pattern reported by Scott and Crossman (1973) for northern populations of river shiners.

Examination of intestinal contents showed that *N. blennius* in the Arkansas River consumes a wide variety of food items (Tables 1 and 2). In all four seasons, detritus dominated the diets of adults and juveniles in terms of volume and frequency of occurrence. Aquatic insects and algae were also important food items. Some food items, e.g. terrestrial insects, were ingested when seasonally available. Only two individuals had fish remains in the gut. This occurred in a June sample when larvae of several fish species were abundant in the river.

As indicated by Morisita's Index (MI), there were no sexual differences in diet in any season in terms of volume

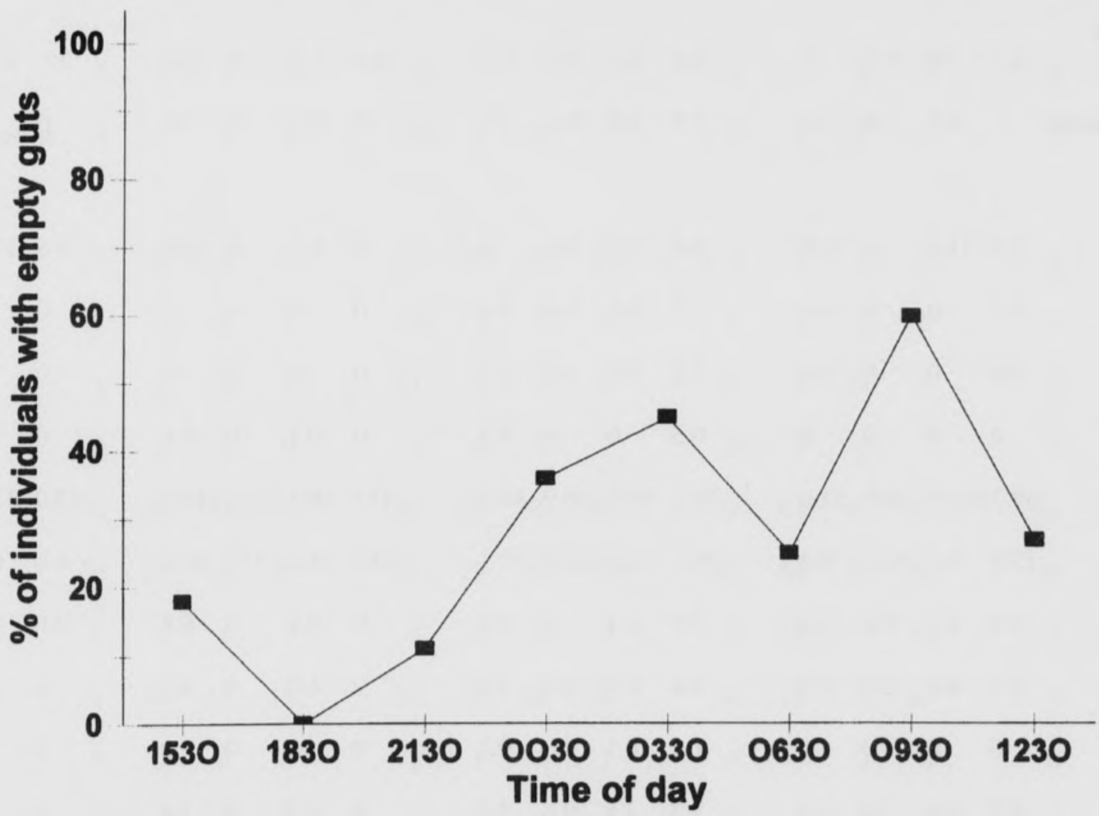

Fig. 2. Feeding periodicity of *Notropis blennius* in the Arkansas River expressed as percent empty guts during the 24-hour sample on 29-30 June 1998. Peaks represent times of least feeding activity, valleys represent times of greatest feeding activity.

of food items ingested. Juveniles and adults differed in this feature only in fall samples, when juveniles fed mainly on larval Trichoptera. In terms of percent frequency of occurrence of food items, juveniles and adults were very different in all seasons as indicated by the low MI values. Adults fed on a wider variety of food categories than juveniles in all seasons except winter. The juveniles also ingested smaller food items than the adults. No distinct sexual differences were found in variety of food items ingested. Diets of males and females also differed in percent frequency of occurrence in all four seasons. Seasonal feeding intensity was indicated by the percentage of empty

Table 1. Gut contents expressed as mean percent volume by season for male (M), female (F), juvenile (J), and adult (A) *Notropis blennius* from the Arkansas River, 1996-97. For each season, the first Morisita's Index (MI) value compares the amount of diet overlap between males and females, and the second MI value compares diet overlap between adults and juveniles.

	Spring				Summer				Autumn				Winter			
Item	**M**	**F**	**J**	**A**	**M**	**F**	**J**	**A**	**M**	**F**	**J**	**A**	**M**	**F**	**J**	**A**
Coleoptera	1.7	1.8	0	2.1	0	0.5	0	0.4	4.3	1.2	75	2.5	9.1	1.9	3.9	6.6
Diptera	6.9	4.6	0	7.1	2.4	2.4	8.	91.4	3.3	1.7	0	2.5	1.4	3.2	0	4.4
Ephemeroptera	0	0.9	0	0.5	3	2.2	0.8	2.7	6.5	5.7	0	4.1	0	0.5	0.6	0
Trichoptera	1.1	1.3	0	1.5	0.5	0	0	0.2	0	0.9	0	0.6	5.7	5.6	0	10.5
Other aquatic insects	4.2	7.9	0.7	7.	0.2	0.3	0.6	0.3	2.3	2	0	2.2	30.	27.7	28.7	29.2
Terrestrial insects	1.	0.8	0	1.2	2.8	2.6	10.6	1.4	0	0.1	0	0.1	0	0	0	0
Crustaceans (Cladocera, Copepoda)	1.8	11.4	4	6.9	3.8	7.5	8.6	6	0	0.5	0	0.3	9.5	11.6	14.4	7.3
Protozoa	0.1	0	0	0.1	1.1	0.2	0.8	0.4	0	0	0	0	0	0	0	0
Oligochaeta	0.6	0	0	0.4	5.2	0.9	2.8	2.1	0	0	5	0	0	0	0	0
Rotifers	0	0	0	0	0.5	0	0	0.2	0	0.1	0	0.1	0	0	0	0
Detritus	59.7	50.07	58.6	54.6	52.1	42.6	38.9	46.5	47.5	48.7	2.5	49.4	33.9	33.2	37.6	30.2
Algae	15.8	9.5	32.1	8.4	20.7	33.5	24.2	30.4	29.8	23.3	17.5	26.6	6.6	6.6	8	5.3
Seeds	3.3	2.1	0.5	3.2	0.5	3.4	0	2.9	4.	9.2	0	6.8	3.6	5.6	6.1	3.4
Vegetation	3.3	8.4	2.1	6.5	4.8	2.9	3.1	3.5	2	4.3	0	3.5	0	3.9	0.7	3.1
Fish	0	0	0	0	0.1	0.1	0.3	0.1	0	0	0	0	0	0	0	0
Eggs	0.7	0.4	1.9	0.3	2.2	1.1	0.6	1.6	0	2.3	0	1.4	0	0	0	0
Morisita's Index	0.904		0.913		0.952		0.953		0.986		0.334		0.980		0.943	

its, which was greatest in winter and lowest in summer and il (Table 2). Most guts that contained food in winter ıonths had a low percent fullness. The diversity of food ems showed a similar pattern, with fewer types of food consumed in winter and the greatest variety consumed in summer.

Feeding activity during the 24-hr summer sampling period of 29-30 June 1998 was determined by the

able 2. Percent frequency of occurrence by season of various food items in male (M), female (F), juvenile (J), and adult (A) *Votropis blennius* from the Arkansas River, 1996-97. For each season, the first Morisita's Index (MI) value compares the amount f diet overlap between males and females, and the second MI value compares diet overlap between adults and juveniles.

	Spring				Summer				Autumn				Winter			
Item	M	F	J	A	M	F	J	A	M	F	J	A	M	F	J	A
Gut empty	17	28	19	23	9	12	10	12	23	9	0	16	39	26	31	35
Coleoptera	3	1	0	2	0	2	0	2	5	4	100	5	9	2	5	6
Diptera	10	4	0	8	16	15	55	9	7	9	0	8	2	2	0	4
Ephemeroptera	0	1	0	1	7	6	10	5	13	11	0	10	0	2	3	0
Trichoptera	1	1	0	2	4	0	0	2	0	2	0	1	4	5	0	8
Other aquatic insects	8	13	4	12	2	1	5	1	5	6	0	6	28	31	31	29
Terrestrial insects	4	3	0	4	16	7	25	7	0	2	0	1	0	0	0	0
Crustaceans (Cladocera, Copepoda)	7	10	8	9	24	20	35	19	0	4	0	2	9	14	15	8
Protozoa	1	0	0	1	13	3	15	5	0	0	0	0	0	0	0	0
Oligochaeta	1	0	0	1	11	2	5	5	0	0	50	0	0	0	0	0
Rotifers	0	0	0	0	4	0	0	2	0	2	0	1	0	0	0	0
Detritus	75	56	81	62	89	86	90	86	72	83	50	79	52	60	59	53
Algae	50	28	46	37	76	79	70	79	67	64	50	66	26	26	33	20
Seeds	6	8	4	7	7	8	0	9	8	23	0	16	7	5	8	4
Vegetation	14	18	15	16	22	13	30	14	10	19	0	16	0	5	3	2
Fish	0	0	0	0	2	1	5	1	0	0	0	0	0	0	0	0
Eggs	3	1	8	1	2	3	10	2	0	4	0	2	0	0	0	0
Morisita's Index	0.926		0.957		0.985		0.901		0.968		0.531		0.973		0.969	

percentage of empty guts (Fig. 2). The greatest feeding activity occurred shortly before dark (1830 to 2130 hours), and two other periods of feeding activity occurred near dawn (0630 hr) and at 1230 hr. Some feeding occurred throughout the 24-hr period, with empty guts most common at 0930 (60%), 0330 (45%), and 0030 (36%) hours. Sixty-eight percent of the individuals having empty guts in the 24-hr samples were females.

Young-of-year (YOY) were collected during the breeding season for the first time in late July in 1996 and in late June in 1997 (Fig. 3). Some Individuals less than 35 mm SL (sub adults) were collected in spring 1997, i.e. age group I. Therefore, three age groups (0, I, and II) were present in samples only during summer months when YOY (age group 0) first appeared. The YOY age group represented the largest proportion of individuals in the population by late summer. Length-frequency histograms (Fig. 3) indicate that *N. blennius* in the Arkansas River reaches a maximum age of about two years. There was no discernible bias in the sex ratio of adult females to males (1.0 : 1.2). Females attained greater standard lengths than males, and in most samples the largest individuals were females. The largest specimen captured was a 69 mm SL female, whereas the largest male was 58 mm SL.

A total of 33 fish species was taken from the Arkansas River sampling locality in 1996 and 1997. *Menidia beryllina* was the most abundant species collected. Other species taken in relatively large numbers included *Dorosoma cepedianum, D. petenense, Notropis atherinoides, Cyprinella lutrensis,* and *Pimephales vigilax.* Infrequently collected cyprinids included *Campostoma anomalum, Carassius auratus, Cyprinella venusta, Cyprinus carpio, Luxilus cardinalis, Macrhybopsis storeriana, Notemigonus crysoleucas, Notropis boops,* and *N. buchanani.*

Discussion

Notropis blennius has a moderately long spawning season extending from June through August. Protracted reproductive seasons have been reported for a number of cyprinids in the southern United States, and Matthews and Heins (1984) concluded that protracted spawning may be adaptive to a variable environment. By distributing reproductive activity over a long period of time, the chance of losing a large portion of the annual recruitment is reduced. The bimodal peaks in GSI values and mean ovum diameters in June and August 1996 (Fig. 1), along with the bimodal YOY length-frequency distribution in September 1996 (Fig. 3), indicate the likelihood of multiple spawnings. The presence of small individuals in the January and February 1997 samples (Fig. 3) further supports an extended spawning period for *N. blennius.* The young fish collected in January and February probably hatched in late August or early September but grew very little during the fall and winter months. The timing of spawning peaks, which varied in 1996 and 1997, during the breeding season may be related to environmental factors such as food availability, temperature, and discharge, which can be highly variable below Trimble Lock and Dam. Water temperatures during this study varied between 7°C in December 1996 and 31°C in August 1997. Temperatures during the peak spawning periods in 1996 and 1997 ranged from 26 to 31°C. Discharges at the time of sampling varied from 142 to 481 m^3/sec throughout the breeding season in 1996 and from 708 to 1,558 m^3/sec during the 1997 reproductive season.

Although data on the average GSIs and ovum diameters indicated an extended spawning period, it could not be determined from those data whether a single individual spawned more than once. Because ovaries of females taken during the breeding season contained two or more different complements of ova, it is likely that some individuals spawned more than once. The presence of several sizes of ova in a mature ovary was considered by Mathur and Ramsey (1974) to indicate multiple spawning in *Notropis baileyi.* Nothing is known of the spawning behavior of *N. blennius.*

Our samples in the 1996 and 1997 spawning seasons contained no females with ripe eggs. Heins and Baker (1988) reported that ripe eggs are present only for a few hours or less within a cycle of 4-5 days in a variety of minnow species, and random field samples are not likely to contain many, if any, females with ripe eggs. The five females with ripe eggs taken on 3 August 1998 exhibited low fecundities (97-667 ripe ova) compared to those reported by Becker (1983) in a Wisconsin population of *N. blennius* (2630-3039 ripe ova). Becker's specimens were much larger than our Arkansas River specimens, and our specimens, taken relatively late in the spawning season, may have been partially spent.

Whitaker (1977) reported that *N. blennius* in the White River of Indiana fed primarily on aquatic insects (mainly chironomids) in summer, ooze (detritus) in autumn, and seeds in winter and early spring. Becker (1983) described the river shiner as primarily an insect feeder in Wisconsin. The river shiner in the Arkansas River is a generalist feeder that apparently forages on items suspended throughout the water column as well as items lying on the substrate. It does not conform to a specific trophic level but is apparently an opportunist feeding on whatever may be most available in its environment. No data were obtained on the abundance of potential food items in the environment of *N. blennius* at the time of fish sampling. *Notropis blennius* is primarily a diurnal feeder, but up to 64% of the individuals in one of the nocturnal samples ingested food. Differences in percent frequency of occurrence in food items ingested between adults and juveniles were due mainly to the juveniles'

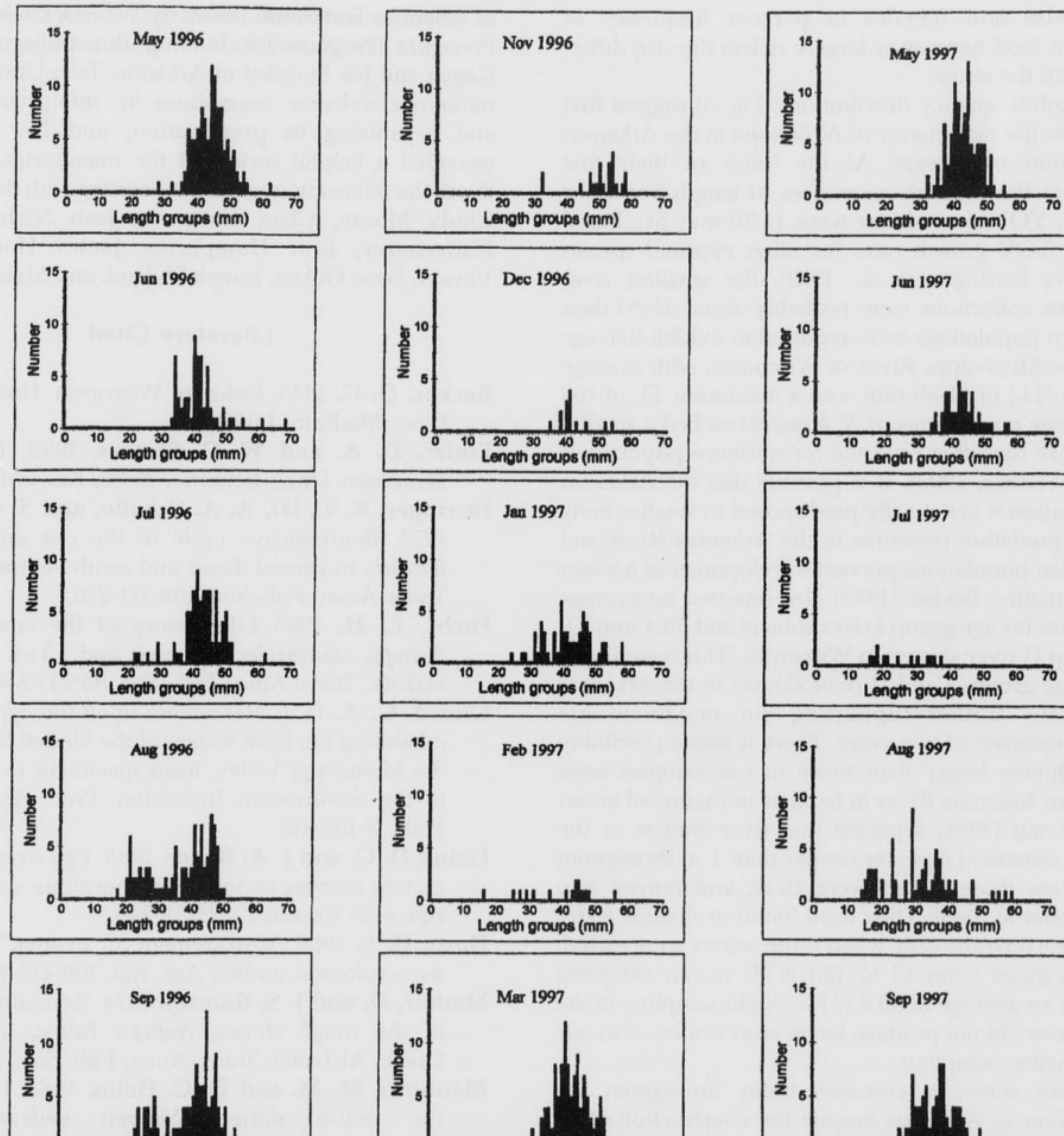

Fig. 3. Length-frequency distributions by month for *Notropis blennius* from the Arkansas River, 1996-97.

preference for smaller food items. Similarly, the differences between males and females in percent frequency of occurrence of food items may largely reflect the size differences between the sexes.

The length-frequency distributions (Fig. 3) suggest that the maximum life expectancy of *N. blennius* in the Arkansas River is about two years. At the times of their first appearance in the monthly sequences of length-frequency distributions, YOY river shiner were 14-20 mm SL. Based on reported YOY growth rates for other cyprinid species (Fuchs, 1967; Farringer et al., 1979), the smallest river shiners in our collections were probably about 15-30 days old. Northern populations were reported to exhibit five age classes in the Mississippi River of Wisconsin, with average total lengths (TL) of 61-89 mm, and a maximum TL of 108 mm. Tennessee populations of *N. blennius* reached a smaller maximum size than that reported for northern populations (Etnier and Starnes, 1993). It is possible that the Arkansas River population is genetically predisposed to smaller body size or that predation pressures in the Arkansas River and other southern populations prevent development of a wider age class structure. Becker (1983) also reported an average TL of 37.1 mm for age group I river shiners and 58.4 mm TL for age group II river shiners in Wisconsin. This is similar to lengths of age groups I and II river shiners in the Arkansas River, thereby further supporting our maximum life expectancy estimate of two years. There is also a possibility that river shiners larger than those in our samples were present in the Arkansas River in habitats not sampled in our study. Trautman (1981) reported that river shiners in the Ohio River remained in water deeper than 1 m throughout the day, when those waters were clear, and moved into shallower water at night. They were found in shallow water in Ohio in the daytime only when those waters were turbid. Turbidities ranged from 15 to 123 NTU at our sampling locality with an average of 39.2 NTU. Night sampling in the Arkansas River did not produce larger river shiners than our monthly daytime sampling.

The river shiner is common today throughout the Arkansas River in Arkansas despite the construction of 13 locks and dams on that segment of the river during the 1960s through 1971. Pflieger (1997) reported that *N. blennius* increased in absolute abundance in the environmentally altered Missouri River in Missouri during the last 50 years, comprising 0.1 percent of the small fishes collected in the 1940s and 7.7 percent of those collected in the 1980s. Based on our data, the river shiner is a short-lived, *r*-stratigist. A protracted spawning period, during which a female may spawn more than once, and generalist food habits are probably important life history attributes contributing to its continued success in the altered environment of the Arkansas River more than 30 years after the construction of the Arkansas River Navigation System.

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Literature Cited

Becker, G. C. 1983. Fishes of Wisconsin. Univ. Wisconsin Press, Madison, 1,052 pp.

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

Farringer, R. T., III, A. A. Echelle, and S. F. Lehtinen. 1979. Reproductive cycle of the red shiner, *Notropis lutrensis*, in central Texas and south central Oklahoma. Trans. Amer. Fish. Soc. 108:271-276.

Fuchs, E. H. 1967. Life history of the emerald shiner, *Notropis atherinoides*, in Lewis and Clark Lake, South Dakota. Trans. Amer. Fish. Soc. 96:247-256.

Girard, C. A. 1856. Researches upon the cyprinoid fishes inhabiting the fresh waters of the United States, west of the Mississippi Valley, from specimens in the museum of the Smithsonian Institution. Proc. Acad. Nat. Sci. Phila. 8:165-213.

Heins, D. C. and J. A. Baker. 1988. Egg sizes in fishes: do mature oocytes accurately demonstrate size statistics of ripe ova? Copeia 1988:238-240.

Horn, H. S. 1966. Measurement of "overlap" in comparative ecological studies. Am. Nat. 100:419-424.

Mathur, D. and J. S. Ramsey. 1974. Reproductive biology of the rough shiner, *Notropis baileyi*, in Halawakee Creek, Alabama. Trans. Amer. Fish. Soc. 103:88-93.

Matthews, M. M. and D. C. Heins. 1984. Life history of the redfin shiner, *Notropis umbratilis* (Pisces: Cyprinidae), in Mississippi. Copeia 1984:385-390.

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

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

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can. Bull. 184:1-966.

Surat, E. M., W. J. Matthews, and J. R. Bek. 1982. Comparative ecology of *Notropis albeolus*, *N. ardens* and *N. cerasinus* (Cyprinidae) in the upper Roanoke River drainage, Virginia. Amer. Midl. Nat. 107:13-24.

Trautman, M. B. 1981. The fishes of Ohio. 2nd Ed., Ohio St. Univ. Press, Columbus, 782 pp.

hitaker, J. O., Jr. 1977. Seasonal changes in food habits of some cyprinid fishes from the White River at Petersburg, Indiana. Amer. Midl. Nat. 97:411-418.

Breeding Season Distribution of Cerulean Warblers in Arkansas in the 1990s

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Abstract

The Cerulean Warbler (*Dendroica cerulea*) has been declining in numbers in its North American nesting range, and the same is true in Arkansas. To provide specific sites that can be monitored in the future, this study describes places where the bird was documented in the state in the 1990s. The warbler was found in mature deciduous forest in both upland and bottomland situations but was most abundant in the upland Ozark forests and uncommon in other regions of the state. Most (70%) of the occupied sites were on federal and state lands. Pattern of overall distribution was essentially the same in the 1990s as it was in an earlier period through 1973. Data in one case suggest that group selection type of forest harvest may produce habitats that are beneficial to Cerulean Warblers.

Introduction

Overall trends from the Breeding Bird Survey (Sauer et al., 1997) show Cerulean Warblers (*Dendroica cerulea*) declined at a rate of 3.7% per year from 1966 to 1996 in the nesting range comprising eastern North America (AOU, 1998). In Arkansas, where the species occurs in relatively low abundance, the decrease is estimated at less than 1.5% per year (Sauer et al., 1997). This situation led to investigation of the status of the species by establishing the Cerulean Warbler Atlas Project coordinated in the Partners In Flight program at the Laboratory of Ornithology, Cornell University (Rosenberg et al., 1998). Volunteers searched for the warbler and submitted reports that were compiled at Cornell for the years 1997 to 1999.

The present paper lists records obtained by observers in Arkansas from 1990 to 1999. This longer period provides a better view of the bird's current distribution and abundance in the state than just a year or two of searching. The main objectives of the study are 1) to determine the present status of Cerulean Warblers in Arkansas, and 2) to carefully document their present locations so that these sites may be monitored in the future to determine population trends.

Methods

Records of breeding season (late May through July) Cerulean Warblers for the 1990s in Arkansas were sought from a variety of sources. Key observers of birds in the state were consulted, the Bird Record Files of the Arkansas Audubon Society (curated by Max Parker of Malvern, Arkansas) were searched, personnel at the National Forests in Arkansas and Arkansas Natural Heritage Commission were consulted, and results from the ongoing Arkansas Breeding Bird Atlas were screened, as were the Breeding Bird Survey findings in the 1990s (USGS 1999). In addition, Jennifer Akin was hired from end of May through most of June 1998 to search previously known Cerulean Warbler sites and many potential new sites in the lowlands of southern and eastern Arkansas.

Only one person noted a singing male was present, and only two recorded the presence of male and female and young. For all the other records there was no indication of sex and age of the birds or whether singing or not. It is presumed, however, that the reports were mainly of singing males heard, followed by searching and sighting of the vocalizing individuals, because hearing the song is essentially the only way to find this small bird that dwells hidden in lofty forest canopies. In the many reports of several birds at a site there was no indication of the sexes of the birds and again it is presumed that most were vocalizing males. If this had been a systematic survey, which it was not, forms detailing information to report would have been distributed in advance. Instead, the study relied on past records submitted in diverse formats. Nevertheless, these records do document well the important data and main focus of this paper, which is to determine locations where Cerulean Warblers now occur for use in future surveys on the status of the bird. Other matters, including date of observation in the breeding season, number of birds found, and sex and age ratios, are ɔt of central importance.

In every case, the number of birds present was record- l and an attempt was made to precisely document the sites cording to section, township, and range designations plus titude and longitude of each location. Elevation and type habitat were noted, in addition to date and observer. Most ɔservations included all of the above. However, informa- ɔn was incomplete for some sightings. A few records, par- ularly those early in the decade, could only be located ith respect to the nearest town. The warbler site data ıown below bearing Kellner's name prior to 1998 for the Ozark National Forest contain discrepancies between lati- ıde and longitude designations and corresponding section, ownship and range positions. This resulted from difficulties n transposing between the two systems using points marked on topographic maps. This discrepancy was eliminated 1998 and 1999, when Kellner determined lat-long coordinates directly in the field using a Global Positioning System (GPS) instrument. (Although section designations were the location data provided for most sites, latitude and longitude were added obtained from mapped positions because that is the site information used at Cornell University to construct the Cerulean Warbler Atlas.)

Results

The numbers of Cerulean Warblers found in Arkansas from 1990 through 1999 and their locations are listed below by physiographic region in Arkansas and alphabetically by county within the physiographic regions. The format for each listing is as follows: 1) the county, 2) section, township and range, 3) latitude and longitude, 4) elevation of the site, 5) the number of birds found at the site, 6) date(s), 7) habitat, 8) observers(s) (some of these items were not available for some sites because various observers had their own formats for reporting sightings). When the site was on public lands, a designation was appended to those site listings showing what agency was involved. These are BNR=Buffalo National River, DDP=Devil's Den State Park, HCWA=Howard County Wildlife Management Area, OUNF=Ouachita National Forest, OZNF=Ozark National Forest, and WRWR=White River National Wildlife Refuge. (Scientific names for vernacular names of trees named in habitat descriptions are given in the Appendix using the terminology of Smith, 1988 and Hunter, 1989.)

As already explained, most records were of presumably singing male birds, but a few times females and non-singing males, and even young birds, were reported too and not separately enumerated. When a specific number of birds at a site is associated with several dates at that site it means that number of Cerulean Warblers was found there on each of the dates. When there is a range of numbers given it means the observer(s) could not tell exactly how many. If the range was associated with two or more dates it means different numbers of birds were found there on the different dates, specifics often not provided. In totaling bird numbers (Table 1) the upper value in a range of numbers was used. When the number of birds was not reported the phrase "at least 1 bird" is used and one bird is added to the total in each case. If only the year is given, the exact date is not known but the observation was indeed made in the period from late May through July. The exact positions of warbler sites in the two National Forests are available on maps kept in the respective forest offices, but map positions were not submitted with most other records. Elevations are given first in feet, followed by conversions to meters, because both the contour maps used and GPS data submitted were in feet.

The most important information is locations of warbler sightings, and this therefore is listed first beginning with the county, because it provides instructions on how to find the sites in the future when determining changes in status through the years. Because the records submitted were mainly opportunistic discoveries of Cerulean Warblers from a variety of observers and not based on systematic surveys, obviously many sites were missed. The statewide coverage was uneven with a concerted effort being made only in the Ozark National Forest. Nevertheless, records came from every region of the state.

In most cases only one bird was present at a site, in others more than one. Sometimes the observer was not sure of the number, and sometimes the number varied with visits to the site. Primarily, however, there was only one visit reported for each site. In any case, the number of birds found is not as valid as the actual site locations because certainly at all sites there could have been birds that were missed. Therefore, the numbers of Cerulean Warblers found is only an estimate of the minimum numbers present.

Except for the exact warbler locations marked on the maps mentioned above available in the offices of the two National Forests, the other locations are identified as shown below no closer than township section, or nearest minute of latitude and longitude. This means that some searching will be necessary in relocating these sites in the future. Fortunately most sightings were along roads, and not many roads exist in a single township section, and along roads in general there are few forest patches suitable for Cerulean Warblers. These two criteria can be used in future searches for the sites reported below.

The dates of the sightings are given but special importance should not be attributed to specific dates. Since all dates are within the breeding season for Cerulean Warblers in Arkansas (late May through July) it is assumed that the birds at any site would have been found on any date in that period. Therefore, the dates simply indicate when the observer happened to be at a particular site. For some sites listed below only the year of the observation is given because the specific date in the breeding season was not reported.

Forest type was reported only in very general terms often indicating little more than degree of maturity, or whether upland or bottomland topography, or mentioning basic types of trees. This was the information most commonly omitted in incomplete reporting.

Ozark Plateaus Region

1) Benton, S13 T20N R28W, 36°24'N 93°54'W, 1500 ft (457 m), 1 bird, late June 1996, 9 May 1998, upland oak-hickory forest, Ellen Neaville.

2) Benton, S7 T17N R32W, 36°10'N 94°26'W, 965 ft (294 m), 3 birds, 18 June 1998, mature silver maple and box elder bottomland forest with protruding introduced tulip tree grove, Steve Duzan, Doug James, Abby Powell, OZNF.

3) Carroll, S6 T17N R22W, 39°09'N 93°21'W, 2000 ft (610 m), 1-3 birds, 17 & 13 May and 4 June 1994, 23 & 25 May 1997, upland oak-hickory forest, Mike Mlodinow.

4) Carroll, S4 T18N R22W, 36°15'N 93°19'W, 1200 ft (366 m), 1 bird, 8 June 1995, 13 & 16 May 1996, 15 June 1997, upland oak forest, Mike Mlodinow.

5) Crawford, S13 T12N R30W, 35°42'N 94°08'W, 1500 ft (457 m), 2 birds, 12 June 1998, mature upland oak-hickory forest, R. Kannan, Doug James, David Chapman.

6) Crawford, S26 T12N R33W, 35°42'N 44°28'W, 1000 ft (305 m), 3 birds, 22 May 1999, Steve Duzan, Ralph Oldegard, OZNF.

7) Crawford, S13 T12N R33W, 35°43N 94°27'W, 1500 ft (457 m), 3 birds, 24 May 1999, upland oak-hickory forest, John Prather, Jeff Briggler, OZNF.

8) Crawford, S24 T12N R33W, 35°42'N 94°28'W, 1250 ft (381 m), 1 bird, 4 June 1999, upland oak-hickory forest, Jeff Briggler, OZNF.

9) Franklin, 35°41'N, 93°49'W, 2 birds, June 1994, Boston Mountain route of Breeding Bird Survey, John Andre, OZNF.

10) Franklin, S36 T13N R27W, 35°44'N 93°48'W, 2250 ft (686 m), 7 birds, 3 July 1994, 23 May 1998, mature upland northern red oak-hickory forest, Paul Rodewald, Doug James, Jennifer Akin, OZNF.

11) Franklin, S25 T12N R28W, 35°41'N 93°56'W, 1500 ft (457 m), 1 bird (singing male), July 1998, upland oak-hickory forest, John Prather, OZNF.

12) Johnson, S20 T11N R21W, 35°35'N 93°14'W, 1530 ft (466 m), 1 bird, 2 June 1999, mature upland northern red and white oak forest, Chris Kellner, OZNF.

13) Madison, north of Marble, 1 bird, summer 1998, upland shortleaf pine-oak forest, Donna O'Daniel.

14) Madison, S12 T15N R28W, 35°53'N 93°55'W, 1500 ft (457 m), 1 bird, early June 1995, upland oak-hickory forest, Mike Mlodinow.

15) Pope, S26 T12N R21W, 35°40'N 93°13'W, 1400 ft (427 m), 1 bird, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

16) Pope, S20 T12N R20W, 35°40'N 93°09'W, 1000 ft (303 m), 5 birds, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

17) Pope, S32 T12N R20W, 35°39'N 93°08'W, 1000 ft (305 m), 1 bird, 27 May 1998, upland mature northern red oak forest, Chris Kellner, Jan Self, OZNF.

18) Pope, S6 T11N R19W, 35°38'N 93°03'W, 1400 ft (427 m), 4 birds, May 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

19) Pope, S29 T12N R19W, 35°39'N 93°02'W, 1600 ft (489 m), 3 birds, 20 May 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

20) Pope, S30 T12N R19W, 35°39'N 93°03'W, 1400 ft (427 m), 3 birds, 20 May 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

21) Pope, S10 T12N R20W, 35°43'N 93°06'W, 1640 ft (500 m), 2 birds, 21 May 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

22) Pope, approx 35°39'N 93°03'W, 1750 ft (533 m), 2 birds with young, 6 June 1994, upland forest, Paul Rodewald, OZNF.

23) Pope, S19 T11N R19W, 35°35'N 93°03'W, 1500 ft (457 m), 5 birds, 5 June 1994, Paul Rodewald, OZNF.

24) Pope, S12 T12N R20W, 35°42'N 93°04'W, 1800 ft (549 m), 20 birds, June & July 1993, 16 May 1994, 6 May 1996, 28-30 May 1997, May 1998, mature upland northern red oak forest, Paul Rodewald, John Andre, Chris Kellner, OZNF.

25) Pope, S11 T12N R20W, 35°43'N 93°05'W, 1900 ft (579 m), 8 birds, May 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

26) Pope, S2 T12N R20W, 35°43'N 93°05'W, 2000 ft (610 m), 2 birds, June 1997, May & June 1998, Chris Kellner, Jan Self, John Prather, OZNF.

27) Pope, S8 T12N R18W, 35°42'N 93°55'W, 2000 ft (610 m), 3 birds, 2 June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

28) Pope, S18 T11N R14W, 35°36'N 93°03'W, 1400 ft (427 m), 1 bird, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

29) Pope, S5 T11N R14W, 35°38'N 93°02'W, 1600 ft (488 m), 2 birds, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

30) Pope, S9 T11N R9W, 35°37'N 93°02'W, 1400 ft (427 m), 6 birds, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

31) Pope, S8 T11N R19W, 35°37'N 93°02'W, 1600 ft (488 m), 5 birds, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

32) Pope, S7 T11N R19W, 35°37'N 93°03'W, 1700 ft (518 m), 3 birds, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

33) Pope, S19 T11N R19W, 35°35'N 93°03'W, 1500 ft

57 m), 1 bird, June 1998, 27 May 1999, upland forest, John ather, OZNF.

34) Pope, S9 T12N R20W, 35°42'N 93°06'W, 1890 ft 76 m), 7-8 birds, 22 June 1999, mature upland northern d and white oak forest, Chris Kellner, OZNF.

35) Pope, S15 T12N R20W, 35°41'N 93°05'W, 1740 ft 30 m), 5-6 birds, 24 June 1999, mature upland northern d and white oak forest, Chris Kellner, OZNF.

36) Pope, S8 T12N R18W, 35°41'N 92°55W, 1940 ft 91 m), 1 bird, 29 July 1999, mature upland northern red nd white oak forest, Chris Kellner, OZNF.

37) Newton, 35°49'N 93°04'W, 1-2 birds, June 1993, 994, 1996, 1997, Lurton route Breeding Bird Survey, Lance Peacock, OZNF.

38) Newton, 36°06'N 93°17'W, 1-2 birds, June 1990, 1993, 1994, 1995, Compton route Breeding Bird Survey, Joe Neal, BNR.

39) Newton, S2 T14N R21W, 35°53'N 93°11'W, 2000 ft (610 m), 1-7 birds, end of May 1998, Jan Self, OZNF.

40) Newton, S36 T14N R20W, 35°49'N 92°58'W, 2000 ft (610 m), 2 birds, end of May 1998, Jan Self, OZNF.

41) Newton, S35 T17N R23W, 36°06'N 93°22'W, 2000 (610 m) ft, 1-5 birds, 11 May to 16 June 1994 (4 dates), 22 May to 16 June 1995 (5 dates), 20 May to 9 June 1996 (3 dates), 14 May to 6 June 1997 (4 dates), upland oak-hickory forest, Mike Mlodinow.

42) Newton, S18 T16N R22W, 36°02'N 93°21'W, 1800 ft (549 m), 1 bird, 29 May and 7 June 1995, 22 May 1996, upland oak-hickory forest, Mike Mlodinow.

43) Newton, S19 T14N R22W, 35°51'N 93°22'W, 2000 ft (610 m), 1 bird, 10, 13, 14 June 1998, upland oak forest, edge of group selection cut, Mike Mlodinow, OZNF.

44) Newton, S15 T15N R23W, 35°30'N 93°24'W, 1200 ft (366 m), 1 bird, 1993, upland forest, Chris Kellner, Jan Self, OZNF.

45) Newton, S14 T14N R42W, 35°53'N 93°28'W, 2000 ft (610 m), 1 bird, 1993, upland forest, Chris Kellner, Jan Self, OZNF.

46) Newton, S2 T14N R21W, 35°54'N 93°11'W, 1500 ft (457 m), 5 birds, 3 June 1997, upland forest, Chris Kellner, Jan Self, OZNF.

47) Newton, S6 T14N R20W, 35°54'N 93°09'W, 1500 ft (457 m), 3 birds, 3 June 1997, upland forest, Chris Kellner, Jan Self, OZNF.

48) Newton, S7 T14N R20W, 35°53'N 93°09'W, 1800 ft (549 m), 2 birds, June 1997, upland forest, Chris Kellner, Jan Self, OZNF.

49) Newton, S21 T14N R22W, 35°51'N 93°19'W, 2180 ft (665 m), 1 bird, 30 May 1996, upland forest, Chris Kellner, Jan Self, OZNF.

50) Newton, S33 T14N R22W, 35°50'N 93°20'W, 1480 ft (551 m), 1 bird, 20 June 1995, upland forest, Chris Kellner, Jan Self, OZNF.

51) Newton, S31 T14N R22W, 35°50'N 93°22'W, 1740 ft (530 m), 1 bird, 2 May 1996, upland forest, Chris Kellner, Jan Self, OZNF.

52) Newton, S8 T13N R22W, 35°48'N 93°21'W, 1360 ft (415 m), 1 bird, 7 June 1995, upland forest, Chris Kellner, Jan Self, OZNF.

53) Newton, S29 T14N R20W, 35°50'N 93°08'W, 1660 ft (506 m), 1 bird, 18 June 1995, upland forest, Chris Kellner, Jan Self, OZNF.

54) Newton, S6 T14N R20W, 35°54'N 93°09'W, 1700 ft (518 m), 2 birds, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

55) Newton, S31 T14N R22W, 35°50'N 93°22'W, 1500 ft (457 m), 2 birds, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

56) Newton, S8 T13N R22W, 35°48'N 93°21'W, 1500 ft (457 m), 1 bird, June 1998, mature upland northern red oak forest, Chris Kellner, Jan Self, OZNF.

57) Newton, S6 T14N R22W, 35°53'N 93°21'W, 1340 ft (408 m), 1 bird, 1996, Jan Self, Chris Kellner, OZNF

58) Newton, S35 T14N R24W, 35°50'N 93°30'W, 2250 ft (686 m), 1 bird, 1993, Jan Self, Chris Kellner, OZNF.

59) Newton, S14 T14N R24W, 35°52'N 93°29'W, 2300 ft (701 m), 2 birds, 1993, Jan Self, Chris Kellner, OZNF.

60) Newton, S24 T14N R24W, 35°53'N 93°29'W, 2000 ft (610 m), 2 birds, 1993, Jan Self, Chris Kellner, OZNF.

61) Newton, S25 T14N R24W, 35°51'N 93°28'W, 1900 ft (579 m), 2 birds, 1993, Jan Self, Chris Kellner, OZNF.

62) Newton, S30 T14N R23W, 35°51'N 93°28'W, 2000 ft (610 m), 2 birds, 1993, Jan Self, Chris Kellner, OZNF.

63) Newton, S31 T14N R23W, 35°50'N 93°28'W, 2200 ft (671 m), 1 bird, June 1998, Jan Self, Chris Kellner, OZNF.

64) Newton, S6 T13N R23W, 35°49'N 93°28'W, 1700 ft (518 m), 1 bird, 1993, Jan Self, Chris Kellner, OZNF.

65) Newton, S5 T13N R23W, 35°49'N 93°27'W, 1800 ft (548 m), 2 birds, 1993, Jan Self, Chris Kellner, OZNF.

66) Newton, S10 T13N R23W, 35°48'N 93°25'W, 1600 ft (488 m), 1 bird, 1 June 1995, Jan Self, Chris Kellner, OZNF.

67) Stone, S 5&6 T16N R12W, 36°03'N 92°18'W, 750 ft (229 m), possibly 5 birds, 1996, riverine forest, Bob Clearwater, OZNF.

68) Stone, S1 T16N R12W, 36°03'N 92°12'W, 1000 ft (305 m), 1 bird, 1997, upland forest, Glen Thomas, OZNF.

69) Stone, S16 T16N R12W, 36o02'N 92°15'W, 750 ft (229 m), 1 bird, 1998, bottomland forest, Glen Thomas, OZNF.

70) Stone, S3,4,11 T15N R11W, approximately 35°57'N 92°09'W, 500 ft (152 m), possibly 5 birds, 1998, bottomland forest, Larry Hedrick, OZNF.

71) Van Buren, 35°38'N 93°34'W, June 1994, Rupert route Breeding Bird Survey, 1 bird, June 1994.

72) Van Buren, east of Shirley, T12N, R12W, approxi-

mately 35°40'N 92°15'W, 550 ft (168 m), 3 birds, 25 May 1991, Bo and Don Verser.

73) Washington, S25 T15N R31W, 35°47'N 94°15'W, 1200 ft (366 m), 1 bird, 31 May 1998, mature upland oak-hickory forest, Mike Mlodinow, David Chapman, DDP.

Ouachita Mountains Region

74) Hot Spring, Social Hill area, approximately 34°20'N 92°55'W, at least 1 bird, 300 ft (91 m), 4 July 1994, bottomland forest, Jerry Davis.

75) Howard, Howard County Wildlife Management Area, approximately 34°13'N 94°10'W, 830 ft (253 m), 2 birds, 2,7 June 1990, Helen and Max Parker, HCWA.

76) Logan, S4 T4N R26W, 35°02'N 93°46'W, 1500 ft (457 m), at least 1 bird, 15 June 1994, mature upland white oak-hickory forest, Joe Neal, OUNF.

77) Montgomery, S27 T4S R27W, 34°23'N 93°53'W, 958 ft (292 m), 2 birds (1 at each of 2 adjacent locations), 29 May 1998, bottomland sweet gum, sugar maple, white oak forest, Jennifer Akin, OUNF.

78) Montgomery, S14 T1S R23W, 34°39'N 93°26'W, 600 ft (183 m), at least 1 bird, 7 July 1995, mature bottomland oak-hickory forest, Jerry Davis, OUNF.

79) Montgomery, S32 T4S R27W, 34°21'N 93°55'W, 1000 ft (305 m), 5 birds, 29 June 1994, mature oak-hickory-sweet gum riparian forest, Jerry Davis and Larry Hedrick, OUNF.

80) Montgomery, S29 T2S R27W, 34°32'N 93°55', 900 ft (274 m), at least 1 bird, cut over bottomland hardwood forest, Larry Hedrick.

81) Polk, S12 T1S R32W, 34°45'N 94°22'W, 2000-2250 ft (610-685 m), 3 birds, 13 June 1999, mid-aged upland black oak, white oak, cucumber tree forest, Doug James, David Chapman, OUNF.

Gulf Coastal Plain Region

82) Calhoun, S10 T16S R14W, 33°21'N 92°32'W, 82 ft (25 m), 1 bird, 3 June 1998, bottomland beech, sweet gum, oak forest, Jennifer Akin.

83) Clark, 34°03'N 93°15'W, 1 bird, June 1990 & 1995, Hollywood route Breeding Bird Survey, Helen Parker.

84) Clark, S34 T6S R22W, 34°10'N 93°14'W, 350 ft (107 m), 1 bird, 6 July 1998, mature oaks, sweet gum, sycamore forest. Max and Helen Parker.

85) Cleveland, S17 T10S R10W, 33°51'N 92°09'W, 93 ft (28 m), 2 birds, 8 June 1998, Bottomland black willow, silver maple, sycamore forest, Jennifer Akin.

86) Grant, S21 T4S R12W, 34°22'N 92°18'W, 250 ft (76 m), 1 bird, 8 June 1998, mature upland-bottomland forest with hickories, oaks, sweetgum dominants, Helen Parker.

87) Grant, S4 T4S R15W, 34°24'N 92°42'W, 250 ft (76 m), 1 bird, 28 May 1990, mature bottom land forest, Helen and Max Parker.

88) Union, SE of Strong, T19S R12W, approximately 33°03'N 92°20'W, 100 ft (31 m), 3 birds (adults feeding young), 25 May 1996, Cade and Mary Coldren.

Mississippi Delta Region

89) Arkansas, 34°16'N 91°06'W, 172 ft (52 m), 1 bird, 1992, bottomland forest, Paul Hamel, WRWR.

90) Desha, 33°44'N 91°09'W, 146 ft (45 m), over 10 birds, 1992 and 1998, bottomland forest, Paul Hamel.

91) Desha, on Big Island across Mississippi River from Rosedale, Miss., approximately 33°45'N 91°10'W, 150 ft (46 m), 8 birds, 20 June 1991, mature bottomland forest, Bob Ford.

92) Desha, near Rohwer, approximately 33°45'N 91°14'W, 145 ft (44 m), 5-13 birds, 29-30 June 1991, 4 July 1992, Bob Ford.

93) Monroe, White River National Wildlife Refuge north of Highway 1, T3S R1W, approximately 34°25'N 91°05'W, 175 ft (53 m), 1-2 birds, 24 May and 27 June 1991, Bob Ford, WRWR.

94) Monroe, 34°24'N 91°07'W, 174 ft, 1 bird, 1992, bottomland forest, Paul Hamel, WRWR.

95) Phillips, one site, 2 birds, 1992, mature bottomland forest, Robert Cooper, WRWR.

96) Phillips, 1 bird, another site, 1992, mature bottomland forest, Robert Cooper, WRWR.

97) Prairie, S20 T4N R4W, 34o°57'N 91°27'W, 183 ft (56 m), 1 bird, 21 May 1998, mature bottomland mixed oaks, sweet gum, bald cypress forest, Max and Helen Parker.

Table 1. Number of Cerulean Warbler sites and maximum numbers of birds reported at the sites in each physiographic region of Arkansas.

Physiographic region	Number of sites	Number of birds
Ozarks	73	196
Ouachitas	8	16
Coastal Plain	7	10
Delta	9	39
Total	97	261

Discussion

Cerulean Warblers were detected at 97 sites (Table 1) in Arkansas from 1990 to 1999, comprising a combined total of 261 birds. By far the most sites and birds were in the Ozark Plateaus physiographic region (Table 1, Fig. 1) in rthern Arkansas especially in the northwestern part of the te. The species was uncommon in the rest of the state. pulation centers (Fig. 1) were in upland forests in adjoin- ; Newton and Pope Counties in the Ozarks (57 and 92 ds documented, respectively) and in bottomland forests Desha County (31 birds) in the Delta region.

The importance of extensive forests existing on public ıds was pronounced. Over two-thirds of the sites (68 out 97 total equals 70%) occurred on such properties, with most (57 sites) in the Ozark National Forest, followed by 5 sites each in the Ouachita National Forest and White River National Wildlife Refuge, and one site each at the Buffalo National River, Devil's Den State Park and Howard County Wildlife Management Area (Arkansas Game & Fish Commission). The overall pattern of habitat types occupied amplifies what has been reported for Cerulean Warblers in

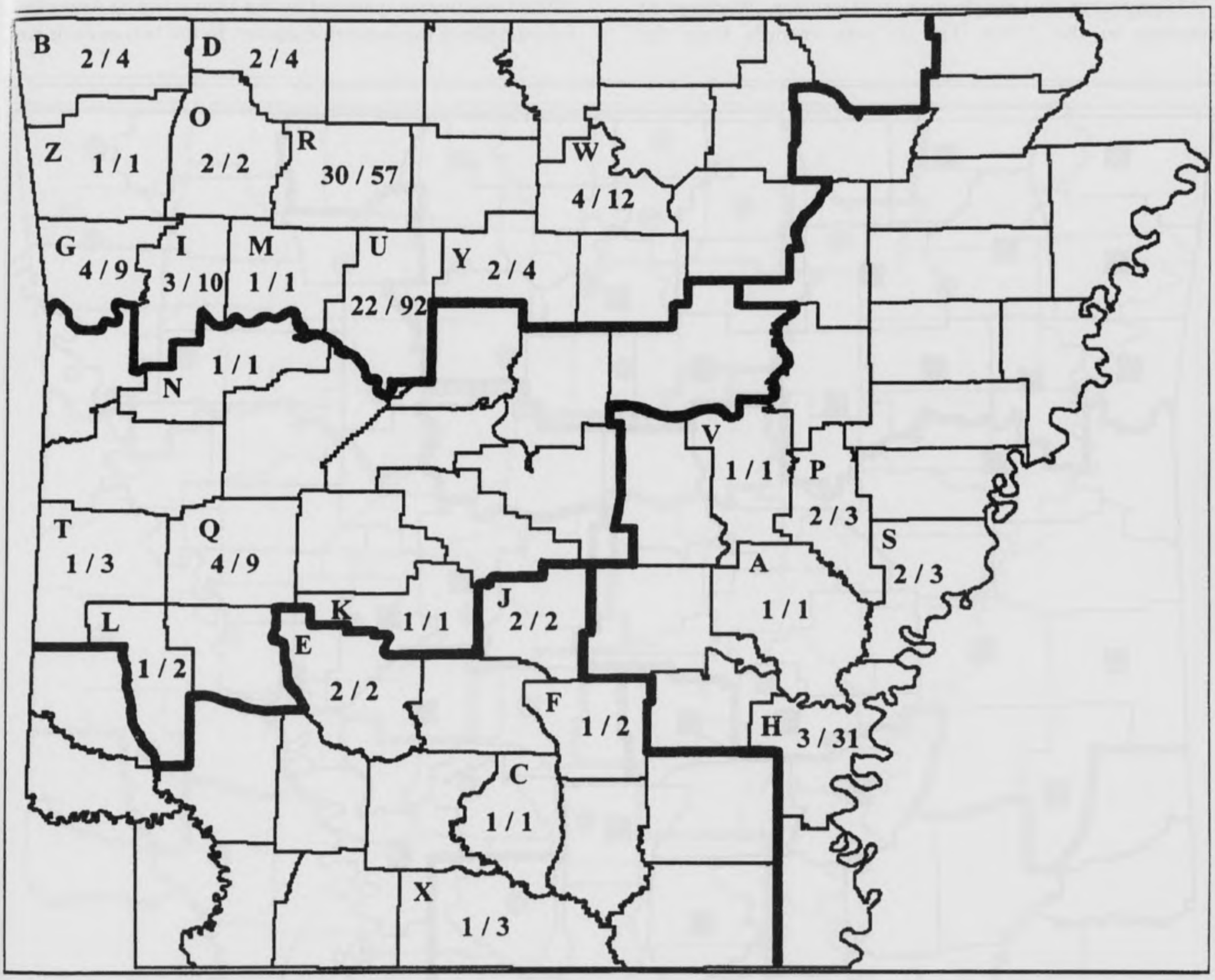

Fig. 1. Number of Cerulean Warbler sites (before the slash) and number of birds at the sites (after the slash) in the Arkansas counties where the birds were found in the 1990s. The bold lines outline physiographic regions in the state which are the Ozark Plateaus in the north, Gulf Coastal Plain in the south, Ouachita Mountains in between, and Mississippi Delta to the east. Letters in the upper left of counties indicate county identifications as follows: A-Arkansas, B-Benton, C-Calhoun, D-Carroll, E-Clark, F-Cleveland, G-Crawford, H-Desha, I-Franklin, J-Grant, K-Hot Spring, L-Howard, M-Johnson, N-Logan, O-Madison, P-Monroe, Q-Montgomery, R-Newton, S-Phillips, T-Polk, U-Pope, V-Prairie, W-Stone, X-Union, Y-Van Buren, Z-Washington.

the state (James and Neal, 1986) and elsewhere (Hamel, 1992; Rosenberg et al., 1998): that they occur in mature upland and bottomland hardwood forests. The occupied upland sites were mainly in the Ozarks with a smaller number in the Ouachitas, usually above 1000 ft (305 m) elevation but primarily higher with nearly three-fourths of upland sites exceeding 1500 ft (457 m) to over 2000 ft (609 m). In the other regions warblers were found in low bottomland or riverine forests sites down to below 100 ft (30 m) in elevation.

Comparing the distribution of Cerulean Warblers in Arkansas in the 1990s (Fig. 2) with records from the Arkansas Audubon Society Bird Records File compiled from the 1940s through 1973 (Fig. 3) shows no striking changes in the county pattern of distribution although looking carefully at the two figures there is a noticeable presence of warbler occurrences in the eastern Ozarks and adjacent counties in the early years (Fig. 3) that appears shifted to the western Ozarks in later years (Fig 2). This pattern is mainly attributable to differences in coverage in the two periods and dominated by Ben Coffey and his colleagues in the eastern Ozarks active during the early years, replaced in the 1990s by activities spawned by the University of Arkansas at Fayetteville in the western counties. In the two periods com-

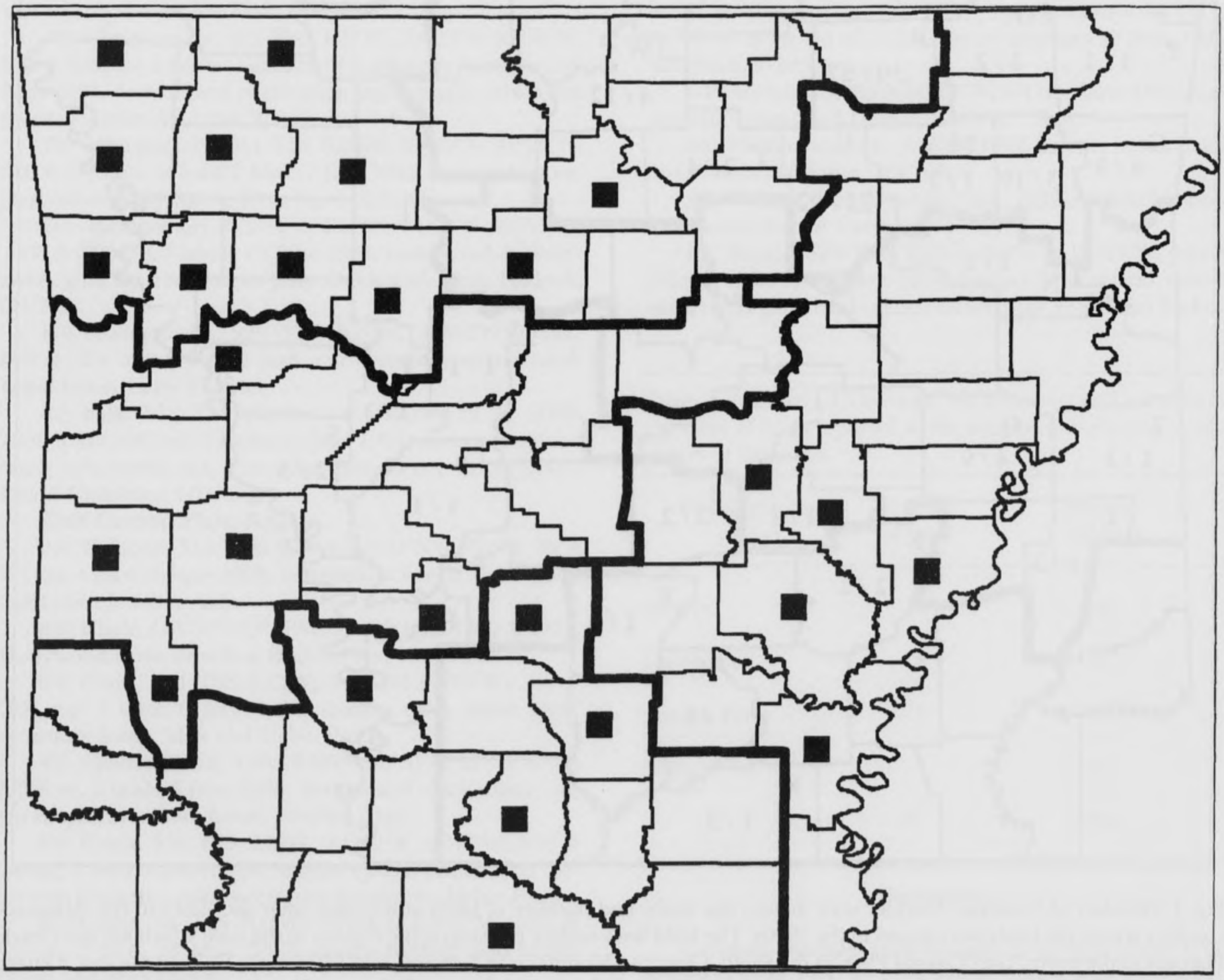

Fig. 2. Counties in Arkansas where Cerulean Warblers were found in the 1990s (squares). Bold lines outline the physiographic regions of Arkansas as described in Fig. 1.

ned there were a total of 38 counties of occurrence; the ırbler was found during both periods in 16 counties, 10 unties in the 1990s only, and in 12 counties only through 73. This distribution did not deviate significantly from a nomial expansion (Chi-square=1.158, d.f.=2, $P>0.05$), dicating there was no pattern of change occurring between e two time periods. There were 28 counties with Cerulean 'arblers through 1973 and 26 counties in the 1990s. Due to e lack of any systematic surveys, it is not possible to assess liably any changes in distribution and abundance in the rds over time.

Jennifer Akin's survey of former and potential Cerulean Warbler areas in lowland forests of southern and eastern Arkansas covered 23 sites. She found birds at 3 places; all were locations where the species was found previously in the 1950s. None were found at the other localities that included two places where birds were found in the 1950s, but where now the habitat is greatly altered.

Mature forests occupied by Cerulean Warblers possess a degree of forest canopy irregularity, either with trees protruding above the others, or with small breaks in the canopy (Rosenberg et al., 1998; Paul B. Hamel, pers. comm.). It is

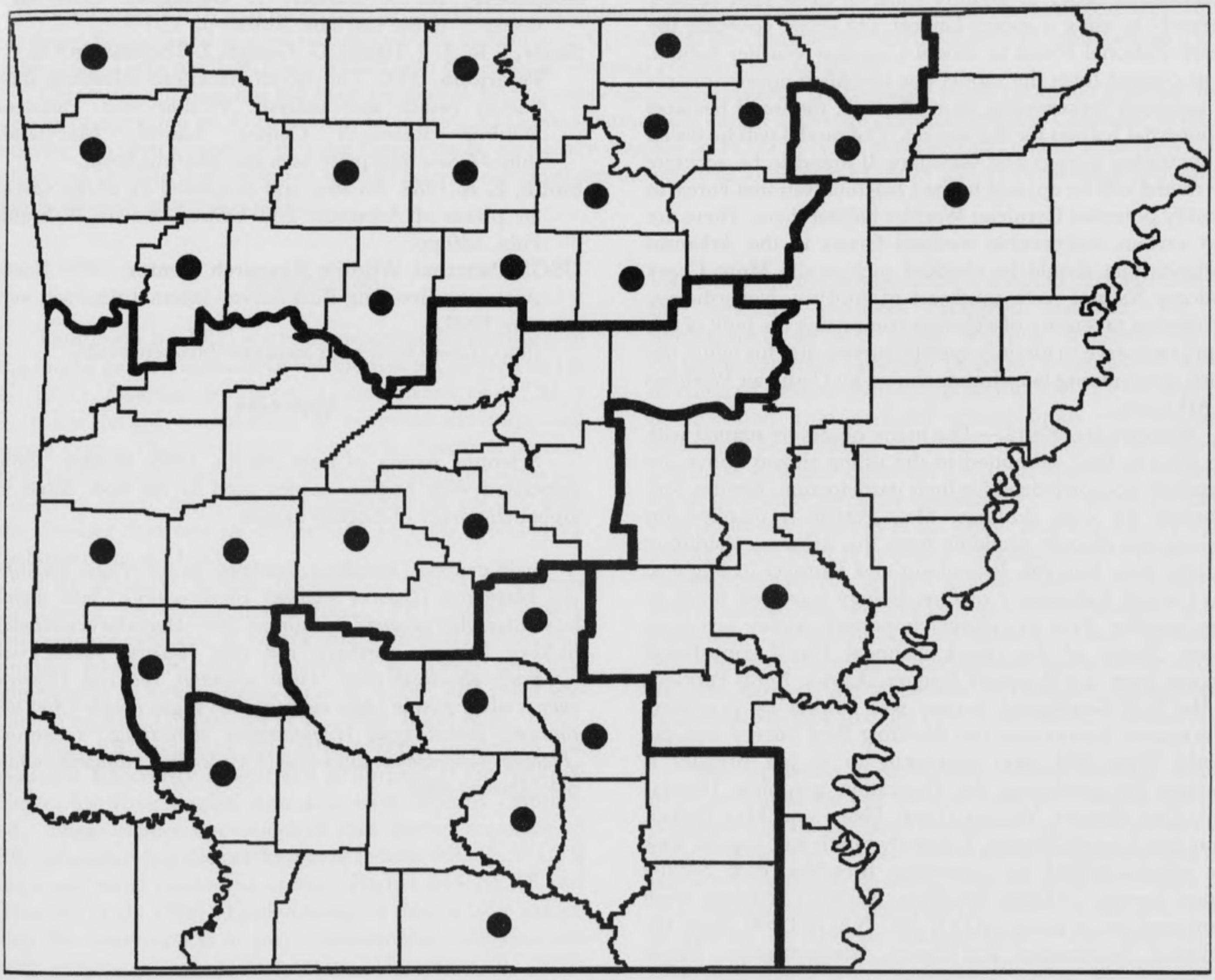

Fig. 3. Counties in Arkansas where Cerulean Warblers were found from the 1940's through 1973 (circles). Bold lines outline the physiographic regions of Arkansas described in Fig. 1.

therefore interesting that Mlodinow (item 43 listed above) visited a location in the Ozark National Forest from 1994 through 1998 and found a Cerulean Warbler only in 1998 after the site received group selection treatment. Group selection is a forest harvest method where a small number of mature trees are harvested leaving the main forest structure relatively unmodified, but it does create openings in the canopy. This possible beneficial effect of group selection treatment on Cerulean Warblers is being investigated by one of us (Kellner).

Unquestionably, there are undiscovered sites where Cerulean Warblers occur in Arkansas, especially in the Ouachitas where it is very difficult to reach many promising locations. In order to identify some of these sites Kellner currently is using a recent landsat TM scene covering the Ozark National Forest to model Cerulean Warbler habitat. In its current form the model has identified approximately 50 locations representing more than six thousand hectares of potential habitat for the species. The model will be tested in upcoming springs and summers. If found to be accurate the model will be applied to the Ouachita National Forest to identify potential Cerulean Warbler habitat there. There are also various inaccessible wetland forests in the Arkansas lowlands that should be checked such as the Moro Creek Bottoms Natural Area southeast of Fordyce. Nevertheless, the current inventory of sightings comprising the bulk of this paper can serve to identify specific survey sites for future use when determining later trends shown by Cerulean Warblers in Arkansas.

ACKNOWLEDGMENTS.—The many observers named with the records they submitted in the listing shown above are gratefully acknowledged for their participation. Besides contributing his own findings, Max Parker is thanked for making the records available from the Arkansas Audubon Society files. Kenneth Rosenberg and Partners in Flight at the Cornell Laboratory of Ornithology provided funds to hire Jennifer Akin to conduct important survey activities. Karen Tinkle of the Ozark National Forest contributed records from the Sylamore Ranger District. Keith Pardieck of the U.S. Geological Survey was helpful by providing information concerning the Breeding Bird Survey and the World Wide Web sites pertaining to it. Jeff Briggler is thanked for producing the illustration graphics. Thomas Foti, Gary Graves, Vernon Howe, Helen and Max Parker, Shug and Luvois Shugart, Kimberly Smith and Lyndal York are acknowledged for operating Breeding Bird Survey routes having Cerulean Warblers. Kellner's activities were supported by a grant (JOVE No. NAG8-1284) from the National Aeronautics and Space Administration. Major improvements of the manuscript were accomplished by incorporating recommendations from David Saugey and three anonymous reviewers.

Literature Cited

American Ornithologists' Union. 1998. Check-list of North American Birds. 7th edition. American Ornithologists' Union, Washington, D.C. 829 pp.

Hamel, Paul B. 1992. Land manager's guide to the birds of the South. The Nature Conservancy, Southeastern Region, Chapel Hill, N.C. 437 pp.

Hunter, C. G. 1989. Trees, shrubs, and vines of Arkansas. Ozark Society Foundation, Little Rock, Ark. 207 pp.

James, D. A. and J. C Neal. 1986. Arkansas birds, their distribution and abundance. Univ. Arkansas Press. 402 pp.

Rosenberg, K., S. Barker, T. Gallagher. 1998. Bird research--in the fast lane. Birdscope 12:1-3.

Sauer, J. R., J. E. Hines, G. Gough, I. Thomas and B. G. Peterjohn. 1997. The North American Breeding Bird Survey results and analysis. Version 96.3. Patuxent Wildlife Research Center. Laurel, Maryland. (http://www.mbr-pwrc.usgs.gov/bbs/bbs.html).

Smith, E. B. 1988. An atlas and annotated list of the vascular plants of Arkansas. 2nd Edition. Edwin B. Smith Publ. 489 pp.

USGS Patuxent Wildlife Research Center. 1999. North American Breeding Bird Survey internet data set, version 1999.1 (http://www.mp2-pwrc.usgs.gov/bbs/retrieval/).

Appendix

Scientific names of trees (Smith, 1988, Hunter, 1989) associated with English names used in the text, listed in alphabetic order of English names.

bald cypress (*Taxodium distichum*), beech (*Fagus grandifolia*), black oak (*Quercus velutina*), black willow (*Salix nigra*), box elder (*Acer negundo*), cucumber tree (*Magnolia acuminata*), hickory (*Carya*), northern red oak (*Quercus rubra*), oak (*Quercus*), shortleaf pine (*Pinus echinata*), red oak (*Quercus rubra*), silver maple (*Acer saccharinum*), sugar maple (*Acer saccharum*), sweet gum (*Liquidambar styraciflua*), sycamore (*Platanus occidentalis*), tulip tree (*Liriodendron tulipifera*), white oak (*Quercus alba*).

Characterization of a POROS™-fumonisin B_1 Affinity Column for Isolating Ceramide Synthase from Rat Liver

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Abstract

Fumonisin B_1 is a mycotoxin produced by fungi of the genus *Fusarium,* common pathogens of corn and other grain plants. 1 ɔxic effects associated with fumonisin B_1 include equine leukoencephalomacia, porcine pulmonary edema, rat renal carcino- r a, and murine hepatocellular carcinoma. Increased risk for esophageal cancer in humans has been epidemiologically asso- c ated with consumption of corn contaminated with *Fusarium,* suggesting that fumonisin B_1 may be involved. The biological effects of fumonisin B_1 exposure result primarily from disruption of *de novo* sphingolipid biosynthesis via inhibition of ceramide synthase. Exposure of animals or cultured cells to fumonisin B_1 results in the characteristic accumulation of sphinganine, a toxic sphingolipid intermediate, concomitant with depletion of essential complex sphingolipids.

Ceramide synthase has not been purified to homogeniety and characterized. We prepared crude ceramide synthase from detergent-extracted rat liver homogenates using PEG-precipitation and cation exchange chromatography. Ceramide synthase activity was then sequestered, using fumonisin B_1 covalently coupled to POROS-NHϑ particles, and eluted selectively. The observed 119-fold enrichment in specific activity demonstrates the utility of fumonisin-POROS affinity chromatography in the purification of ceramide synthase.

Introduction

Fumonisin B_1 (FB1) is a toxin produced by members of the fungal genus *Fusarium* (Gelderblom et al., 1988; Thiel et al., 1991). *Fusarium moniliforme,* a common source of FB1, is a typical fungal contaminant of economically important cereal crops. The infection of corn with *Fusarium,* particularly problematic after periods of drought-induced stress followed by warm, moist weather, produces ear rot and stalk rot diseases that can be devastating to crop productivity (Schaafsma et al., 1993).

FB1 produces diverse pathological effects in animals consuming FB1-contaminated food. FB1 causes equine leukoencephalomacia in horses (Marasas et al., 1988), pulmonary edema in swine (Harrison et al., 1990), immunosuppression in turkey poults (Li et al., 2000), and renal toxicity in rabbits (Gumprecht et al., 1995; Bucci et al., 1998). Two-year FB1 exposure studies in rodents, funded by the National Toxicology Project and performed at the National Center for Toxicological Research, were recently completed. These studies demonstrated that dietary exposure to FB1 produced hepatic carcinoma in female B6C3F_1/NCTR mice and renal carcinoma in male Fischer 344/NCTR rats (Howard et al., 1999). Epidemiological studies have associated the consumption of corn contaminated with *Fusarium* with esophageal cancer in humans (Marasas et al., 1988; Chu and Li, 1994).

Disruption of sphingolipid biosynthesis via inhibition of ceramide synthase appears to be the principal biochemical effect of exposure to FB1 (reviewed in Merrill et al., 1995). FB1 is structurally similar to the sphingoid base substrates of the ceramide synthase catalyzed reaction (Fig. 1). Sphinganine, an acyl group acceptor substrate for the ceramide synthase catalyzed reaction, accumulates rapidly in cultured cells or tissues exposed to FB1. Ceramides can be liberated from complex sphingolipids via enzymatic hydrolysis or produced via *de novo* biosynthesis through the ceramide synthase catalyzed reaction. Increased ceramide levels produced by either mechanism have been associated with apoptosis (Mathias et al., 1998). Blocking the ceramide synthase catalyzed N-acylation of sphinganine by FB1 also causes depletion of complex sphingolipid pools, including: dihydroceramides, ceramides, glucosylceramides, sphingomyelin, gangliosides, cerebrosides, and sulfatides. Maintenance of complex sphingolipid pools are important for cell survival and depletion of complex sphingolipids contributes to FB1 toxicity (Yoo et al., 1996; Tolleson et al., 1999).

The regulation of ceramide synthase catalytic activity must be critical for cell survival because it affects the concentrations of sphingolipid mediators that influence cell survival and death processes. Furthermore, signal transduction pathways regulating ceramide synthase gene expression and its enzymatic activity may exert an effect on the homeostatic balance of strategic sphingolipids. The first step in understanding the biochemical nature of ceramide biosynthesis is the isolation of the active enzyme. Several groups have reported the partial purification of ceramide synthase, but none have been successful in completing its isolation to homogeniety. We endeavored to test a FB1 affinity chro-

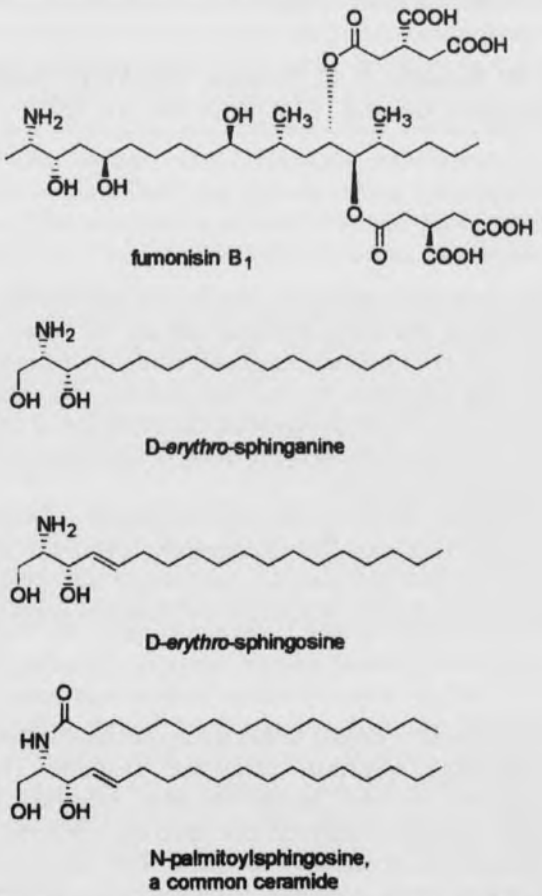

Fig. 1. Structures of fumonisin B_1, sphinganine, sphingosine, and N-palmitoylsphingosine, depicting stereochemical similarities.

matography column for isolating fumonisin-binding proteins expected to be present in rat liver. We previously discovered that our FB1 affinity column sequestered rat liver argininosuccinate synthetase from rat liver extracts and that both rat liver and recombinant human argininosuccinate synthetases are inhibited by FB1 *in vitro* (Ki' = 6 mM and 35 mM for human and rat liver argininosuccinate synthetase, respectively; Jenkins et al., 2000). Although ceramide synthase is believed to represent the most significant target for the biological action of FB1, other enzyme systems are affected by FB1. Fukuda *et al.* (1996) showed that FB1 inhibits recombinant rat protein phosphatase 5 (PP5) with an IC_{50} of 80 µM and PP1γ2, PP2A, PP2B, and PP2C with IC_{50} values 300-1000 µM. PP5 is reportedly expressed in many tissues, including hepatocellular carcinoma cell lines, but it is poorly expressed in normal liver samples and would not be expected in the sample used in this study (Shirato et al., 2000). We predicted that ceramide synthase or other FB1-binding proteins could be recovered from rat liver extracts using FB1 affinity chromatography.

Materials and methods

Sample Preparation.--All sample processing and chromatographic procedures were performed at 4°C except where indicated. Rat liver extract was prepared by mechanical distruption (Polytron, Brinkmann Instruments Company, Westbury, NY) of frozen rat livers in 50 mM sodium phosphate buffer, pH 6.5 containing 10 mM EDTA, 150 mM sodium chloride, and 2% Triton X-100™ followed by 30 min incubation at 0°C. Cellular debris and other insoluble matter was removed by centrifugation for 15 min at 21,000g. Polyethylene glycol (PEG) was added to 10% (w/v) to the supernatant and contaminating proteins were removed from the rat liver detergent extract by precipitation and centrifugation. Ceramide synthase activity was precipitated by increasing the PEG concentration to 20%. In some cases rat liver cytosol was prepared by disrupting rat liver samples in the absence of detergents, then removing cellular debris and organelles by high speed centrifugation, adding Triton X100 to 2% and preparing cytosolic 10-20% PEG fractions. The 10-20% PEG precipitates were collected by centrifugation and redissolved in 25 mM sodium phosphate buffer, pH 6.5 containing 1 mM EDTA and 2% Triton X-100, and applied to a 5x20 cm SP-Sepharose strong cation exchange column. Ceramide synthase activity was eluted from the cation exchange column using an increasing pH and salt gradient (linear gradient from 0-40% Buffer B over 120 min; flow rate 3.0 mL/min; Buffer A: 25 mM sodium phosphate, 1 mM EDTA, 0.2% Brij-35, pH 6.5; Buffer B: 25 mM sodium phosphate, I mM EDTA, 0.2% Brij-35, 2.0 M sodium chloride, pH 7.5). Fractions containing ceramide synthase activity were pooled and dialyzed twice against 50 volumes of 50 mM sodium phosphate, 1 mM EDTA, 0.2% Brij-35, pH 6.8.

POROS-FB1 Affinity Chromatography.--The POROS-FB1 affinity matrix was prepared by coupling FB1 tricarbyllate groups to free primary amine groups on 20 µm POROS-NH™ particles (Perceptive Biosystems, Foster City, CA), as previously described (Newkirk etal., 1998; Jenkins et al., 2000). A suspension of POROS-FB1 matrix was slurry packed into a 0.46 cm x 10.0 cm polymer column jacket fitted with 2 µm end frits and installed into a Varian ProStar biocompatible HPLC system equipped with a Varian ProStar variable wavelength UV/Vis detector, a BioRad Econo Gradient monitor, and a BioRad Model 2128 fraction collector. Data were collected and processed using MacIntegrator II Software (Varian) and a Macintosh Quadra personal computer, which also provided control for the pump units.

The POROS-FB1 affinity column was equilibrated in dialysis buffer and loaded at 4 mL/min. Ceramide synthase activity was eluted from the POROS-FB1 column using a two-step gradient of increasing ionic strength (linear gradient from 0-25% Buffer B from 0-10 minutes, 25-100% Buffer

B rom 10-15 min; flow rate 4 mL/min; Buffer A: 50 mM sc ium phosphate, 1 mM EDTA, 0.2% Brij-35, pH 6.8; B fer B: 2.0 M sodium chloride dissolved in Buffer A).

Analytical Procedures.--Protein concentrations were d ermined using the Pierce BCA Protein Assay Kit with b vine serum albumin standards (Pierce Endogen, R ckford, IL) according to the manufacturer's specificati ns. Denaturing polyacrylamide gel electrophoresis was p formed using 4-20% gradient Ready Gels (BioRad, H rcules, CA) with BioSafe Coomassie Stain. Ceramide sy thase activity was measured using the method described b Hirshberg et al. (1993) and adapted slightly for our use (J nkins et al., 2000). Assay reactions were performed in 50 mM sodium phosphate buffer, pH 6.9. Samples were desalted prior to activity measurements by three sequential dilutions (1:10) with cold assay buffer and centrifugal ultrafiltration at 4°C using Ultrafree 0.5 microconcentrator devices (10,000 MWCO, Millipore, Bedford, MA). Desalted samples were incubated with 0.2 µCi [^{14}C]-palmitoyl coenzyme A (60 mCi/mmole, NEN, Boston, MA) and 40 µM D-*erythro*-sphingosine (Sigma Chemical Co., St. Louis, MO) in 0.25 mL reactions for 20 min at 37°C. The reactions were quenched by placing the tubes in an ice/water bath for 1 min prior to extraction. Samples containing polyethylene glycol were extracted twice with 0.5 mL diethyl ether. All other samples were extracted once with 0.6 mL 2:1 chloroform/methanol and once with 0.4 mL chloroform. The organic extracts were dried *in vacuo*, dissolved in chloroform, and applied to LK5DF silica thin layer plates (Whatman Inc., Clifton, NJ). Thin layer chromatography was performed using 90:7:3 chloroform/methanol/concentrated ammonium hydroxide. Authentic N-palmitoylsphingosine was included as a reference standard and visualized by post-run exposure to iodine vapor. [^{14}C]-N-palmitoylsphingosine reaction products were quantified by phosphorimagining (Molecular Dynamics Corporation, Sunnydale, CA) with ImageQuant software. Background reaction rates for protein-free reactions were subtracted from all measurements. Specific activity values were determined by dividing the net amount of ceramide product formed, expressed as volume integration counts, by the amount of protein added to the reaction.

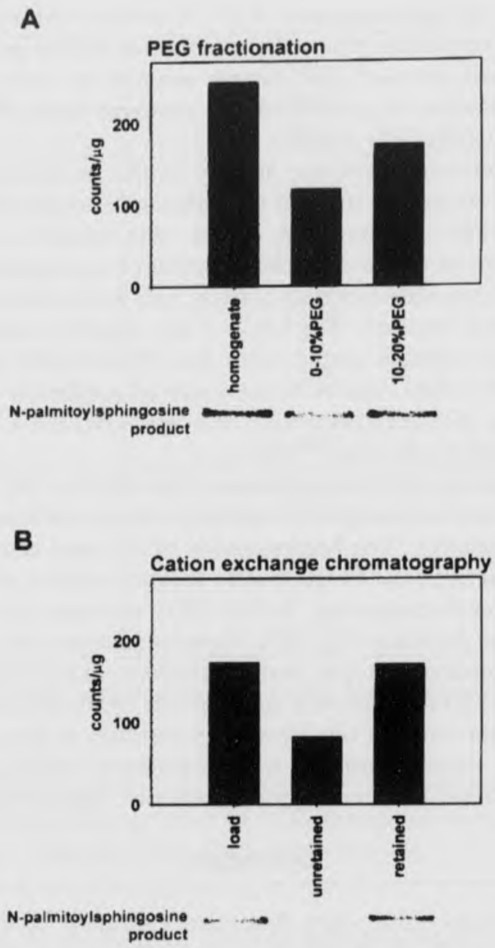

Fig. 2. Extraction of ceramide synthase activity from rat liver. (A) Ceramide synthase activity in rat liver fractions (100 µg protein/reaction) was determined as given in Materials and Methods. (B) Ceramide synthase activity in cation exchange chromatography fractions. Aliquots (100 µg/reaction) from 10-20% PEG fraction (load), unretained fraction, and retained fractions were subjected to ceramide synthase assay as described in Materials and Methods. Insets displayed under plots: [^{14}C]-N-palmitoylsphingosine reaction products quantified by tlc and phosphorimaging.

Results

Ceramide synthase activity was detected in rat liver detergent extracts and concentrated using polyethylene glycol precipitation (Fig. 2A). Prior work in our laboratory determined that ceramide synthase activity could be detected in the absence of detergents. However, the addition of detergents prevented excessive losses of ceramide synthase through nonspecific association with heterogenous protein precipitates (data not shown). A large amount of extraneous protein was removed by differential precipitation with PEG, and the sample volume was reduced (Table 1). Although the apparent specific activity appeared to be relatively unchanged following PEG precipitation, the presence of PEG in these samples may have interfered with enzyme catalyzed reaction. We observed that the specific activity recovered somewhat after cation exchange chromatography in the subsequent step (Fig. 2B). Ceramide synthase activity was retained by the SP-Sepharose column and eluted at 135-140 min in approximately 0.35 M sodium chloride. UV spectroscopy of the retained and nonretained fractions (data not shown) revealed that a large amount of nonproteinaceous UV-absorbing material was removed from the redissolved 10-20% PEG fraction.

The ceramide synthase activity in the pooled and dialyzed SP-Sepharose fraction was efficiently adsorbed by the POROS-FB1 column and eluted with sodium chloride whereas most of the extraneous protein was excluded (Fig. 3A-C). Ceramide synthase activity was not detected in the unretained sample (Fig. 3C). The specific activity of ceramide synthase eluted from the POROS-FB1 column increased 17-fold relative to the material applied to the column (Fig. 3C), and the protein recovery indicated a 119-fold enrichment by this step (Table 1).

Denaturing gel electrophoresis showed that the heterogeneity of active samples correlated inversely with increased specific activity. The heterogeneity of the most active sample eluted from the POROS-FB1 column was less than that of rat liver homogenate, 10-20% PEG fractions, or the SP-Sepharose fractions (Fig. 3D). Several proteins are particularly prominent in the active fractions eluted from the POROS-FB1 column with apparent Mr of 29, 38, 51, and 74 kDa. Prior work in our laboratory resulted in the purification of a small quantity of a homogeneous 38 kDa protein that exhibited ceramide synthase activity (data not shown).

Discussion

Scribney (1966) first described ceramide biosynthesis (i.e., ceramide synthase) in brain and liver microsomes. Morell and Radin (1970) determined the acyl group specificity specificity of ceramide synthase in rat brain extracts. Later, the presence of ceramide synthase activity in liver microsomal fractions was confirmed by Narimatsu et al. (1986) and extended by Mandon et al. (1992) and Hirshberg et al. (1993) who detected ceramide synthase activity present on the cytosolic surface of the endoplasmic reticulum. Shimeno et al. (1995, 1998) also observed ceramide synthase activity in mitochondrial fractions. Studies performed in our laboratory confirmed that ceramide synthase activity could be detected in both fractions and that conditions that partially disrupt organelle integrity released ceramide synthase activity into the soluble, microsome-free cytosolic fraction. We utilized Triton X-100 as a nondenaturing detergent to extract ceramide synthase from whole liver homogenates.

The purification of ceramide synthase has been a daunting problem for several research groups. Shimeno et al. (1998) employed anion exchange chromatography followed by sphingosine affinity chromatography in the partial purification of ceramide synthase. Sphingosine was coupled to the column matrix via its primary amine group, resulting in

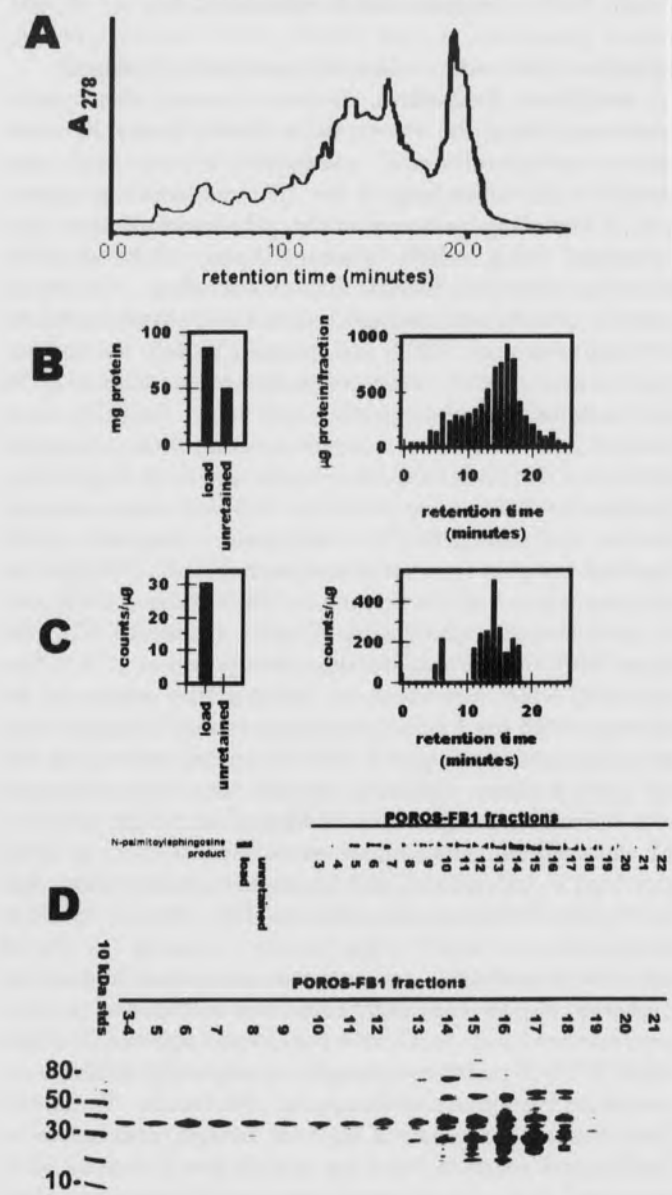

Fig. 3. POROS-FB1 affinity chromatography. (A) POROS-FB1 chromatogram. Dialyzed fraction from strong cation exchange chromatography containing crude ceramide synthase activity was applied to 0.46x10 cm POROS-FB1 column and eluted with sodium chloride. (B) Protein levels in POROS-FB1 chromatographic samples. (C) Ceramide synthase activity in POROS-FB1 chromatographic samples. Insets under plots: [^{14}C]-N-palmitoylsphingosine reaction products quantified by tlc and phosphorimaging. (D) Denaturing polyacrylamide gel electrophoresis of POROS-FB1 chromatographic samples.

Table 1 – Analysis of ceramide synthase isolation scheme

sample	volume (mL)	protein concentration (mg/mL)	protein yield (mg)
Homogenate[a]	596	37.0	22,040
0-10% PEG fraction[a]	174	70.5	12,300
10-20% PEG fraction[a]	87	31.9	2,780
SP-Sepharose (unretained)[a]	331	3.04	1,010
SP-Sepharose (retained)[a]	30	16.3	490
POROS-FB1 load[b]	28	3.10	86.7
POROS-FB1 (unretained)[b]	83.5	0.60	50.1
POROS-FB1 (retained)[b]	4	0.18	0.73

[a]These samples and those presented in Fig. 2 are related to processing 141 g rat liver as described in the Materials and Methods section.

[b]These samples and those presented in Fig. 3 are related to processing 250 g rat liver in the absence of detergent and performing a high speed centrifugation to remove nuclei, mitochondria, and microsomes prior to PEG precipitation in the presence of detergent and SP-Sepharose chromatography. Similar results were obtained with whole liver extracts.

essentially a saturated hydrocarbon, hydrophobic column matrix. Although some enrichment in specific activity was reported using this affinity matrix, it was probably due to hydrophobic interaction chromatography instead of specific ligand binding because the substrate amine subject to enzyme recognition by ceramide synthase was acylated to provide immobilization to the column matrix.

Our approach differs in that we first select for ceramide synthase using solubility in PEG. This eliminated many proteins that did not exhibit ceramide synthase activity. PEG fractionation was followed by cation exchange chromatography (SP-Sepharose) then affinity chromatography using the POROS-FB1 column. The latter chromatographic technique has been used to isolate anti-fumonisin antibodies (Newkirk et al., 1998). That study demonstrated that unique FB1 epitopes available for specific protein binding were present in the POROS-FB1 matrix. Additionally, argininosuccinate synthase was isolated as a protein that bound to POROS-FB1, and inclusion of FB1 inhibited its catalytic activity (Jenkins et al., 2000). POROS-FB1 affinity chromatography has proven to be useful and versatile in the purification of FB1 binding proteins.

The complete purification of ceramide synthase remains an elusive goal. Its hydrophobicity and tendency to associate nonspecifically with other proteins present obstacles for its further purification. The possibility that ceramide synthase exists as a component of a multi-protein complex cannot be excluded by our results. Size exclusion chromatography using Sephacryl S-200 indicated that ceramide synthase segregates with higher molecular weight protein-containing complexes (data not shown). The stability of ceramide synthase catalytic activity present in partially purified ceramide synthase seems to be lower than that of crude extracts, suggesting that the presence of additional proteins may contribute to its stability. These characteristics indicate that native ceramide synthase may be associated in complexes with other proteins.

The nature of the substrates of the ceramide synthase-catalyzed reaction creates difficulties in the accurate determination of its catalytic activity. The sphingoid base substrates for ceramide synthase are considerably hydrophobic. This presents specific biochemical problems in kinetic assays that require saturating substrate concentrations to achieve zero-order rate conditions. The hydrophobicity of sphinganine and sphingosine allows them to associate nonspecifically with many proteins via hydrophobic interactions. The effective concentrations of these substrates can be lowered through nonspecific adsorption to extraneous proteins in a concentration-dependent manner. Some investigators presaturate carrier proteins with excess sphinganine (or sphingosine) for inclusion in ceramide synthase assays in order to prevent removal of free sphinganine by nonspecific binding. However, this results in an indeterminate amount of free and bound substrate and does not ensure adequate concentrations of free sphingoid base substrate. Thus, reaction rates observed in ceramide synthase activity measurements are generally dependent both on the concentration of the enzyme and the substrate and are only informative in a qualitative way regarding relative catalytic activity. The purification of ceramide synthase will eventually allow accurate determinations of the rate constants of this enzyme for its substrates and determination of inhibition constants for FB1 and related molecules.

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Literature Cited

Bucci, T. J., P. C. Howard, W. H. Tolleson, J. B. Laborde, D. K. Hansen. 1998. Renal Effects of fumonisin myco-toxins in animals. Toxicol. Pathol. 26:160-164.

Chu, F. S. and **G. Y. Li.** 1994. Simultaneous occurrence of fumonisin B1 and other mycotoxins in moldy corn collected from the People's Republic of China in regions with high incidences of esophageal cancer. Appl. Environ. Microbiol. 60:847-852.

Fukuda, H. H. Shima, R. F. Vesonder, H. Tokuda, H. Nishino, S. Katoh, S. Tamura, T. Sugimura, and **M. Nagao.** 1996. Inhibition of protein serine/threonine phosphatases by fumonisin B1, a mycotoxin. Biochem. Biophys. Res. Commun. 220:160-165.

Gelderblom, W. C., K. Jaskiewicz, W. F. Marasas, P. G. Thiel, R. M. Horak, R. Vleggaar, and **N. P. Kriek.** 1988. Fumonisins–novel mycotoxins with cancer-promoting activity produced by *Fusarium moniliforme.* Appl. Environ. Microbiol. 54:1806-1811.

Gumprecht, L. A., A. Marcucci, R. M. Weigel, R. F. Vesonder, R. T. Riley, J. L. Showker, V. R. Beasley, and **W. M. Haschek.** 1995. Effects of intravenous fumonisin B1 in rabbits: nephrotoxicity and sphingolipid alterations. Nat. Toxins 3:395-403.

Harrison, L. R., B. M. Colvin, J. T. Greene, L. E. Newman, and **J. R. Cole, Jr.** 1990. Pulmonary edema and hydrothorax in swine produced by fumonisin B1, a toxic metabolite of *Fusarium moniliforme.* J. Vet. Diagn. Invest. 2:217-221.

Hirshberg, K., J. Rodger, and **A. H. Futerman.** 1993. The long-chain sphingoid base of sphingolipids is acylated at the cytosolic surface of the endoplasmic reticulum in rat liver. Biochem. J. 290:751-757.

Howard, P. C., R. M. Eppley, M. E. Stack, A. Warbritton, K. A. Voss, R. J. Lorentzen, R. Kovach, and **T. J. Bucci.** 1999. Carcinogenicity of fumonisin B_1 in a two-year bioassay with Fischer 344 rats and B6C3F$_1$ mice. Proc. Int. Symp. Mycotoxicol., 45-54.

Jenkins, G. R., W. H. Tolleson, D. K. Newkirk, D. W. Roberts, K. L. Rowland, T. Saheki, K. Kobayashi, P. C. Howard, and **W. B. Melchior, Jr.** 2000. Identification of fumonisin B1 as an inhibitor of argininosuccinate synthetase using fumonisin affinity chromatography and *in vitro* studies. J. Biochem. Molecular Toxicol. 14:320-328.

Li, Y. C., D. R. Ledoux, A. J. Bermudez, K. L. Fritsche, and **G. E. Rottinghaus.** 2000. The individual and combined effects of fumonisin B1 and moniliformin on performance and selected immune parameters in turkey poults. Poult. Sci. 79:871-878.

Mandon, E. C., I. Ehses, J. Rother, G. van Echten, and **R. J. Randall.** 1992. Subcellular localization and membrane topology of serine palmitoyltransferase, 3-dehydrosphinganine reductase, and sphinganine N-acyltransferase in mouse liver. J. Biol. Chem. 267: 11144-11148.

Marasas, W. F., T. S. Kellerman, W. C. Gelderblom, J. A. Coetzer, P. G. Thiel, and **J. J. van der Lugt.** 1988. Leukoencephalomalacia in a horse induced by fumonisin B1 isolated from *Fusarium moniliforme.* Onderstepoort J. Vet. Res. 55:197-203.

Mathias, S., L. A. Pena, and **R. N. Kolesnick.** 1998. Signal transduction of stress via ceramide. Biochem. J. 335:465-80.

Merrill, A. H., Jr., E. Wang, J. J. Schroeder, E. R. Smith, H. S. Yoo, and **R. T. Riley.** 1995. Disruption of sphingolipid metabolism in the toxicity and carcinogenicity of fumonisins. Pp. 429-443, *In* Molecular Approaches to Food Safety Issues Involving Toxic Microorganisms (M. Eklumd, J. Richard, and K. Mise, eds.) Alaken Press, Fort Collins, Colorado.

Morell, P. and **N. S. Radin.** 1970. Specificity in ceramide biosynthesis from long chain bases and various fatty acyl coenzyme A's by brain microsomes. J. Biol. Chem. 245: 342-350.

Narimatsu, S., S. Soeda, T. Tanaka, and **Y. Kishimoto.** 1986. Solubilization and partial characterization of fatty acyl-Coa:sphingosine acyltransferase (ceramide synthestase) from rat liver and brain. Biochim. Biophys. Acta 877: 334-341.

wkirk, D. K., R. W. Benson, P. C. Howard, M. I. Churchwell, D. R. Doerge, and D. W. Roberts. 1998. On-line immunoaffinity capture, coupled with HPLC and electrospray ionization mass spectrometry of automated determination of fumonisins. J. Agric. Food Chem. 46:1677-1688.

haafsma, A. W., J. D. Miller, M. E. Savard, and R. Ewing. 1993. Ear rot development and mycotoxin production in corn in relation to inoculation method and corn hybrid for three species of *Fusarium*. Can. J. Plant Pathol. 15:185-192.

ribney, M. 1966. Enzymatic synthesis of ceramides. Biochem. Biophys. Acta 125:542-547.

Shimeno, H., S. Soeda, M. Yasukouchi, N. Okamura, and A. Nagamatsu. 1995. Fatty acyl-Co A:sphingosine acytransferase in bovine mitochondria: its solubilization and reconstitution onto the membrane lipid microsomes. Biol. Pharm. Bull. 18:1335-1339.

Shimeno, H., S. Soeda, M. Sakamoto, T. Kouchi, T. Kowakame, and T. Kihara. 1998. Partial purification and characterization of sphingosine N-acyltransferase (ceramide synthase) from bovine mitochondrion-rich fraction. Lipids 33: 601-605.

Shirato, H., H. Shima, H. Nakagama, H. Fukuda, Y. Watanabe, K. Ogawa, Y. Matsuda, and K. Kikuchi. 2000. Expression in hepatomas and chromosomal localization of rat protein phosphatase 5 gene. Int. J. Oncol. 17:909-912.

Thiel, P. G., W. F. Marasas, E. W. Sydenham, G. S. Shephard, W. C. Gelderblom, and J. J. Nieuwenhuis. 1991. Survey of fumonisin production by *Fusarium* species. Appl. Environ. Microbiol. 57:1089-1093.

Tolleson, W. H., W. B. Melchior, Jr., S. M. Morris, L. J. McGarrity, O. E. Domon, L. Muskhelishvili, J. James, and P. C. Howard. 1999. Fumonisin B1 induces apoptosis in cultured human keratinocytes by sphinganine accumulation and ceramide depletion. Int. J. Cancer 14:833-843.

Yoo, H. S., W. P. Norred, J. Showker, R. T. and Riley. 1996. Elevated sphingoid bases and complex sphingolipid depletion as contributing factors in fumonisin-induced cytotoxicity. Toxicol. Appl. Pharmacol. 138:211-218.

Identification of Florida Largemouth Bass Alleles in Arkansas Public and Private Aquaculture Ponds

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Abstract

The Florida subspecies of the largemouth bass (LMB) has often been introduced into waters outside of its range, with escape of individuals into associated waterways common. Sustaining pure lines within controlled hatchery settings is also difficult. The present study investigated LMB populations by way of allozyme analysis of three diagnostic loci of 115 LMB in three public and seven private aquaculture ponds within Arkansas. The goal was to determine the success of hatcheries in maintaining pure subspecies. None of the pond populations studied were fixed for all alleles. Private ponds had northern LMB allele frequencies of up to 0.40 in putative Florida LMB ponds. State fish hatcheries had higher proportions of predicted alleles. Most bass surveyed were intergrades (63%).

Introduction

The Florida largemouth bass (*Micropterus salmoides floridanus*; FLMB) is one of two subspecies of largemouth bass and was considered to possess superior growth characteristics to the northern largemouth bass (*M. s. salmoides*, NLMB) {Addison and Spencer, 1971}. Its range has been greatly enhanced due to stocking, including northern U.S. waters. However, several studies have suggested countergradient variation for growth rates versus latitude (Inman et al., 1976; Cichra et al., 1980; Fields et al., 1987; Philipp and Whitt, 1991), prompting fisheries managers to predominantly stock FLMB in southern waters. As a result of these stockings, introgression of FLMB with native stocks of northern largemouth bass (*M. s. salmoides*; NLMB) has been prevalent (Philipp et al., 1983). The Arkansas Game and Fish Commission has been stocking FLMB in reservoirs since the mid-1970's (D. Brader, Manager, Andrew Hulsey State Fish Hatchery, pers. comm.). Consequently, many Arkansas reservoir bass populations contain FLMB alleles (Philipp et al., 1983; Dunham et al., 1993; Fulton, 1998). Most of these reservoirs are no longer stocked with FLMB (D. Brader, pers. comm.).

Maintenance of pure stock of largemouth bass (LMB) in controlled hatchery settings has proven difficult. Intraspecific contamination of broodstock in state hatcheries has been a common phenomenon (Philipp et al., 1983; Gilliland and Whittaker, 1989). Indeed, 70% of the FLMB at the Andrew Hulsey Fish Hatchery (Hot Springs, Arkansas) in 1988 were intergrades (D. Brader, pers. comm.). These findings resulted in ongoing genetic testing within the Hulsey State Fish Hatchery FLMB broodstock and the separation of subspecies between hatcheries. LMB stocked from other Arkansas state fish hatcheries were expectedly NLMB; however the genetic identity of the broodstock has never been verified (B. Beavers, Manager, Joe Hogan State Fish Hatchery, pers. comm.).

The objective of the present study was to evaluate the genetic purity of putative fixed LMB populations of public and commercial farm ponds in Arkansas using three diagnostic loci. Levels of introgression were determined from allelic combinations.

Study Sites.--LMB were obtained from three of the four state fish hatcheries maintained by the Arkansas Game and Fish Commission: the William H. Donham State Fish Hatchery (Corning, AR); Joe Hogan State Fish Hatchery (Lonoke, AR); and Andrew Hulsey State Fish Hatchery (Hot Springs, AR). The Hulsey Fish Hatchery is the only public hatchery in the state rearing FLMB, whereas the other two hatcheries rear and provided NLMB. The Hulsey Fish Hatchery stocked almost 500,000 fingerling FLMB into seven southern Arkansas reservoirs during the past year (B. Beavers, pers. comm.). The Hogan Fish Hatchery stocked almost 250,000 NLMB fingerlings into 24 Arkansas reservoirs, as compared to less that 30,000 NLMB fingerlings stocked into seven Arkansas reservoirs from the Donham Fish Hatchery. The fourth state fish hatchery (Centerton State Fish Hatchery) is located in northwest Arkansas (Centerton, AR). This hatchery stocked less than 30,000 NLMB fingerlings into three reservoirs, and was not included in the present study. Additionally, a commercial fish farm in east-central Arkansas provided LMB from seven ponds. Six of the seven ponds contained putative FLMB, and the seventh contained putative NLMB.

Methods

All specimens (n = 115) from the fish hatcheries were shipped live to Arkansas State University where they were stored at –70°C. Specimens ranged from approximately 3-[illegible] cm TL. Liver and muscle homogenates were electrophoresed on cellulose acetate plates (Helena Laboratories). The plates were stained for allozymes using the recipes of Hebert and Beaton (1989). Loci used to distinguish the LMB phenotypes (Gilliland, 1992) were isocitrate dehydrogenase (sIDHP-B, Enzyme Number 1.1.1.42) in Tris-Glycine (TG) buffer, aspartate aminotransferase (sAAT-B, 2.6.1.1) in TG buffer, and malate dehydrogenase (sMDH-B, 1.1.1.37) in Tris-Citrate buffer. Alleles are differentially fixed for the loci sIDHP-B and sAAT-B for both FLMB and NLMB. The two alleles of *sAAT-B**, which occur solely in FLMB, *sAAT-B*3* and *sAAT-B*4*, were combined, as were the two alleles solely occurring in NLMB, *sAAT-B*1* and *sAAT-B*2*, to clarify reporting within the goal of the study. Two alleles for *sMDH-B* (*1 and *2) occur in the NLMB, one of which (*sMDH-B*2*) is fixed for the FLMB.

Allele frequencies were determined for each locus. Individual LMB were designated as FLMB or NLMB if they were homozygous for all three loci specific for that subspecies, F_1 intergrades if they were heterozygous for each locus, and F_x if they had other allelic combinations. It should be noted that these designations are for communication and labeling purposes, since bass fixed for each of the three loci may be an intergrade (Johnson and Fulton, 1999).

Results

Ten (10) specimens from each pond, but Hulsey Hatchery (n = 25), were screened for products of the three diagnostic loci. None of the public or private LMB populations sampled were fixed for all alleles (Table 1). Allele frequencies from the seven private pond populations differed greatly from what would be expected of pure strains of LMB. The six ponds containing putative FLMB had NLMB allele frequencies of up to 0.65, with ranges typically from 0.30 to 0.40. Alleles of the sMDH-B locus were closest to the expected, although a confounding factor is that the NLMB also can possess the *sMDH*2* allele. The LMB of the Hulsey State Fish Hatchery were closest to being fixed for all alleles, with single individuals being heterozygous for the sIDH-B and sMDH-B loci. Allele frequencies of the bass for the Donham and Hogan State Fish Hatcheries were more variable than for those bass of Hulsey Hatchery, but less so than that found in the private pond populations.

Phenotypic results showed that most populations had a large number of F_x individuals. This was particularly true for the commercial pond populations which were predominated by F_x individuals (Table 2). Very few individuals were fixed for all alleles of these three diagnostic loci (x 16%; range of 0-40%). The private ponds 1-6 were putative FLMB, but fixation only ranged from 0-40%, and pond 7, putative NLMB, had 10% of individuals fixed for NLMB alleles. Among state fish hatcheries, the Donham and Hulsey Hatcheries had less than 50% of bass having a phenotype of F_x, whereas Hogan State Fish Hatchery bass had an F_x phenotype frequency of 90%. The Donham and

Table 1. Allele frequencies of sAAT-B, sIDH-B, s-MDH-B for largemouth bass populations found in seven commercial ponds, William H. Donham, Joe Hogan, and Andrew Hulsey State Fish Hatcheries.

Locus	Site									
Allele	Commercial Pond							State Fish Hatchery		
	1	2	3	4	5	6	7*	Donham*	Hogan*	Hulsey
sAAT-B										
sAAT-B*1&2	0.25	0.40	0.40	0.30	0.40	0.10	0.75	0.80	0.85	0.00
sAAT-B*3&4	0.75	0.60	0.60	0.70	0.60	0.91	0.25	0.20	0.15	1.00
sIDH-B										
sIDH-B*1	0.35	0.50	0.35	0.30	0.65	0.15	0.85	1.00	0.90	0.02
sIDH-B*3	0.65	0.50	0.65	0.70	0.35	0.85	0.15	0.00	0.10	0.98
sMDH-B										
sMDH-B*1	0.00	0.15	0.20	0.00	0.00	0.08	0.75	0.90	0.75	0.02
sMDH-B*2	1.00	0.85	0.80	1.00	1.00	0.92	0.25	0.10	0.25	0.98

*Putative NLMB populations

Table 2. Phenotypic frequencies for FLMB, NLMB, F_1 and F_x individuals at seven private hatchery ponds, Donham, Hogan, and Hulsey State Fish Hatcheries.

Location	NLMB	F_1	F_x	FLMB
	Phenotype			
Pond 1	0 (0%)	0 (0%)	7 (70%)	3 (30%)
Pond 2	0 (0%)	1 (10%)	9 (90%)	0 (0%)
Pond 3	0 (0%)	1 (10%)	7 (70%)	2 (20%)
Pond 4	0 (0%)	0 (0%)	9 (90%)	1 (10%)
Pond 5	0 (0%)	0 (0%)	10 (100%)	0 (0%)
Pond 6	0 (0%)	0 (0%)	6 (60%)	4 (40%)
Pond 7	1 (10%)	0 (0%)	9 (90%)	0 (0%)
Donham	7 (70%)	0 (0%)	3 (30%)	0 (0%)
Hogan	1 (10%)	0 (0%)	9 (90%)	0 (0%)
Hulsey	0 (0%)	0 (0%)	2 (8%)	23 (92%)

Hogan State Fish Hatcheries were putative NLMB. The Donham Hatchery bass did possess a 70% fixed NLMB population, but the Hogan Hatchery possessed only a single individual designated as NLMB. Conversely, the bass originating from the Hulsey State Fish Hatchery were mostly fixed for FLMB alleles (92%).

Discussion

It was not the intent of this study to provide an in-depth assessment of the allelic and phenotypic frequencies of these bass populations. Rather, the goal of this study was to determine if genetic contamination of breeding stocks had occurred. Despite periodic genetic screening, the Hulsey Hatchery bass possessed NLMB alleles. The two state fish hatcheries without a genetic screening program for bass (Hogan and Donham) had greater allelic contamination. Florida bass alleles were common in both hatchery populations, resulting in a high degree of introgression. FLMB from Hulsey Hatchery are stocked in selected southern Arkansas reservoirs, whereas bass from Hogan and Donham State Fish Hatcheries are shipped throughout the state. Bass from the private fish farm are represented and sold commercially as FLMB. Introgression was particularly high within these populations (84%). These bass can legally be stocked in private ponds throughout the state. Although illegal, bass are often transported to other waterways by anglers (S. Barkley, Arkansas Game and Fish Commission, pers. comm.). Thus, alleles from these sources can potentially enter public water systems.

There is great concern about the long-term effects of diluting native coadapted gene complexes of NLMB with genes from Florida stocks, and about the ability of FLMB and intergrades between FLMB and NLMB to survive and thrive in northern waters (Philipp, 1992). Many studies have focused on differential growth parameters and thermal tolerance of the two subspecies and their intergrades (e.g., Inman et al., 1976; Cichra et al., 1980; Fields et al., 1987). Although differential growth and survival have been identified for NLMB and FLMB when they co-exist in temperate waters (Fields et al., 1987; Philipp and Whitt, 1991), no significant differences were identified in a northern Arkansas bass population containing alleles of both subspecies (Johnson and Fulton, 1999). Nonetheless, once exogenous alleles enter a system they may have long term effects (Philipp, 1992).

The cause for concern may be lessened for a non-native species introduced into an artificial system such as a reservoir. However, of perhaps greater concern is the potential effect of escaped individuals into surrounding lotic waters. Annual stockings of up to 750,000 LMB annually within 41 reservoirs (B. Beavers, pers. comm.) provides great opportunity for the spread of exogenous alleles. Water levels of many of these reservoirs are maintained by pumping water out of and in to adjacent streams, which can lead to genetic contamination of native riverine stocks. Exogenous alleles have been detected in native LMB populations of Oklahoma (Gelwick et al., 1995) and Alabama (Dunham et al., 1992). This potential of escape behooves fisheries managers to develop not only long-term management plans but also containment strategies for the stocking of FLMB and other introduced species.

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Literature Cited

Addison, J. H. and **S. L. Spencer.** 1971. Preliminary evaluation of three strains of largemouth bass, *Micropterus salmoides* (Lacepede), stocked in ponds in south. Proc. Southeast. Assoc. Game Fish Comm. 25:366-374.

Cichra, C. E., W. H. Neil, and **R. L. Noble**. 1980. Differential resistance of northern and Florida largemouth bass to cold shock. Proc. Ann. Conf. Southeast. Assoc. Fish Wild. Agencies 43:36-40.

Dunham, R. A., C. J. Turner, and **W. C. Reeves**. 1992. Introgression of the Florida largemouth bass genome into native populations in Alabama public lakes. N. Am. J. Fish. Mgmt. 12:494-498.

Dunham, R. A., L. Robison, and **J. DiBona.** 1993. Biochemical genetics of largemouth bass in Arkansas. Ark. Game Fish Comm. Rep. F-47.

Fields, R., S. S. Lowe, C. Kaminski, G. S. Whitt, and **D. P. Philipp**. 1987. Critical and chronic thermal maxima of northern and Florida largemouth bass and their reciprocal F_1 and F_2 hybrids. Trans. Am. Fish. Soc. 116:856-863.

Fulton, W. T. 1998. Genotype, growth, condition and health of largemouth bass (*Micropterus salmoides*) in Lakes Ashbaugh and SWEPCO, Arkansas. Thesis, Arkansas State University, Jonesboro, Arkansas. 123 pp.

Gelwick, F. P., E. R. Gilliland, and **W. J. Matthews.** 1995. Introgression of the Florida largemouth bass genome into stream populations of northern largemouth bass in Oklahoma. Trans. Am. Fish. Soc. 124(4):550-563.

Gilliland, E. R. 1992. Experimental stocking of Florida largemouth bass into small Oklahoma reservoirs. Proc. Ann. Conf. Southeast. Assoc. Fish Wild. Agencies 46:487-494.

Gilliland, E. R. and **J. Whittaker.** 1989. Introgression of Florida largemouth bass introduced into northern largemouth bass populations in Oklahoma reservoirs. Proc. Ann.Conf. Southeast. Assoc. Fish Wild. Agencies 39:56-64.

Hebert, P. D. N. and **M. J. Beaton.** 1989. Methodologies for allozyme analysis using cellulose acetate electrophoresis. Helena Laboratories, Beaumont, Texas. 32 pp.

Inman, C. R., R. C. Dewey, and **P. P. Durocher** 1976. Growth comparisons and catchability of three largemouth bass strains. Proc. Ann. Conf. Southeast. Assoc. Fish Wild. Agencies 30:40-47.

Johnson, R. L. and **W. T. Fulton.** 1999. Persistence of Florida largemouth bass alleles in a northern Arkansas population of largemouth bass, *Micropterus salmoides* Lacepede. Ecol. Fresh. Fish 8:35-42.

Philipp, D. P. 1992. Stocking Florida largemouth bass outside its native range. Trans. Am. Fish. Soc. 121:686-691.

Philipp, D. P., W. F. Childers, and **W. F. Whitt.** 1983. A biochemical genetic evaluation of the northern and Florida subspecies of largemouth bass. Trans. Am. Fish Soc. 112:1-20.

Philipp, D. P. and **W. F. Whitt.** 1991. Survival and growth of northern, Florida, and reciprocal F_1 hybrid largemouth bass in central Illinois. Trans. Am. Fish. Soc. 120:58-64.

Bedrock Geology and Sea-Level History of Fayetteville Quadrangle, Washington County, Arkansas

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Abstract

A digital map depicting the detailed bedrock geology of Fayetteville Quadrangle, Washington County, Arkansas was produced at 1:24,000 scale. This map was developed utilizing state-of-the-art Geographic Information Systems technology and represents the most detailed map of the geology of Fayetteville Quadrangle that has been produced. In addition, the stratigraphy was interpreted to develop a regional sea-level history for the quadrangle.

The bedrock geology of Fayetteville Quadrangle consists of sedimentary rocks of the Mississippian and Pennsylvanian systems. The Mississippian System is represented by (in ascending order) the Boone, Batesville, Fayetteville, and Pitkin Formations. The Pennsylvanian System is represented by (in ascending order) the Hale, Bloyd, and Atoka Formations. Each of these formations has members that were mapped at 1:24,000 scale, with the exception of the Hindsville Member of the Batesville Formation. Depositional environments represented by Fayetteville Quadrangle strata range from shallow marine to terrestrial and were interpreted to reflect the interplay of tectonics and eustasy during the Mississippian-Pennsylvanian Periods. Analysis of the apparent tempo and amplitude of sea-level variations suggests tectonic processes dominated over eustatic processes during these times. Within Fayetteville Quadrangle there are also several geologic structures that deserve further investigation. These structures include faults, fractures, domes, and so-called collapse or subsidence structures.

Introduction

Fayetteville Quadrangle (Fig. 1) is located in Washington County, Arkansas, and is named for the city of Fayetteville, which occupies the northeast portion of the quadrangle. The quadrangle boundaries are 36°00.0'N 94°15.0'W (southwest), 36°07.5'N 94°15.0'W (northwest), 36°07.5'N 94°07.5'W (northeast), and 36°00.0'N 94°07.5'W (southeast).

The Carboniferous geology of the southern Ozark region has attracted worldwide interest because of exposures of the Morrowan Series at the base of the Pennsylvanian System and for the excellent outcrops of fossiliferous strata in proximity to the Mississippian-Pennsylvanian boundary (Frezon and Glick, 1959; Manger and Sutherland, 1984; McFarland, 1998). The geologic history and depositional dynamics of this interval continue to attract the attention of the geologic community as a means of investigating the interplay of tectonics and eustasy in the development of continental margin and foreland basin sequences (Houseknecht, 1986; Viele, 1989; Ethington et al., 1989; Viele and Thomas, 1989; Handford and Manger, 1990; 1993; Hudson, 2000). The section continues to serve as the training ground for students at the University of

Fig. 1. Location map of Arkansas showing Washington County (shaded) and Fayetteville Quadrangle (white inset) in Washington County.

Arkansas as they prepare for employment in the petroleum industry (most recently in theses by Valek, 1999; M. King, 2001, J. King, 2001; Combs, 2001; Cooper, 2001; Anderson, 2001). Despite continued interest in the Carboniferous stratigraphy of northern Arkansas, there has been no mapping of the Carboniferous geology of this region since thesis work undertaken in the late 1950's and early 1960's (Pohlo, 1958; Neumeier, 1959; Wainwright, 1961; Cate, 1962; Vest, 1962; Carr, 1963) at the University of Arkansas and during preparation of the revised *Geologic Map of Arkansas* by Haley et al. (1976).

With the advent of satellite positioning services, advanced digital technologies, and Geographic Information Systems during the last decade, it is now possible to develop highly detailed geologic maps from field data with locations determined using the Global Positioning System (GPS) and transferred to digital mapping programs. Development of geologic maps in digital formats permits relatively easy manipulation of these data and their export to a variety of software platforms where they can be modified or adapted for many community planning projects.

Thus, detailed mapping of the geology of Fayetteville Quadrangle is relevant not only for its scientific value but also as an aid to development of the Fayetteville area by providing knowledge of the geology and spatial distribution of various strata.

Materials and Methods

Field mapping of Fayetteville Quadrangle was conducted throughout the summer of 2000. Global Positioning System receivers were used to determine locations of 482-field sites where stratigraphic units, formation or member boundaries, or geologic structures were observed in outcrop. A Garmin Etrex Summit GPS receiver with a built in barometric pressure gauge was used in conjunction with a paper topographic map to determine elevation of outcrops located in steep terrains. In the areas of low elevation where outcrops were difficult to observe, a two-meter Dutch augur was used to penetrate the ground and recover samples of weathered rock for stratigraphic identification.

All field locations and observations were sketched onto a 1:24,000 scale topographic map in the field, logged into the field book, and later digitized using Geographic Information System software (MapInfo version 5.0). Geology was transferred from the field map to a Digital Raster Graphic (DRG) of Fayetteville Quadrangle using a "heads-up" digitizing method. Using this method, geologic contacts were drawn directly on the computer screen by moving the cursor over a digital raster graphic (DRG) of Fayetteville Quadrangle and clicking the mouse button at short intervals to trace contacts onto the displayed topography (Sullivan, 1999). Each stratigraphic unit was digitized as a separate layer within the geographic information system such that the display of each layer could be toggled on or off. Faults were digitized as lines onto a separate layer as well. Once all stratigraphic units and geologic structures were digitized, map layers representing those stratigraphic units and geologic structures could be displayed hierarchically to generate the geologic map of the study area (Figs. 2, 3). A legend for the map is presented as Fig. 4. The final step in preparing the digital geologic map was to convert all data layers to several digital formats to ensure compatibility with popular GIS applications. Digital formats produced for this study were 1) MapInfo native format, 2) ArcView shape files, and 3) AutoCad DXF. All data were archived on CD-ROM.

Results

Lithostratigraphy of the Mississippian System.--In the Fayetteville Quadrangle, the Mississippian System is represented by, in ascending order, the Boone Formation, the Batesville Formation, the Fayetteville Formation, and the Pitkin Formation (Simonds, 1891; Adams and Ulrich, 1904, 1905; Purdue, 1907; Croneis, 1930; Frezon and Glick, 1959; Haley et al., 1976; McFarland, 1998). The Mississippian System composes the majority of the surface area of Fayetteville Quadrangle (Figs. 2, 3). Each formation of the Mississippian System contains marine fossils, thus indicating marine depositional environments throughout this portion of the stratigraphic succession.

The Boone Formation is a fossiliferous limestone containing abundant chert, especially in its upper interval (Simonds, 1891; Shelby, 1986; Sullivan, 1999). The Boone Formation represents marine deposition on a relatively shallow (5–50 m deep) continental shelf or ramp. The Boone Formation forms bedrock over 16.5% of Fayetteville Quadrangle.

The Batesville Formation rests unconformably on the upper, eroded surface of the Boone Formation (Simonds, 1891; Haley et al., 1976; McFarland, 1998). The Batesville Formation in Fayetteville Quadrangle is sandstone or (less commonly) sandy limestone (Hindsville Member) (Handford and Manger, 1990; 1993) and has a distinctive basal breccia containing angular to sub-angular chert pebbles derived from erosion and weathering of the underlying Boone Formation (McFarland, 1998). Throughout Fayetteville Quadrangle, the Batesville Formation weathers quickly and forms flat areas or areas of gentle slope (outcrops are rare). The Batesville Formation and its weathered equivalent forms the surface of 14.7% of Fayetteville Quadrangle, primarily in the northwest quadrant.

The Fayetteville Formation is a black to dark gray, organic-rich, fissile shale (Simonds, 1891). The Fayetteville Formation is subdivided into two informally named strati-

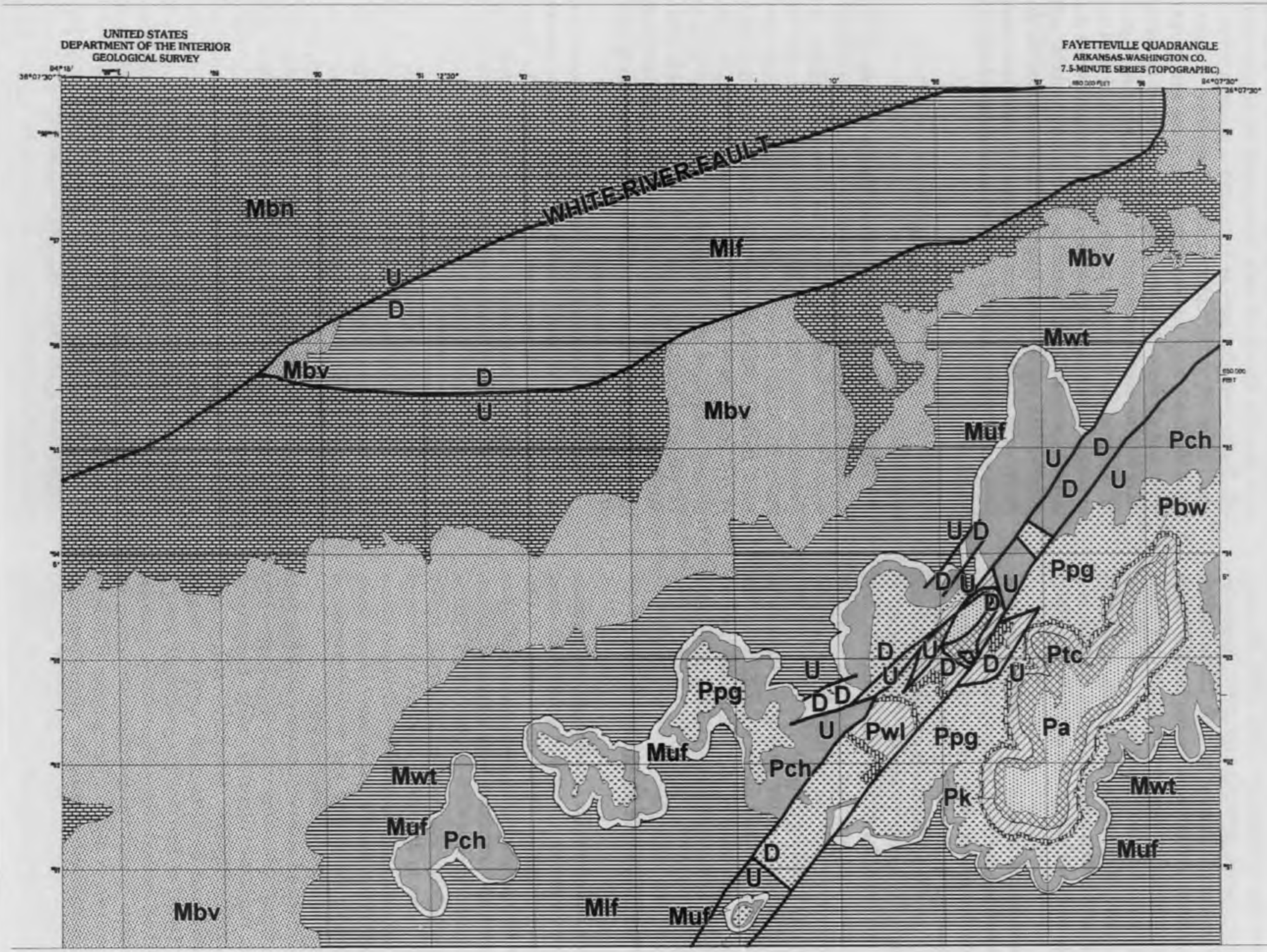

Fig. 2 Map showing bedrock geology of the northern half of Fayetteville Quadrangle digitized onto Fayetteville Quadrangle 7.5-minute digital raster graphic (DRG). Overlying grid is Universal Transverse Mercator (UTM)in 1-km intervals.

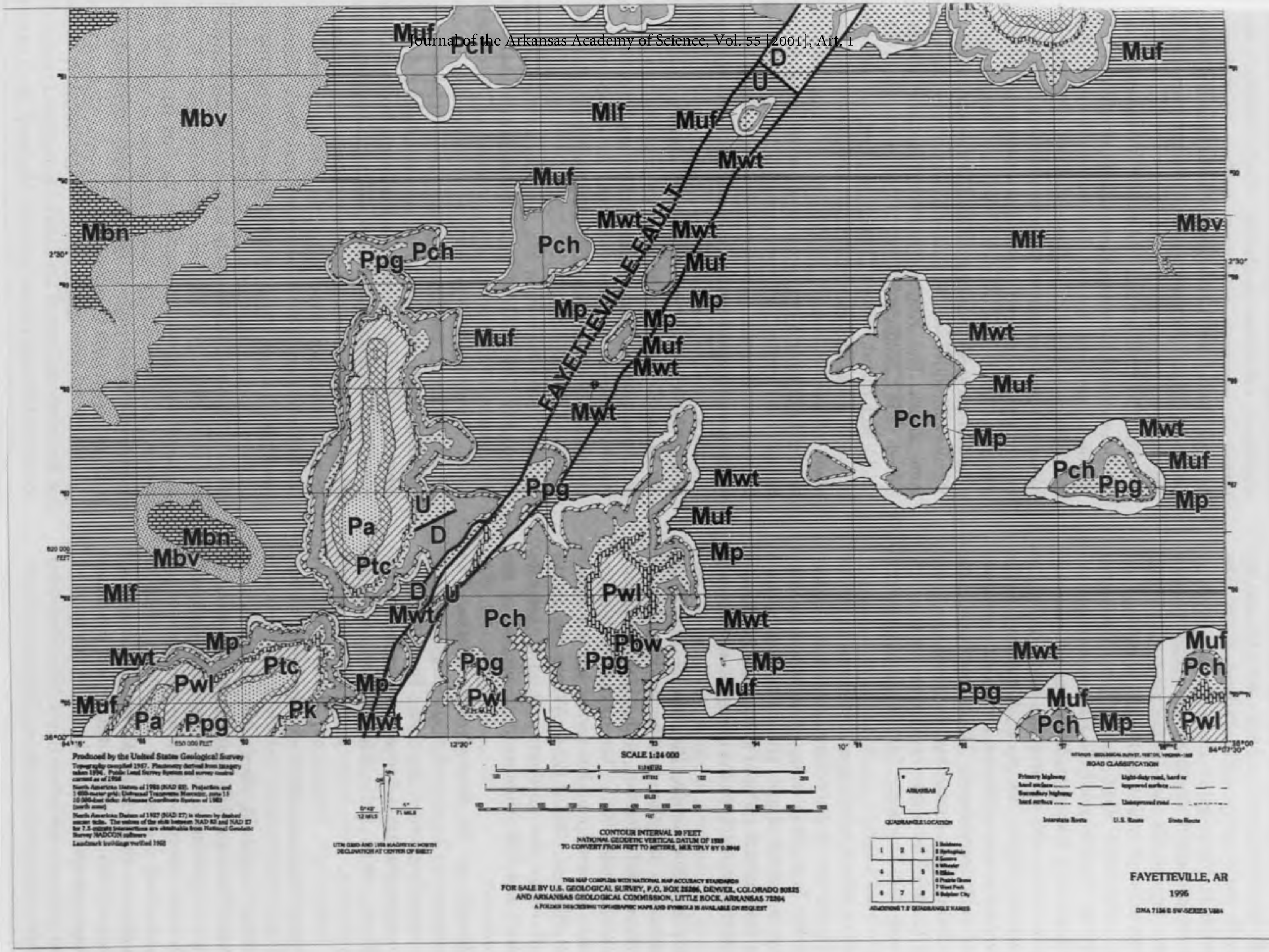

Fig. 3 Map showing bedrock geology of the southern half of Fayetteville Quadrangle digitized onto Fayetteville Quadrangle 7.5-minute digital raster graphic (DRG).

graphic units and one formal member: lower Fayetteville shale (informal), the Wedington Sandstone (formal), and the upper Fayetteville shale (informal)(McFarland, 1998). The lower Fayetteville is black fissile shale characterized by abundant siderite-cemented septarian concretions at its base. The lower Fayetteville shale is the most widely outcropping stratum in Fayetteville Quadrangle, occurring over 45.5% of the quadrangle (Figs. 2, 3). The Wedington Sandstone Member of the Fayetteville Formation is typically tan to gray, hard, very fine to medium grained, siliceous, crossbedded sandstone with an average thickness of 1.5 meters (McFarland, 1998). In some locations of the Wedington Sandstone, a fossiliferous limestone comprises the upper three to six centimeters. The upper Fayetteville shale is black, fissile shale, containing abundant small iron concretions (< 20 cm). The upper Fayetteville shale weathers quickly to soft clay. The upper Fayetteville shale occurs over 4.7% of the quadrangle.

The Pitkin Formation is the uppermost formation of the Mississippian System in Fayetteville Quadrangle (Easton, 1942; Tehan, 1976). Typically, it is an oolitic, bioclastic limestone obviously of marine origin. The Pitkin Formation is present only in the southern half of Fayetteville Quadrangle (Figs. 2, 3), occurring in outcrops over only 1% of the quadrangle.

In Fayetteville Quadrangle, the top of the Pitkin Formation is erosional and therefore unconformable with the overlying Cane Hill Member of the Hale Formation (McFarland, 1998; Tehan, 1976). This unconformable contact is also the Mississippian–Pennsylvanian boundary (Handford and Manger, 1990; 1993). Where the Pitkin Formation is absent in the northern part of Fayetteville Quadrangle, the Cane Hill Member rests directly on the Fayetteville Formation.

Lithostratigraphy of the Pennsylvanian System.--The Pennsylvanian System in Fayetteville Quadrangle is represented by, in ascending order, the Hale Formation, the Bloyd Formation, and the Atoka Formation (Simonds, 1891; Adams and Ulrich, 1904; 1905; Purdue, 1907; Croneis, 1930; Frezon and Glick, 1959; Haley et al., 1976; Handford and Manger, 1990; 1993; McFarland, 1998). The Hale Formation is comprised of two members; the lower portion is named the Cane Hill Member, and the upper portion is termed the Prairie Grove Member (Adams and Ulrich, 1905; Cate, 1962). The Cane Hill Member is comprised of several lithologic components: a basal tan, very thin-bedded, medium grained, siliceous/calcareous sandstone or calcareous conglomerate containing limestone pebbles reworked from the underlying Pitkin Formation; alternating very thin-bedded (< 0.15 m thick) siltstone and sandstone layers, often ripple-marked; and thick, tan, ripple-marked, medium grained, siliceous sandstone (Cate, 1962; Handford and Manger, 1990; 1993; M. King, 2001). The Prairie Grove Member of the Hale Formation is a tan to dark brown, thick-bedded, fine to coarse grained, fossiliferous (crinoid stems abundant), calcareous sandstone, which exhibits a characteristic honeycomb weathered surface (Handford and Manger, 1990; 1993). Large-scale cross bedding was also observed. Hale Formation strata occur over 13.5% of Fayetteville Quadrangle (Figs. 2, 3).

The Bloyd Formation consists of (in ascending order) the Brentwood Limestone Member, the Woolsey-Dye Shale Member, and the Kessler Limestone Member (Purdue, 1907; Haley et al., 1976; McFarland, 1998). The Brentwood Member is well-indurated, cross bedded limestone containing quartz sand and occasional bryozoan bioherms (Hoaster, 1996). The overlying Woolsey Member is composed of greenish gray silty shale (McFarland, 1998). The Woolsey Member weathers rapidly, forming gentle to moderate slopes. The Woolsey Member contains a coal bed called the Baldwin Coal (approximately 0.2 m thick)(McFarland, 1998). This coal bed is widespread throughout Fayetteville Quadrangle and serves as a convenient marker horizon (M. King, 2001; J. King, 2001). The Kessler Limestone Member can be observed in several locations in the Fayetteville Quadrangle (Figs. 2, 3). The Kessler Limestone Member weathers to a dull tan to brown, crumbly surface and freshly broken clasts of this rock usually emit a smell of petroleum distillates. In some areas the Kessler Limestone Member contains abundant sand. The top of the Kessler Limestone, when exposed in a roadcut, has a phosphatic, conglomerate surface marking the unconformity between the Morrowan and Atokan Series (Cate, 1962). Strata of the Bloyd Formation occur over 3% of Fayetteville Quadrangle.

The Atoka Formation is a sequence of marine mostly tan to gray silty sandstones and grayish-black shales (Taff and Adams, 1900; Henbest, 1953; McFarland, 1998; Valek, 1999). In Fayetteville Quadrangle, the lowermost member of the Atoka is the Trace Creek Shale. It rests unconformably on the Kessler Limestone Member of the Bloyd Formation. The Trace Creek Shale is black, fissile shale with some thin beds of sandstone. This is a marine shale (Henbest, 1953). The unit is rarely observed in outcrop but forms a moderate slope below the first sandstone of the Atoka Formation. Above the Trace Creek Shale Member, a sandstone unit of the Atoka Formation forms prominent bluffs and caps a few mountains in Fayetteville Quadrangle (Figs. 2, 3). Atoka sandstone in Fayetteville Quadrangle is a fine to medium grained, hard, sandstone, which is somewhat resistant to weathering. Only the first sandstone layer above the Trace Creek Shale Member is observed in Fayetteville Quadrangle. Atoka Formation rocks occur over 1.9% of Fayetteville Quadrangle.

Structural Geology.--Fayetteville Quadrangle is situated on the southern flank of the Ozark Dome that is centered in southeast Missouri (Croneis, 1930). Regional dip is generally less than 5° to the south. Fractures can be easily observed

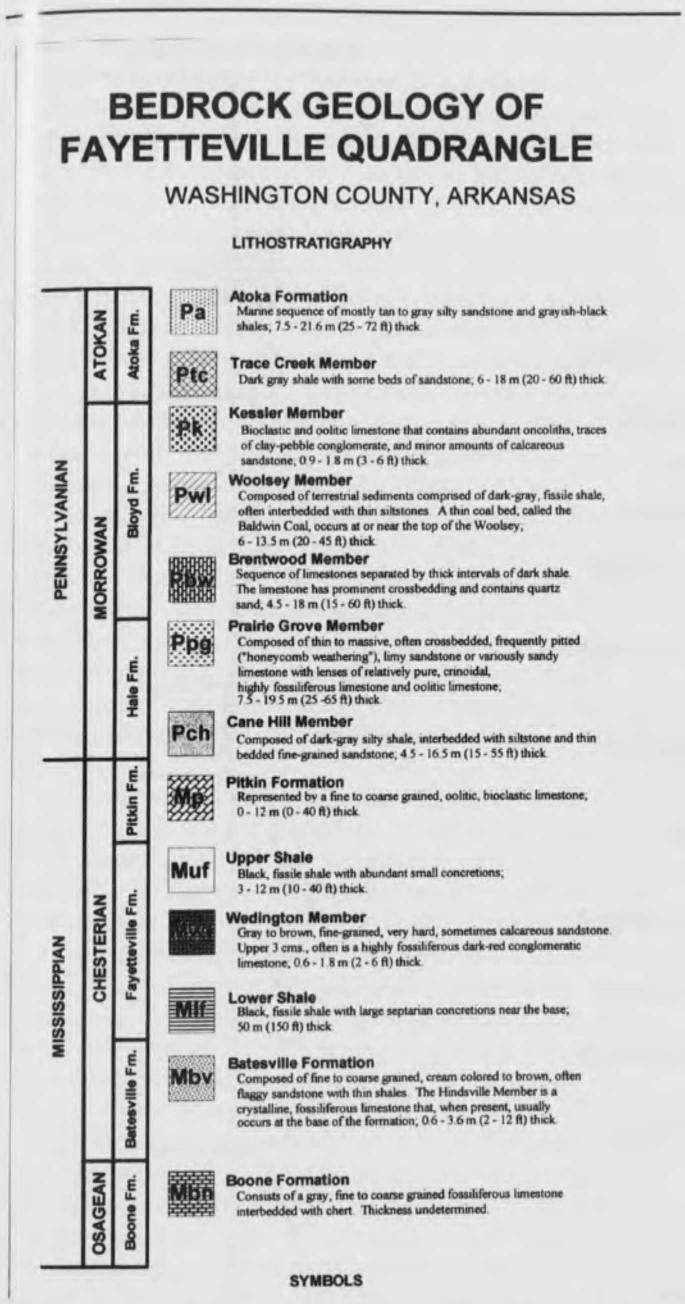

Fig. 4. Legend to accompany geologic map of Fayetteville Quadrangle (Figs. 2, 3).

in outcrops of all ages, and these fractures are believed to result from brittle deformation related to flexure of the Ozark Plateaus and formation of the Ozark Dome during the Ouachita orogeny (Viele, 1989; Viele and Thomas, 1989; Hudson, 2000). Two major faults traverse the Fayetteville Quadrangle. They are the Fayetteville Fault and the White River Fault (Croneis, 1930)(Figs. 2, 3).

The Fayetteville Fault crosses Fayetteville Quadrangle SW-NE (Figs. 2, 3) and through the center of the city of Fayetteville. The strike of the Fayetteville Fault is N30°E. The Fayetteville Fault has at least one prominent branch fault (Figs. 2, 3) and an undetermined number of smaller related branch faults. The Fayetteville Fault is a normal fault, downthrown toward the southeast. Total displacement on the Fayetteville Fault is not known but appears to be approximately 35 m (M. King, 2001).

The White River Fault strikes N65°E through the northern quarter of Fayetteville Quadrangle. The White River Fault has a significant branch on its south side and forms a prominent graben in northern Fayetteville (Fig. 2). The White River Fault is also a normal fault, downthrown to the south. Total displacement on this fault was estimated to be approximately 20 m because a construction site in north Fayetteville revealed the trace of the fault and showed the Boone Formation juxtaposed with upper Fayetteville Formation strata (M. King, 2001).

One small domed structure was discovered and mapped two kilometers south of the town of Farmington, Arkansas (southwest corner of Fig. 3). The Boone Formation crops out at the surface core of the dome and is surrounded by eroded outcrops of both the Batesville Formation and the lower shale of the Fayetteville Formation (Fig. 3). Whether the origin of this dome is structural or depositional is not known. However, localized mounds (either small bioherms or olistoliths) are well documented in the Boone Formation (Manger and Thompson, 1982; Shelby, 1986), and it seems most probable that this dome is the surface expression of a mound in the Boone Formation on top of which sediments of the Batesville Formation and Fayetteville Formation were draped, displaying quaquaversal dips similar to those observed across Silurian reefs of the northern midcontinent (Heckel and O'Brien, 1975).

Where faulting is most complex in Fayetteville Quadrangle, so called collapse or subsidence structures (Quinn, 1963) have formed. These structures are enigmatic, though the prevailing consensus regarding their formation suggests they result from dissolution and collapse of underlying limestone units.

Discussion

Regional Sea-Level History.--The stratigraphy of Fayetteville Quadrangle is composed of alternating lithologies (limestone, shale, sandstone) in genetically related packages bound by prominent regional unconformities. These depositional sequences represent the response of the sedimentary system of northwest Arkansas to fluctuating relative sea-level (i.e., combined effects of tectonics and eustasy) during the late Mississippian and Pennsylvanian Periods. The stratigraphic succession illustrated in Figure 5 indicates the major unconformities marking the Osagean-Chesterian boundary, Chesterian-Morrowan (Mississippian-

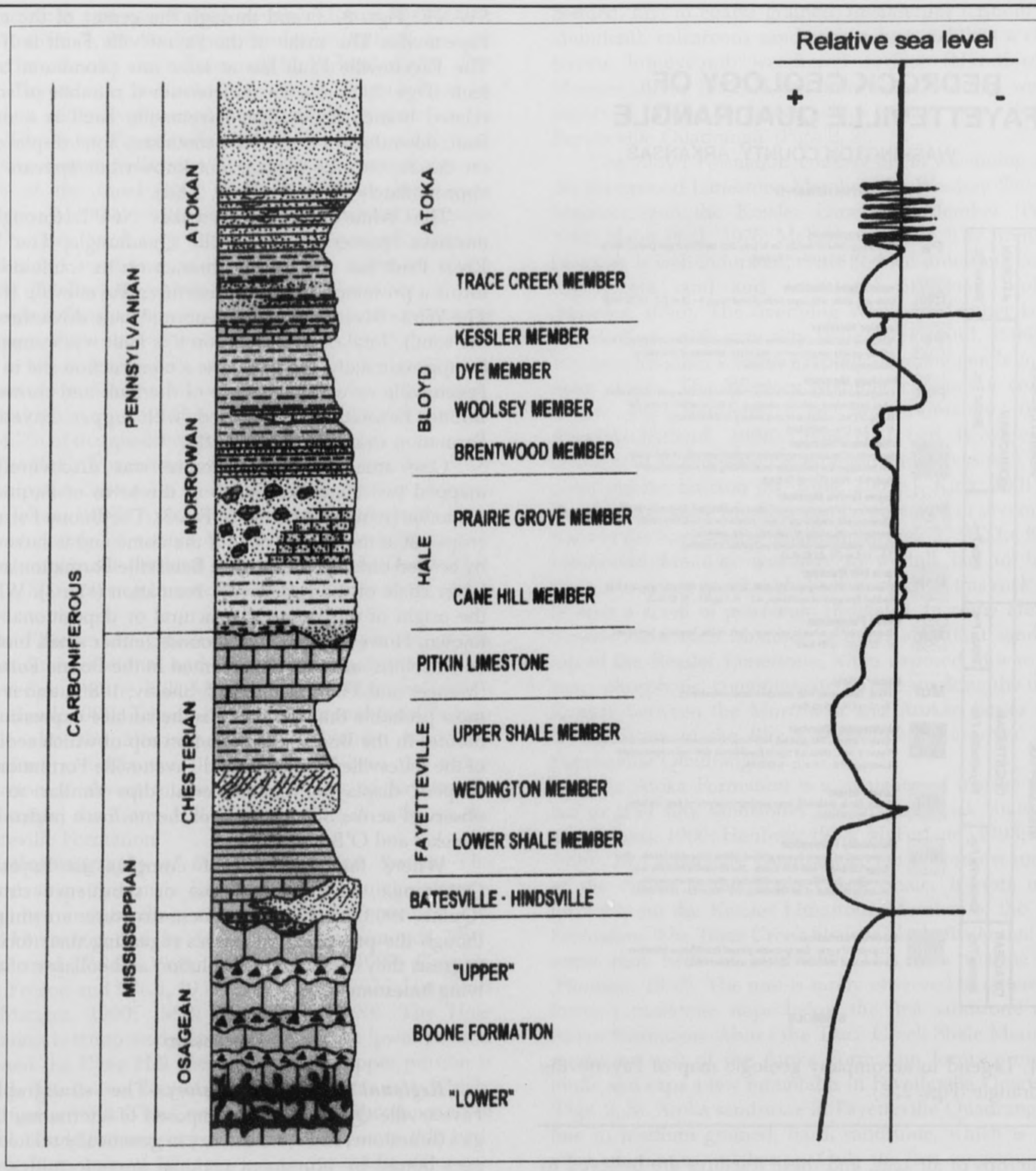

Fig. 5. Lithostratigraphy and interpreted sea-level history of Fayetteville Quadrangle, Washington County, Arkansas (adapted from Brown, 2000; M. King, 2001). King et al., Fig. 1.

Pennsylvanian) boundary, and Morrowan-Atokan boundary. The sedimentary facies of strata exposed throughout Fayetteville Quadrangle have been interpreted in the context of relative sea level in order to generate the relative sea-level curve (Fig. 5).

The Mississippian (Osagean) Boone Formation is limestone that clearly represents relatively shallow marine conditions. The occurrence of oolitic limestone near the top of the Boone Formation in some areas suggests water depths no greater than 5–8 m (Shelby, 1986). Following deposition of the Boone Formation, the shallow seas apparently retreated from the area for some time as the upper surface of the Boone Formation displays evidence of subaerial exposure and karstification. This subaerial exposure surface represents the Osagean-Chesterian boundary. Weathering of the Boone Formation during this interval produced a residuum of chert pebbles that were incorporated into the basal deposits of the (Chesterian) Batesville Formation during the ensuing transgression (McFarland, 1998). Batesville Formation sandstones are interpreted to represent deltaic or nearshore sand, but were definitely deposited under marine conditions (Manger and Sutherland, 1984).

Transgression and relative sea-level rise continued through the Chesterian with deposition of the lower Fayetteville shale of the Fayetteville Formation. Deposition of shale implies deeper, quiet water conditions. Though the lower Fayetteville shale contains appreciable organic matter (septarian concretions often contain hydrocarbons), the water column was apparently well oxygenated because ammonoid fossils (nektonic organisms) are abundant in the shale.

A minor regressive event within the Chesterian is represented by the abrupt transition from lower Fayetteville shale to sandstone of the Wedington Member of the Fayetteville Formation. The depositional environment of the Wedington Member appears to be fluvial/deltaic based on the occurrence of medium to fine grained sand that is often cross bedded (Manger and Sutherland, 1984). Fluvial/deltaic deposition appears to have ended abruptly as relative sea level rose once more, depositing a thin layer (0.05 m-0.10 m thick) of brachiopod-rich limestone across the top of the Wedington sandstone.

As relative sea level continued to rise, the upper shale of the Fayetteville Formation was deposited. This unit has higher silt content than the lower Fayetteville shale, indicating either eolian transport (Cate, 1962), relatively shallower water than the lower Fayetteville shale, or a closer sediment source. Finally, the Chesterian interval is capped by deposition of marine limestone of the Pitkin Formation (Tehan, 1976). The Pitkin Formation appears to be conformable on the Fayetteville Formation (McFarland, 1998) and represents a shallow-marine inner shelf environment (Easton, 1942; Tehan, 1976; Handford and Manger, 1990). The top of the Pitkin Formation was subaerially exposed and forms the Chesterian-Morrowan (Mississippian-Pennsylvanian) boundary. In the northern half of Fayetteville Quadrangle, the Pitkin Formation was completely eroded to the Fayetteville Formation, suggesting an up-ramp situation. This is the major relative sea-level event recorded by Fayetteville Quadrangle strata, and it has been a topic of great interest to the geologic community throughout the world.

The Pennsylvanian (Morrowan) Cane Hill Member of the Hale Formation was deposited on the Mississippian-Pennsylvanian unconformity at the top of the Pitkin Formation. Basal deposits of the Cane Hill Member contain clay pebbles and limestone clasts reworked from the underlying Pitkin Formation. Much of the Cane Hill Member appears to have been deposited very near sea level because thinly layered shale, siltstone, and sandstone indicate a tidal flat depositional setting (Cate, 1962; Handford and Manger, 1990; 1993; M. King, 2001) (Fig. 5). Continued transgression of the Fayetteville area during earliest Pennsylvanian time resulted in deposition of the Prairie Grove Member (Hale Formation), a more massive sandstone with larger-scale cross bedding indicative of tide-dominated channels or shallow shelf settings dominated by longshore currents. Deepening relative sea level ultimately resulted in deposition of shale conformably on top of the Prairie Grove Member, and this shale marks the basal deposit of the Bloyd Formation (McFarland, 1998).

The (Morrowan) Bloyd Formation is subdivided into the Brentwood Member, the Woolsey-Dye Shale Member, and the Kessler Member (Purdue, 1907; Haley et al., 1976; McFarland, 1998). The Brentwood Member represents continued transgression but is interrupted by several minor regressive/transgressive intervals presumably caused by glacio-eustatic processes (McGilvery, 1982). Deposition of the Brentwood Member appears to terminate with development of an unconformity separating clearly marine deposits (bryozoan-bearing limestone and green shale) from clay deposits of the Woolsey Member, which appears to have been deposited in a marine-marginal terrestrial environment (McFarland, 1998). The Woolsey Member contains abundant fossils of plant fragments and also hosts a thin (0.2 m thick) coal bed known as the Baldwin Coal. This coal bed occurs throughout Fayetteville Quadrangle and represents marine-marginal swamp environments. The Kessler Member of the Bloyd Formation in Fayetteville Quadrangle is a bioclastic and oolitic marine limestone representing transgression over the Woolsey Member (McFarland, 1998). The top of the Kessler Member exhibits a phosphatic conglomerate, indicative of regression and subaerial exposure. This conglomerate represents an unconformity developed between the Bloyd Formation (Morrowan) and the Atoka Formation (Atokan).

Only the basal portion of the Atoka Formation is exposed in Fayetteville Quadrangle. The Trace Creek Member of the Atoka Formation is the first member of the formation and represents marine transgression of the Morrowan-Atokan unconformity (Henbest, 1953). An unnamed sandstone layer above the Trace Creek Member represents the highest stratigraphic level of the Atoka Formation in Fayetteville Quadrangle (Fig. 4).

The strata exposed in Fayetteville Quadrangle record relative sea-level changes over an interval of at least 40 million years (Ethington et al., 1989). The most prominent unconformities are found at the contacts of the Boone Formation-Batesville Formation, the Pitkin Formation-Hale Formation, and the Bloyd Formation-Atoka Formation. These unconformities appear to represent time intervals on the order of 10 million years, 7 million years, and 4 million years, respectively (Ethington et al. 1989), or 52.5% of the total depositional interval. Thus, if one takes into account other minor unconformities that may occur within some units (e.g. Brentwood Member of the Bloyd Formation), it is conceivable that the stratigraphic succession in Fayetteville Quadrangle represents as little as 25% to 30% of the total time interval; the remainder of the interval would be represented by the unconformities. Clearly, the stratigraphic succession in Fayetteville Quadrangle reflects relative sea-level oscillations driven by the interplay of tectonics and eustasy. The dominance of either tectonic or eustatic processes in controlling sea level cannot be definitively assessed based on available data. However, the relatively prolonged interval of emergence indicated by the regional unconformities (Boone Fm.–Batesville Fm. contact, Pitkin Fm.–Hale Fm. contact, Bloyd Fm.–Atoka Fm. contact) is suggestive of a tectonically modulated sea-level process. In addition, the relative amplitude of sea-level variation indicated by the different sedimentary facies developed in the stratigraphic succession is probably rather small, perhaps only a few 10's of meters. The predominance of shallow water limestone, shale, and marginal marine (i.e. tidal flat) facies indicates that Fayetteville Quadrangle was susceptible to emergence or inundation with relatively small amplitude sea-level fluctuations. There is no doubt that tectonic flexure capable of driving sea-level oscillations of the scale required to generate the observed stratigraphy was developing in this region associated with evolution of the Ouachita orogen and Arkoma Basin to the south (Thomas, 1989; Viele and Thomas, 1989; Hudson, 2000). Therefore, it seems most likely that relative sea-level changes recorded by the strata of Fayetteville Quadrangle were dominated by tectonic processes.

Supplementary Material Available.--Tables with locations and descriptions of the geologic sites recorded during this mapping project (Universal Transverse Mercator coordinate system relative to WGS 84 datum) are available from the authors upon request. These data are archived on CD-ROM in a spreadsheet format but can be generated in various ASCII formats if necessary.

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Literature Cited

Adams, G. I. and E. O. Ulrich. 1904. Zinc and Lead Deposits of Northern Arkansas: United States Geological Survey, Professional Paper 24, 118 pp.

Adams, G. I. and E. O. Ulrich. 1905. Description of the Fayetteville Quadrangle: United States Geological Survey, Geologic Atlas of the United States, Folio No. 119, 6 pp.

Anderson, E. 2001. Bedrock geology of Strickler and Rudy NE Quadrangles and structural evolution of northwest Arkansas: M.S. Thesis, Department of Geosciences, Univ. Arkansas, Fayetteville, Arkansas, 79 pp.

Carr, L. C. 1963. Geology of the Big Spring area, Washington County, Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 95 pp.

Cate, P. D. 1962. The Geology of Fayetteville Quadrangle, Washington County, Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 112 pp.

Combs, J. 2001. Sandstone petrography of the Atoka Formation (Pennsylvanian) and timing of the Ouachita orogeny in northern Arkansas: M.S. Thesis, Department of Geosciences, Univ. Arkansas, Fayetteville, Arkansas, 157 pp.

Cooper, R. C. 2001. Stratigraphy and structural geology of the Natural Dam and Evansville quadrangles, northwestern Arkansas and eastern Oklahoma: M.S. Thesis, Department of Geosciences, Univ. Arkansas, Fayetteville, Arkansas, 59 pp.

Croneis, C. 1930. Geology of the Arkansas Paleozoic area: Arkansas Geol. Sur. Bull. 3, 457 pp.

Easton, W. H. 1942. The Pitkin Limestone: Arkansas Geological Survey Bulletin No. 8., 115 pp.

Ethington, T., S. C. Finney, and J. E. Repetski. 1989. Biostratigraphy of the Paleozoic rocks of the Ouachita orogen, Arkansas, Oklahoma, west Texas. (pp. 563-574.) *In* Hatcher, R. D., Jr., Thomas, W. A., and Viele, G. W. (eds.), The Geology of North America, Volume F-2, The Appalachian-Ouachita Orogen in the United States: United States of America, Geological Society of America.

Frezon, S. E. and E. E. Glick. 1959. Pre-Atoka Rocks of Northern Arkansas: United States Geological Survey Professional Paper 314 H, pp. 171-189.

Haley, B. R., E. E. Glick, W. V. Bush, B. F. Clardy, C. G. Stone, M. B. Woodward, and D. L. Zachry. 1976. Geologic Map of Arkansas, scale 1:500,000.

Handford, R. C. and W. L. Manger. 1990. Sequence Stratigraphy and Sedimentology of the Mississippian

System in Northwestern Arkansas: Society of Economic Paleontologists and Mineralogists Field Guide, 63 pp.

H ndford, R. C. and W. L. Manger. 1993. Sequence Stratigraphy of a Mississippian Carbonate Ramp, Northern Arkansas and Southwestern Missouri: American Association of Petroleum Geologists, Field Guide, 64 pp.

H ckel, P. H. and G. D. O'Brien. 1975. Silurian reefs of the Great Lakes region of North America: American Association of Petroleum Geologists Reprint Series 14, 243 pp.

H nbest, L. G. 1953. Morrow Group and Lower Atoka Formation of Arkansas: American Association of Petroleum Geologists, v. 37: pp. 1935-1953.

Hoaster, J. J. 1996. Depositional environment and stratigraphic position of an early Pennsylvanian carbonate buildup, Arkoma shelf, Northwest Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 61 pp.

Houseknecht, D. W. 1986. Evolution from passive margin to foreland basin: The Atoka Formation of the Arkoma Basin, south-central USA. (pp. 327-345.) *In* Allen, P. A., and Homewood, P. (eds.), Foreland basins: International Association of Sedimentologists Special Publication 8.

Hudson, M. R. 2000. Coordinated strike-slip and normal faulting in the southern Ozark dome of northern Arkansas: Deformation in a late Paleozoic foreland. Geology: pp. 511-514.

King, J. T. 2001. Bedrock geology of West Fork Quadrangle, Washington County, Arkansas: M.S. Thesis, Department of Geosciences, Univ. Arkansas, Fayetteville, Arkansas, 137 pp.

King, M. E. 2001. Bedrock geology of Fayetteville Quadrangle, Washington County, Arkansas: M.S. Thesis, Department of Geosciences, Univ. Arkansas, Fayetteville, Arkansas, 154 pp.

Manger, W. L. and P. K. Sutherland. 1984. The Mississippian-Pennsylvanian boundary in the southern midcontinent, United States: (pp. 369-376.) *In* Ninth Internal Congress on Carboniferous Stratigraphy and Geology, Urbana, Illinois, 1979, Compte Rendu, V. 2, Biostratigraphy.

Manger, W. L. and T. L. Thompson. 1982. Regional depositional setting of Lower Mississippian Waulsortian mound facies, southern Midcontinent, Arkansas, Missouri and Oklahoma. (pp. 43-50.) *In* Bolton, K. Lane, H. R.; LeMone, D. V. (eds.), Symposium on the Paleoenvironmental Setting and Distribution of the Waulsortian Facies, El Paso Geological Society, El Paso, Texas.

McFarland, J. D. 1998. Stratigraphic Summary of Arkansas: Arkansas Geological Commission Information Circular, pp. 36-39.

McGilvery, T. A. 1982. Lithostratigraphy of the Brentwood and Woolsey Members, Bloyd Formation (Type Morrowan) in Washington and Western Madison Counties, Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 161 pp.

Neumeier, D. P. 1959. Geology of the Woolsey area, Washington County, Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 94 pp.

Pohlo, R. H. 1958. Geology of a portion of Prairie Township, Washington County, Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 26 pp.

Purdue, A. H. 1907. Description of the Winslow Quadrangle: U.S. Geological Survey, Geologic Atlas of the United States, Folio No. 154, 6 pp.

Quinn, J. H. 1963. Subsidence structures of northwest Arkansas. Oklahoma Geological Notes 23:203-212.

Shelby, P. R. 1986. Depositional History of the St. Joe-Boone Formations in Northern Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 99 pp.

Simonds, F. W. 1891. The Geology of Washington County: Arkansas Geological Survey, Annual Report for 1888, V. 4, pp. 1-154.

Sullivan, R. A. 1999. Revised Geology of War Eagle Quadrangle, Benton County, Arkansas: M.S. Thesis, Department of Geosciences, Univ. Arkansas, Fayetteville, Arkansas, 70 pp.

Taff, J. A. and G. I. Adams. 1900. Geology of the eastern Choctaw coal field, Indian Territory: United States Geological Survey, 21st Annual Report, Pt. 2, 273 pp.

Tehan, R. E. 1976. The sedimentary petrology of the Pitkin (Chesterian) Limestone, Washington and Crawford Counties, Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 149 pp.

Thomas, W. A. 1989. The Appalachian-Ouachita orogen beneath the Gulf Coastal Plain between the outcrops in the Appalachian and Ouachita Mountains. (pp. 537-553.) *In* Hatcher, R. D., Jr.; Thomas, W. A., and Viele, G. W. (eds.), The Geology of North America, Volume F-2, The Appalachian-Ouachita Orogen in the United States: United States of America, Geological Society of America.

United States Bureau of the Census. 2000. Public Law 94-171 Redistricting data summary file, 2000 Census of Population and Housing, 1 p.

Valek, E. J. 1999. Sequence stratigraphy and depositional dynamics of the Atoka Formation (Pennsylvanian) based on surface exposures in the southern Ozarks, northwestern Arkansas: M.S. Thesis, Department of Geosciences, Univ. Arkansas, Fayetteville, Arkansas, 115 pp.

Vest, J. T. 1962. Morrowan strata of Greers Ferry Reservoir area: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 124 pp.

Viele, G. W. 1989. The Ouachita orogenic belt. (pp. 555-562.) *In* Hatcher, R. D., Jr.; Thomas, W. A., and Viele, G. W. (eds.), The Geology of North America, Volume F-2, The Appalachian-Ouachita Orogen in the United States: United States of America, Geological Society of America.

Viele, G. W. and W. A. Thomas. 1989. Tectonic synthesis of the Ouachita orogenic belt. (pp. 695-728.) *In* Hatcher, R. D., Jr.; Thomas, W. A., and Viele, G. W. (eds.), The Geology of North America, Volume F-2, The Appalachian-Ouachita Orogen in the United States: United States of America, Geological Society of America.

Wainwright, L. L. 1961. The Geology of the Greenland-Prairie Grove Area, Washington County, Arkansas: M.S. Thesis, Department of Geology, Univ. Arkansas, Fayetteville, Arkansas, 74 pp.

Geologic Hazards Associated with Shale Strata and Swelling Clays within Fayetteville Quadrangle, Washington County, Arkansas

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Introduction

The population of Washington County, Arkansas, increased more than 100% from 1970 to 2000 (U.S. Bureau of the Census, 2000). Washington County population was 77,370 in 1970 and increased at an average rate 3% per year to 157,715 in 2000 (Fig. 1). Much of this growth occurred within the urban corridor comprised of the cities of Fayetteville and Springdale (Washington County) and Rogers and Bentonville (Benton County). The rapid population growth within these cities was accompanied by extensive new construction of commercial buildings, residential areas, streets, highways, and utilities. However, throughout Washington County, much of this new infrastructure is situated on late Paleozoic (Mississippian-Pennsylvanian) shale strata containing swelling clays that weather rapidly to form expansive soils. As such, structures constructed on these strata are subject to a variety of geological processes that pose a significant hazard to their long-term viability. Damage to these structures resulting from the effects of soil expansion/contraction and other destabilizing processes cost hundreds of thousands of dollars each year in Fayetteville alone.

Geologic Hazards Associated with Expansive Soils. Definition of the Problem.--An expansive soil is one that typically contains an appreciable quantity of clay that swells or shrinks in response to variations in moisture content (Komornik, 1969); as moisture is absorbed, clay particles swell and as moisture is removed, clay particles shrink. The pattern of volumetric change due to swelling and shrinking of these active clays is three-dimensional (Jennings 1969; Komornik, 1969) and influenced by the amount of moisture change in the soil, the soil density, the superimposed lithostatic pressures in various directions, and the geometric boundary conditions created by man-made structures (Jennings, 1969; Komornik, 1969).

Hazards Associated with Expansive Soils.--Expansion/contraction of clay soils becomes important when the movements are sufficiently large to damage or distort overlying or founded structures. Structures built on expansive soils commonly heave, displaying differential movements that result in simple cracking as well as vertical and horizontal displacement. The consequent damage due to heave and differential displacement can be significant (Jennings, 1969; Komornik, 1969).

In addition to damage caused by heave, adverse effects encountered by facilities placed on expansive clay soils include subsidence in parking lots or other pavements, rotting of wood floors and other wooden components of buildings due to water retention in the soils, excessive runoff after heavy rainfall, water seeps emerging from paved areas or water seeping from concrete floor seams in buildings, downslope creep, and slumping of steeper slopes. In the case of organic-rich shales containing abundant pyrite, weathering of shale and subsequent oxidation of pyrite can induce severe corrosion of buried pipes.

Though there are engineering solutions to many of the problems associated with construction on expansive soils (even retroactive solutions that can be applied after structures have been damaged by soil processes), these solutions are often very costly and in the worst cases can represent a significant fraction of the value of the property. For example, an associate of one of the authors (S.K. Boss) was required to install 36 steel piers to reinforce a home foundation less than one year after construction was completed. The total cost of this remediation amounted to approximately 24% of the assessed value of the property. Remediation costs ranging from 10-15% of the assessed value of homes are common. It is important to note that most homeowners' or small business' insurance policies do not provide for repairs to foundations damaged by expansive soil processes. Thus, costs are usually borne entirely by affected individuals.

Expansive Soil Hazards in Fayetteville Quadrangle.--There are four clay-rich stratigraphic units exposed throughout Fayetteville Quadrangle that weather rapidly to form expansive soils. These units are 1) the lower Fayetteville Shale of the Fayetteville Formation (Simonds, 1891; McFarland, 1998), 2) the upper Fayetteville Shale of the Fayetteville Formation (Simonds, 1891; McFarland, 1998), 3) the Woolsey-Dye Members of the Bloyd Formation (Purdue, 1907; Henbest, 1953; McGilvery, 1982;

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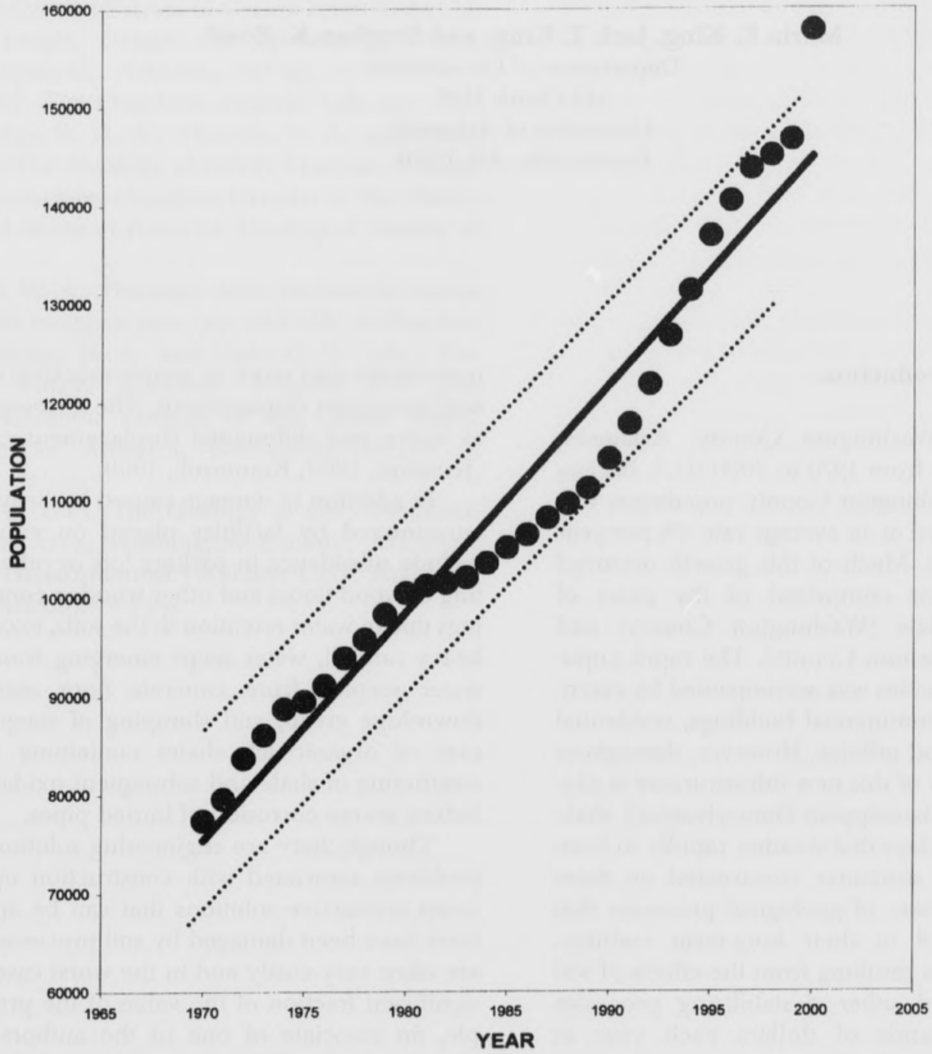

Fig. 1. Population trend for Washington County, Arkansas, 1970 - 2000. Graph shows relatively rapid growth of Washington County over the last 30 years. Note that total population increased 100% (77,370-157,715) from 1970 to 2000. Also note outlying nature of 2000 census result. Solid line indicates best-fit linear regression through data up to 1999 (excluding 2000 data as outlier). Dotted lines represent 95% confidence limits of regression line. Linear regression indicates average annual growth of 3% during the last 30 years. Data obtained from U. S. Census Bureau Arkansas State Data Center, University of Arkansas-Little Rock, Little Rock, Arkansas. URL: (http//www.aiea.ualr.edu/csdc/PopEstimates.html).

McFarland, 1998), and 4) the Trace Creek Member of the Atoka Formation (Taff and Adams, 1900; Henbest, 1953; McFarland, 1998)(Figs. 2-4). Detailed descriptions of the geology, composition, and depositional environments of these strata can be found in King et al. (2001). These units pose common hazards to construction, but also have unique hazards related to their geological constitution and geomorphology. Observed hazards associated with each of these units are considered in turn below.

Lower Fayetteville Shale of the Fayetteville Formation.-- The lower Fayetteville Shale of the Fayetteville Formation covers an extensive area (45.5%) of the Fayetteville Quadrangle (Figs. 2, 3). The city of Fayetteville is expanding rapidly with residential subdivisions, city streets, utilities, and business complexes into areas underlain by this unit. Indeed, most of the flat and gently sloped land in the Fayetteville Quadrangle is underlain by the lower Fayetteville Shale. Thus, the topography of the lower

Fayetteville Shale is suitable for construction, but the soil associated with this unit is quite unfavorable. The weathered clay horizon of this unit ranges from 0 m to 10 m thick and rests on top of the unweathered shale. Adverse effects associated with construction on the lower Fayetteville Shale are differential subsidence of pavements resulting in extreme cracking and unevenness (e.g., Fig. 5A, B), cracking of foundations (e.g., Fig. 5C) and retaining walls (e.g., Fig. 5D), cracking of concrete floors, cracking of concrete driveways, separation of concrete floor seams, rotting of wooden floors and other wooden components of houses, various breaks in masonry above the foundation (e.g., Fig. 5E, F), runoff from heavy rainfall, seeps emerging from paved areas, seeps emerging in houses between concrete floor seams, and corrosion of buried pipes. With the expansion and contraction of the lower Fayetteville Shale clays, even areas with very gentle slopes display evidence of creep.

Upper Fayetteville Shale of the Fayetteville Formation.--The upper Fayetteville Shale of the Fayetteville Formation has a much smaller areal extent (4.7%) than the lower Fayetteville Shale in Fayetteville Quadrangle (King et al., 2001). The upper Fayetteville Shale occurs mostly on moderate to steep slopes between the underlying Wedington Member of the Fayetteville Formation and the overlying Pitkin Formation or Cane Hill Member of the Hale Formation where the Pitkin Formation is missing (King et al., 2001). The outcrop area of the upper Fayetteville Shale is occupied primarily by residential neighborhoods (Figs. 2, 3). The upper Fayetteville Shale also weathers into expandable clays, but the observed hazards differ somewhat from those observed on the lower Fayetteville Shale. Due to the moderate to steep slopes in areas where the upper Fayetteville Shale crops out, creep and slumping are the most critical hazards. Downslope movement within the upper Fayetteville Shale has resulted in creep of pavements with associated buckling and differential subsidence (e.g., Fig. 5B), shifting and cracking of foundations (e.g., Fig. 5C), cracking of masonry above the foundation (e.g., Fig. 5E, F), and cracking and lateral separation of concrete floors. The basal contact of the upper Fayetteville Shale with the Wedington Member of the Fayetteville Formation is the locus of numerous springs and seeps. Where buildings are located on this contact, damage associated with seeping water (e.g. active seepage through foundations, seepage between seams on concrete floors, and moisture damage to wood) is commonplace.

Woolsey-Dye Members of the Bloyd Formation.--The Woolsey-Dye Members of the Bloyd Formation cover 2.3% of the surface area of the Fayetteville Quadrangle (Figs. 2, 3) (King et al., 2001). The Woolsey-Dye Members occur on moderate slopes above the Brentwood Member of the Bloyd Formation. The Woolsey-Dye Members weather quickly into soft gummy clay. Much of the outcrop area of the Woolsey-Dye Members in the Fayetteville Quadrangle remains uninhabited, though several new housing subdivisions were developed on this unit during the last several years. The observed adverse effects of construction situated on the Woolsey-Dye Members are cracking of foundations, cracking in basements, cracking of sidewalks and driveways, cracking of masonry above the foundation, and surface creep as well as slumping (e.g., Fig. 5). Water seeps and springs are common along the contact of the Woolsey-Dye Members and the underlying Brentwood Member of the Bloyd Formation.

Trace Creek Member of the Atoka Formation.--The Trace Creek Member of the Atoka Formation is a black, organic-rich shale at the base of the Atoka Formation (King et al., 2001). The Trace Creek Member has an outcrop extent of 1% in the Fayetteville Quadrangle (Figs. 2, 3). The only inhabited area on the Trace Creek Member in the City of Fayetteville is a residential neighborhood on Mount Sequoyah (Fig. 2). The Trace Creek Member forms steep slopes between a bench formed from the Kessler Member of the Bloyd Formation and the first sandstone of the Atoka Formation. On exposure, the Trace Creek Member weathers quickly into expandable clay subject to slumping. Problems associated with construction on the Trace Creek Member are cracking of foundations and lateral separation of outside walls of houses related to down slope processes.

Conclusions

Paleozoic shale strata are exposed over more than 50% of Fayetteville Quadrangle (Figs. 2, 3). These shale units are known to weather to expansive soils, creating numerous problems for construction. Damage to structures (dwellings, business complexes, streets, sewers, sidewalks, parking lots, etc.) associated with expansion and contraction of weathered clays within these units costs hundreds of thousands of dollars annually to an unsuspecting public.
Many of these costs (particularly those related to repair of damaged home or business foundations) are not protected by homeowners' or businesses' insurance.

Detailed mapping of these clay-rich strata provides an aid to identifying and mitigating these potential hazards. Knowledge of the areal distribution of hazardous stratigraphy in Fayetteville Quadrangle may reduce the overall costs of mitigation through incorporation of appropriate engineering solutions during construction yielding improved building design, better building quality, and lowered building repair costs. Thus, geologic mapping of Fayetteville Quadrangle is relevant and valuable to city planners and developers.

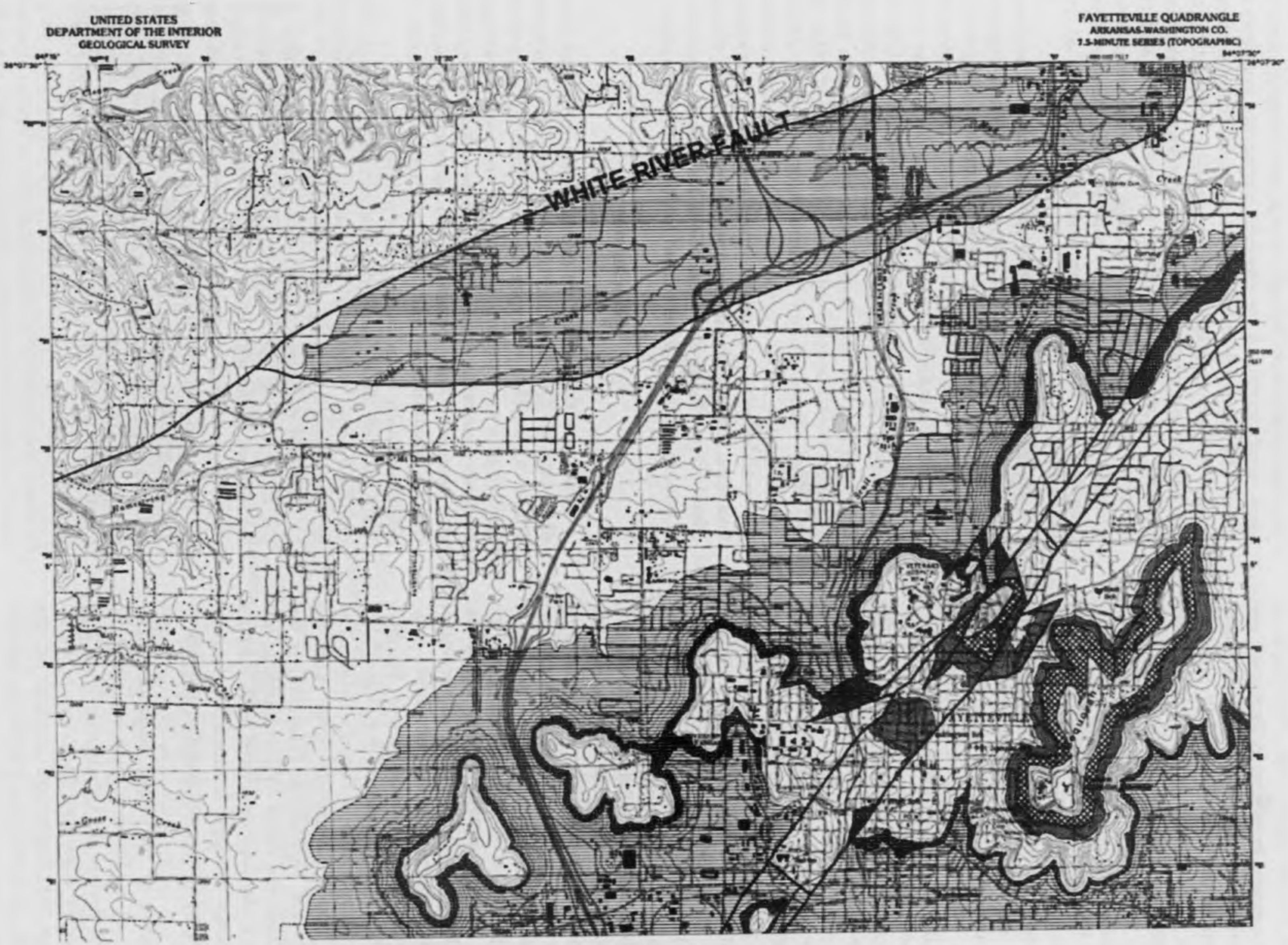

Fig. 2. Map of northern half of Fayetteville 7.5-Minute Quadrangle, Arkansas showing outcrop extents of shale strata containing swelling clays and known to weather to expansive soils.

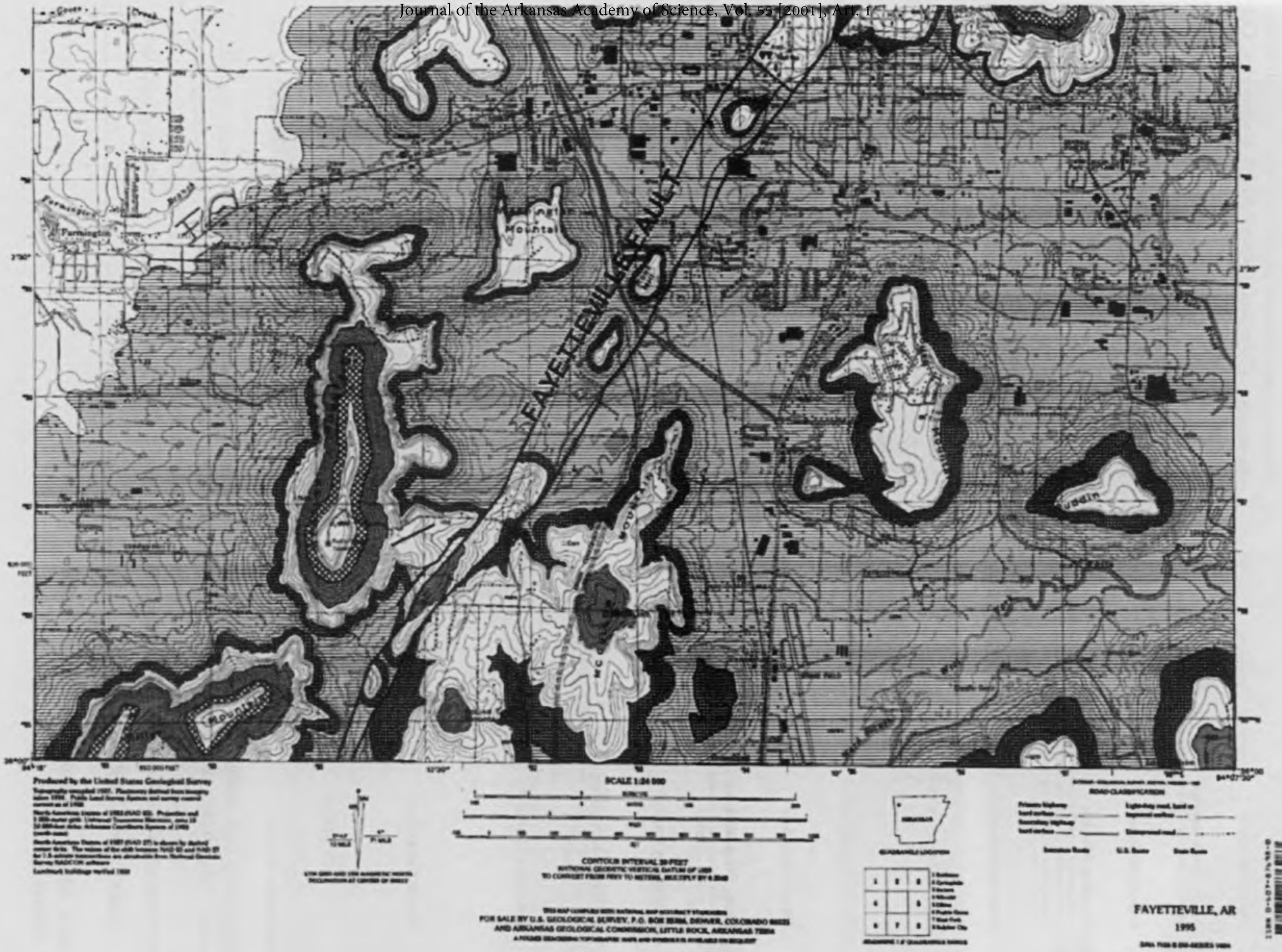

Fig. 3. Map of southern half of Fayetteville 7.5-Minute Quadrangle, Arkansas showing outcrop extents of shale strata containing swelling clays and known to weather to expansive soils.

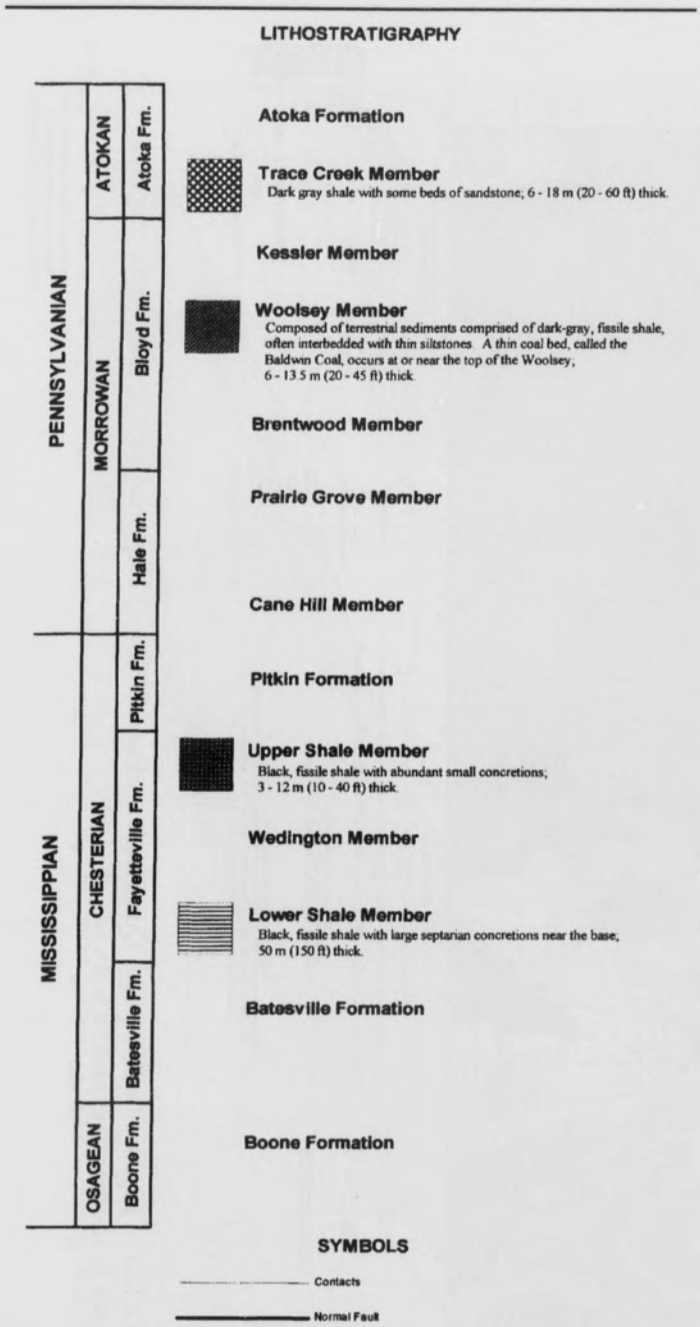

Fig. 4 Legend to accompany Figs. 2 and 3 showing schematic stratigraphic chart of shale strata in Fayetteville Quadrangle.

Literature Cited

Henbest, L. G. 1953. Morrow Group and Lower Atoka Formation of Arkansas: Amer. Assoc. Petrol. Geol. 37:1935-1953.

Jennings, J. E. 1969. The engineering problems of expansive soils. (pp. 11-17). Proceedings of the Second International Research and Engineering Conference on Expansive Clay Soils: Texas A&M University, College Station, Texas.

King, M. E. 2001. Bedrock geology of Fayetteville Quadrangle, Washington County, Arkansas: M.S. Thesis, Department of Geosciences, Univ. Arkansas, Fayetteville, Arkansas, 154 pp.

King, M. E., J. T. King, and **S. K. Boss.** 2001. Bedrock geology and sea-level history of Fayetteville Quadrangle, Washington County, Arkansas. J. Arkansas Acad. Sci. 55:86-96.

Komornik, A. 1969. Factors affecting damage due to movements of expansive clays in the field. (pp. 37-41.) *In* Proceedings of the Second International Research and Engineering Conference on Expansive Clay Soils: Texas A&M University, College Station, Texas.

McFarland, J. D. 1998. Stratigraphic Summary of Arkansas: Arkansas Geological Commission Information Circular, pp. 36-39.

Purdue, A. H. 1907. Description of the Winslow Quadrangle: U.S. Geological Survey, Geologic Atlas of the United States, Folio No. 154, 6 pp.

Taff, J. A. and G. I. Adams. 1900. Geology of the eastern Choctaw coal field, Indian Territory: United States Geological Survey, 21st Annual Report, Pt. 2, 273 pp.

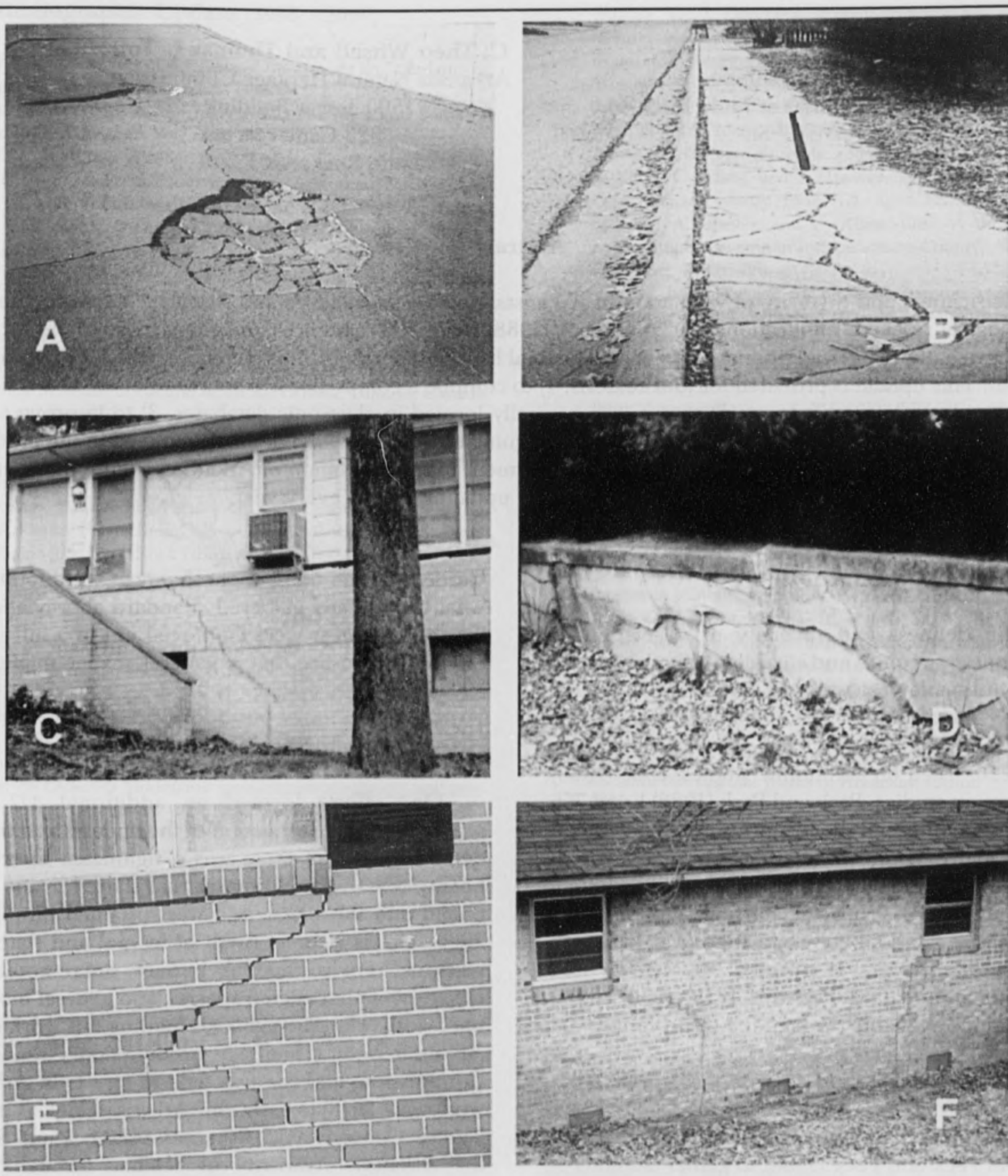

Fig. 5 Images illustrating examples of most common effects of expansive soils on pavements and buildings throughout the Fayetteville Quadrangle. A) Differential subsidence and cracking of pavement; B) Differential subsidence and downslope creep with associated buckling of a sidewalk; C) Cracked masonry foundation of a single-family dwelling; D) Severe cracking and horizontal displacement of a small retaining wall; E) and F) cracking of masonry above foundation of single-family dwellings.

Arkansas Field Botany (Flora and Vegetation) Bibliography (1988-2000)

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Abstract

The floristic richness and diversity of vegetation in Arkansas continues to require and stimulate a growing body of taxonomic and ecological research publications. Peck and Peck (1988) listed 766 references, including those of the two prior lists. Since then we have gathered 417 additional references. The total list now contains 1,183 references, with 70% prepared or published since 1970. This update is provided for four reasons: 1) to compile a comprehensive source to direct and facilitate future studies, 2) to provide easier access to many reports not normally located in electronic databases, 3) to improve communications with botanists outside Arkansas, and 4) to support the ongoing and active efforts of those involved in the production of a manual to the Arkansas Vascular Flora and a book-length treatment of the vegetation of Arkansas. Future plans include placing the entire list on the Internet and developing of a means of updating the list every year.

Introduction

The floristic richness and diversity of vegetation in Arkansas continues to require and stimulate a growing body of taxonomic and ecological research publications. Access to the scattered literature on Arkansas field botany was improved with the publication of three prior lists. Buchholz and Palmer (1926) listed 63 taxonomic studies. Dale (1963) listed 102 vegetation studies. Peck and Peck (1988) listed 766 references, including those of the two prior lists. They noted that there were many significant references in state and federal agency files that remain unpublished, undistributed, and generally unknown. With the current and on-going efforts to summarize the flora and vegetation of Arkansas in book-length treatments, it was deemed appropriate and timely to provide an update to Peck and Peck (1988) and to make these citations available through the same venue.

Methods

We employed much the same methods and inclusion criteria as that of Peck and Peck (1988) to gather citations of additional references. Again, we were particularly interested in any reference that documented or aided in the interpretation of the flora and vegetation of Arkansas. We included references that were essential to comprehend the natural heritage of Arkansas, even if derived from surrounding states. Such works often directly refer to collections made in Arkansas, the disjunct nature of Arkansas populations, or the composition of the vegetation. We took the position that it was better to ere on the side of completeness, than to not include and lose a reference that might be needed in the future. The list was checked against the electronic databases of plant literature at Kew Garden and Missouri Botanical Garden, but no additional references were found to add to what was already gathered. Standard abbreviations for biological references were employed unless a full spelling was required to insure that a general reader might accurately locate a reference.

Results and Discussion

Our efforts located an additional 417 references provided below. Inspection of the updates and the entire list demonstrates that there was a significant increase in field botany research in Arkansas that started in the 1970s, continued into the 1980s, and was sustained through the year 2000. This is a direct result of federal and state funding of research, environmental impact statements, mandated recovery of endangered species, and general biological contract work. The lead agencies funding this work includes the Arkansas Natural Heritage Commission, Arkansas Forestry Commission, and the two federal forests in Arkansas. The work was facilitated by the Arkansas Field Office of The Nature Conservancy, Arkansas Native Plant Society, and the Arkansas Academy of Science through its Journal. Academics and their graduate students continued to participate in most agency projects, a cooperation that has produced a prodigious modern body of work in the last 30 years. A total list of 1,183 references was compiled, with 70% of the references dated 1970 or more recently.

Future efforts will be directed toward placing the entire list of 1,183 reference citations on the Internet and developing a faster means of updating the list, perhaps every year. The authors welcome any reader to submit overlooked references and future publications for inclusion in subsequent updates and lists.

Bibliographic Update (1988 - 2000)

Allen, J. A. 1997. Reforestation of bottomland hardwoods and the issue of woody species diversity. Restoration Ecology 5:125-134.

Allen, R. T. 1988. Additions to the known endemic flora and fauna of Arkansas. Proc. Ark. Acad. Sci. 42:18-21.

Allen, R. T. 1991. The biota of Magazine Mountain (I): An outline of the natural history of Magazine Mountain. Proc. Ark. Acad. Sci. 45:13-17.

Anderson, R. C., J. S. Fralish, and J. M. Baskin. (Eds.) 1999. Savannas, Barrens, and Rock Outcrop Communities of North America. Cambridge University Press, NY.

Anonymous. undated. *Geocarpon minimum* monitoring research, Winn Parish, LA, 1997-1998. Final Report. Repository, Arkansas Natural Heritage Commission, Little Rock, AR.

Argus, G. W. 1985. Computerized catalogue of the herbarium specimens of Salix in the southeastern United States. National Museums of Canada and National Museum of Natural Sciences, Ottawa, Ontario, Canada [pages not numbered]

Arkansas Native Plant Society. 1998. Rare plant conference workbook. Arkansas Native Plant Society, Hot Springs, AR. [11-12 August, 1998]

Arkansas Polytechnic College. Undated. Your guide to the Dardanelle Reservoir Area. Prepared by Faculty Advisory Committee for Leisure Science, Arkansas Polytechnic College, for disribution by US Army Corps of Engineers, Little Rock District. 52 pp. [Includes keys to identification of major tree species of Lake Dardanelle area by Gary Tucker].

Arkansas Vascular Flora Editorial Committee. 2000. Checklist of the vascular flora of Arkansas. Internal Document 4.0 December 2000. University Museum, University of Arkansas, Fayetteville, AR.

Bailey, R. G., P. E. Avers, T. King, and W. H. McNab, eds. 1994. Ecoregions and subregions of the United States. United States Geological Survey, Washington, DC. [Map].

Baker, J. B., ed. 1994. Proc. Symposium on ecosystem management research in the Ouachita Mountains: pretreatment conditions and preliminary findings, October 26 - 27, 1993, Hot Springs, AR. Gen. Tech. Rept. SO-112. USDA Forest Service, Southern Forest Research Station, New Orleans, LA. 259 pp.

Barry, J. 1988. An ecological survey of poverty oat grass, *Danthonia spicata* (L.) Beauv. in northwest Arkansas. M.A. thesis, University of Arkansas, Fayetteville, AR.

Bass, S. M. W. 1981. For the Trees: An illustrated history of the Ozark-St. Francis National Forests, 1908-1978. U.S. Dept. of Agriculture, Forest Service.

Bates, V. 1988-1992. Ouachita National Forest: Sensitive Plant Survey. Vol. II: Sensitive species information. Ranger Districts: Mena (1988), Womble (1988), W. Caddo (1988), Oden (1990), Poteau (1990), Fourche (1991), Cold Spring (1991), Jessieville (1992), and Winona (1992). Series of annual reports by ranger district submitted to Arkansas Nature Conservancy, Arkansas Natural Heritage Commission, and U. S. Forest Service, Southern Region. No page numbers. Repository, Arkansas Natural Heritage Commission, Little Rock, AR.

Bates, V. 1990. Ouachita National Forest: Sensitive Plant Survey. Vol. III. Photographs and slides. Report submitted to Arkansas Nature Conservancy, Arkansas Natural Heritage Commission, and U.S. Forest Service, Southern Region. Repository, Arkansas Natural Heritage Commission, Little Rock, AR.

Bates, V. 2000. Additional surveys for the endangered species Harperella (*Ptilimnium nodosum* (Rose) Mathias) in the Ouachita Mountains region. Submitted to the U. S. Fish and Wildlife Office, Jackson, Mississippi.

Bates, V. and A. B. Pittman. 1991. A review of the status of *Polymnia cossatotensis* Pittman and Bates (Compositae) or the "Cossatot leafcup". Report submitted to Arkansas Natural Heritage Commission. 41 pp.

Bates, V. and A. B. Pittman. 1993. Ouachita National Forest: Sensitive Plant Survey. Vol. I: Overview of plant communities and an inventory of natural areas. Report to Arkansas Nature Conservancy, Arkansas Natural Heritage Commission, and U.S. Forest Service, Southern Region. 144 pp. Repository, Arkansas Natural Heritage Commission, Little Rock, Ar.

Best, M. 1990. The roads of Arkansas. Shearer Publ., Fredericksburg, TN. [Atlas with TRS grids, roads, and streams.]

Board, V. V., C. Allen, and A. Reeves. 1993. Botanical inventory of a cypress-tupelo swamp. Proc. Ark. Acad. Sci. 47:20-22.

Board, V. V., A. Reeves, and C. Allen. 1993. A three-year study on a cypress-tupelo swamp in Independence County, Arkansas. Proc. Ark. Acad. Sci. 47:126-128.

Bogle, A. L. 1970. The genera of Molluginaceae and Aizoaceae in the southeastern United States. J. Arnold Arboretum 51:431 - 453.

BONAP, Biota of North America. 1998. A synonymized checklist of the vascular flora of the United States, Puerto Rico, and the Virgin Islands. Synthesis of the North American Flora, 1999. [http://www.csdl.tamu.edu/flora1998/b98/check98.htm].

Bray, J. R. 1996. Microhabitat diversity of *Trichomanes petersii* in Arkansas. Amer. Fern J. 86:125-126.

Bray, J. R. 1996. *Palhinhaea cernua* new to Arkansas. Amer. Fern J. 86:124.

Bray, J. R. and D. L. Marsh. 1993-1994. Bog clubmosses (*Lycopodiella Holub*) in southern Arkansas. Henderson State University Academic Forum 11:51-54.

Bray, J. R. and D. L. Marsh. 1993. Additional occurrences of the bog clubmosses in southern Arkansas. Proc. Ark. Acad. Sci. 47:131-132.

Bray, J. R., G. A. Whitehead, D. L. Marsh, D. W. McMasters, and W. D. Crank. 1994. Bryophyte and pteridophyte distribution records of southern Arkansas. Proc. Ark. Acad. Sci. 48:239-241.

Bridges, E. L. 1986. Population inventory and monitoring of *Geocarpon minimum* at Warren Prairie Natural Area. Report to Arkansas Natural Heritage Commission, Little Rock, AR. 30 pp.

Bridges, E. L. and S. L. Orzell. 1989. Book Review: An atlas and annotated list of the vascular plants of Arkansas, second edition. Sida 13:391-392.

Brooks, R. E. 1980. *Phyllanthus polygonoides* (Euphorbiaceae) new to Arkansas. Sida 8(3):315.

Brown, C. A. 1986. The Uncommon Bodark". Arkansas Times 12(5):50-55.

Brown, L. E. and R. D. Thomas. 1992. *Isoetes engelmannii* (Isoetaceae) and *Juncus trigonocarpus* (Juncaceae) new to Arkansas. Sida 15:162.

Bryson, C. T., R. Carter, L. B. McCarty, and F. H. Yelverton. 1997. *Kyllinga*, a genus of neglected weeds in the continental United States. Weed Technology 11:838-842.

Bryson, C. T., J. R. MacDonald, R. Carter, and S. D. Jones. 1996. Noteworthy *Carex*, *Cyperus*, *Eleocharis*, *Kyllinga*, and *Oxycaryum* (Cyperaceae) from Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, Tennessee, and Texas. Sida 17(2):501-518.

Bryson, C. T., R. F. C. Naczi, and S. McDaniel. 1992. Notes on noteworthy records of *Carex* (Cyperaceae) from the southeastern United States. Sida 15:125-135.

Bukenhofer, G. A. and L. D. Hedrick. 1997. Shortleaf pine/bluestem grass ecosystem renewal in the Ouachita Mountains. Pp. 509-515, *in* Trans. 62nd North Amer. Wildl. and Natur. Resour. Confr.

Burnett, A. W. and S. A. Schuman. 1983. Alluvial-river response to neotectonic deformation in Louisiana and Mississippi. Science 222:49-50.

Cain, M.D. and M. G. Shelton. 1994. Indigenous vegetation in a southern Arkansas pine-hardwood forest after a half century without catastrophic disturbances. Nat. Areas J. 14:165-174.

Cain, M. D. and M. G. Shelton. 2000. Survival and growth of *Pinus echinata* and *Quercus* seedlings in response to simulated summer and winter prescribed burns. Canad. J. For. Res. 30:1830-1836.

Campbell, J. C., L. Peacock, and S. A. Walker. 1997. Final Report, Pine Bluff Arsenal, Survey of threatened and endangered plants, vegetation, and natural areas. Report by Arkansas Field Office, The Nature Conservancy, Little Rock, AR, submitted to C. M. Becker, Natural

Resources Specialist, Pine Bluff Arsenal, Jefferson, AR.
Campbell, J. J. N. 1995. New combinations in eastern North American *Elymus* (Poaceae). Novon 5(2):128.
Cantino, P. D. 1982. A monograph of the genus *Physostegia* (Labiatae). Contr. Gray Herb. 211:1-105.
Carter, R., M. W. Morris, and C. T. Bryson. 1990. Some rare or otherwise interesting vascular plants from the Delta region of Mississippi. Castanea 55:40-55.
Carulli, J. P., A. O. Tucker, and N. H. Dill. 1988. *Aeschynomene rudis* Benth. (Fabaceae) in the United States. Bartonia 54:18-20.
Catling, P. M. 1983. *Spiranthes ovalies* var. *erostellata* (Orchidaceae), a new autogamous variety from the eastern United States. Brittonia 35(2):120-125.
Chester, E. W., B. E. Wofford, R. Kral, H. R. DeSelm, and A. M. Evans. 1993. Atlas of Tennessee Vascular Plants. Vol. 1: Pteridophytes, Gymnosperms and Angiosperms: Monocots. Misc. Publ. No. 9, Center for Field Biology, Austin Peay State University, Clarksville, TN.
Chester, E. W., B. E. Wofford, and R. Kral. 1997. Atlas of Tennessee Vascular Plants. Vol. 2: Angiosperms: Dicots. Misc. Publ. No. 13, Center for Field Biology, Austin Peay State University, Clarksville, TN.
Christensen, N. L. (undated). Fire regimes in southwestern ecosystems. Unpublished manuscript. Filed with Arkansas Natural Heritage Commission, Little Rock, AR.
Corbet, J. J. 1966. The Arkansas Grand Prairie: delineation and resource use of an agricultural region. Ph. D. dissertation, University of Florida, Gainesville, FL.
Coville, F. V. and J. C. Branner. 1891. A list of the plants of Arkansas. Source unknown. Xeroxed list at Arkansas Natural Heritage Commission, Little Rock, AR.
Croneis, C. 1930. Geology of the Arkansas Paleozoic Era. Bull. 3, Ark. Geol. Survey, Little Rock, AR. 457 pp.
Culwell, D. E. 1991. The vascular flora of Perry County, Arkansas: A progress report. Proc. Ark. Acad. Sci. 45:121.
Culwell, D. E. 1994. Large populations of *Pilularia americana* in Arkansas. Amer. Fern J. 84:133.
Dale, E. E., Jr. 1976. Vegetations on selected sites. Pp. 190-263, in Babcock, R. E. Buffalo National River Ecosystems, Part II. Water Resources Center Publ. No. 38, Univ. Arkansas, Fayetteville, AR.
Dale, E. E., Jr. 1987. Identification of poisonous plants in Arkansas. Pp. 10-18, in Materials Toxic to Cattle. The King Workshop. Arkansas Agricultural Experiment Station Bull. Spec. Rept. 123, Division of Agriculture, University of Arkansas, Fayetteville, AR.
Dale, E. E. Jr. 1998. The effects of fire on oak sprout regeneration at Pea Ridge National Military Park, Arkansas. Final Report, prepared for Pea Ridge National Park, National Park Service, US Dept. Interior. 47 pp.
Dale, E. E., Jr. 1998. Evaluation of vegetation in Bayou Meto Game Management Area. In: D. C. Wolf, M. A. Gross, and J. M. Murdoch [eds.] Nevins Creek Wetland Mitigation Project RC-9603. Final Report, prepared for Arkansas State Highway and Transportation Department, Little Rock, AR.
Dale, E. E., Jr. 1998. Recommendations for establishment of wetland tree species at the Nevins Creek Mitigation site. In: D. C. Wolf, M. A. Gross, and J. M. Murdoch [eds.] Nevins Creek Wetland Mitigation Project RC-9603. Final Report, prepared for Arkansas State Highway and Transportation Department, Little Rock, AR.
Dale, E. E., Jr. and S. A. Ware. 1999. Analysis of oak-hickory-pine forests of Hot Springs National Park in the Ouachita Mountains, Arkansas. Castanea 64:163-174.
Dane, C. H. 1929. Upper Cretaceous formations of southwestern Arkansas. Ark. Geol. Surv. Bull. 1. 215 pp.
Dane, F. 1997. Evaluation of the genetic diversity in *Castanea pumila* var. *ozarkensis* through isozyme and DNA amplification fingerprinting. Unpublished report submitted to Arkansas Natural Heritage Commission, Little Rock, AR. 10 pp.
Dane, F. 1998. Genetic variation and population genetic structure of the Ozark chinkapin (*Castanea pumila* var. *ozarkensis*). Unpublished report submitted to Arkansas Natural Heritage Commission, Little Rock, AR. 18 pp.
Daniels, C. 2001. Original general land office survey notes and plats for the state of Arkansas, 1815-present. Commissioner of State Lands Office, Little Rock, AR. [12 disk CD-ROM set.]
Davis, M. B. 1993. Old growth in the East: a survey. Wild Earth Publication, Cenozoic Society, Richmond, VA. 150 pp.
Delahoussaye, J. A. and J. W. Thieret. 1967. *Cyperus* subgenus *Kyllinga* (Cyperaceae) in the continental United States. Sida 3:128-136.
Delcourt, H. R. and P. A. Delcourt. 1991. Late-quaternary vegetation history of the Interior Highlands of Missouri, Arkansas, and Oklahoma. Pp. 15-30, in Henderson and Hedrick, eds. Restoration of Old Growth Forests in the Interior Highlands of Arkansas and Oklahoma, Proc. of Confer., Ouachita National Forest and Winrock International Institute for Agricultural Development, Hot Springs, AR.
DeLorme. 1997. Arkansas atlas and gazetteer. DeLorme, Yarmouth, ME.
DeSelm, H. R. 1986. Natural forest openings on uplands of the eastern United States. Pp. 366-375, in D. L. Kulhavy and D. N. Conner, eds. Wilderness and natural area in the eastern United States: a management challenge. Stephen F. Austin State University, Nacogdoches, TX.
Diggs, G. M., B. L. Lipscomb, and R. J. O'Kennon. 1999. Shinners and Mahler's Illustrated flora of North Central Texas. Botanical Research Institute of Texas, Fort Worth, TX.
Dougan, M. B., T. W. Dillard, and T. G. Nutt. 1995. Arkansas History: An annotated bibliography. Bibliographies of the States of the United States, No. 5, Greenwood Press, Westport, Connecticut. 365 pp.
Dressel, A. T. 1986. The rich virgin forests of the 1800's —How they helped build our country. Ouachita County Historical Quarterly 17(March):4-14.
du Pratz, M. Le Page. 1774. The history of Louisiana. J. G. Tregle, ed. [English translation of original French text]. Facsimile reprint, 1975. Louisiana Revolution Bicentennnial Comm., LSU Press, Baton Rouge, LA. 405 pp.
Eggers Ware, D. M. 1983. Genetic fruit polymorphism in North American *Valerianella* (Valerianaceae) and its taxonomic implications. Syst. Bot. 8:33-44.
Eliasson, U. H., H. W. Keller, and J. A. Hutchison. 1988. Myxomycetes from Arkansas. Mycotaxon 2:375-398.
Erickson, R. G. 1989. Rediscovery of *Halesia diptera* Ellis (Styracaceae) in Arkansas. Proc. Ark. Acad. Sci. 43:118.
Eyster-Smith, N. M. 1985. Tallgrass Prairies: an ecological analysis of 77 remnants. Ph. D. dissertation, University of Arkansas, Fayetteville, AR.
Farrar, D. R. 1990. Species and evolution in asexually reproducing independent fern gametophytes. Syst. Bot. 15:98-111.
Farrar, D. R. 1992. *Trichomanes intracatum*: The independent *Trichomanes* gametophyte in the eastern United States. Amer. Fern J. 82:68-74.
Farrar, D. R. 1998. The tropical flora of rockhouse cliff formations in the eastern United States. J. Torrey Bot. Soc. 125:91-108.
Fassett, N. C. 1942. Mass collections: *Oxalis violacea*. Castanea 7:31-38.
FNA, Flora of North America Editorial Committee. 1993 +. Flora of North America North of Mexico. Oxford University Press, NY. [Multi-volume work, presently Vols. 1-3, & 22 published of a projected 30 volume sequence].
Ford, B. A., D. A. R. McQueen, R. F. C. Naczi, and A. A. Reznicek. 1998. Allozyme variation and genetic relationships among species in the *Carex willdenowii* complex (Cyperaceae). Amer. J. Bot. 85:546-552.
Foti, T. 1971. The Grand Prairie. Ozark Society Bulletin 5:6-11.

Foti, T. 1976. Arkansas: Its Land and People. Arkansas Dept. Education, Environment and Conservation Office, Little Rock, AR.

Foti, T. L. 1988. Those mysterious blacklands. Aboard the Ark, The Arkansas Nature Conservancy Newslettter. Summer 1988. Little Rock, AR. Pp. 1-2.

Foti, T. L. 1989. Blackland Prairies of southwestern Arkansas. Proc. Ark. Acad. Sci. 43:23-28.

Foti, T. L. 1990. The vegetation of Saratoga Landing Blackland Prairie. Proc. Ark. Acad. Sci. 44:40-43.

Foti, T. L. 1993. The river's gifts and curses. Pp. 30 - 57, in J. Whayne and W. B. Gatewood, eds. The Arkansas Delta, land of paradox. Univ. Arkansas Press, Fayetteville, AR. 321 pp.

Foti, T. L., M. Blaney, X. Li., and K. G. Smith. 1994. A classification system for the natural vegetation of Arkansas. Proc. Ark. Acad. Sci. 48:50-62.

Foti, T. L. and G. A. Bukenhofer. 1998. A description of the sections and subsections of the Interior Highlands of Arkansas and Oklahoma. J. Ark. Acad. Sci. 52:53-62.

Foti, T. L. and G. A. Bukenhofer. 1999. Chapter 1: Ecological classification of the highlands. In USDA, Forest Service. Ozark-Ouachita Highlands Assessment: V. Terrestrial vegetation and wildlife. 5 vols. Southern Region, USDA, Forest Service, Southern Research Station, Gen. Tech. Rept. SRS-35.

Foti, T. L. and M. S. DeVall. 1994. Herbaceous plant diversity of stands in the Ouachita and Ozark National forests. Pp. 50-60, in J. B. Baker. Proc. Symposium on Ecosystem Management Research in the Ouachita Mountains: pretreatment conditions and preliminary findings, October 26-27, 1993, Hot Springs, AR. Gen. Tech. Rept. SO-112. New Orleans, LA. USDA, Forest Service, Southern Forest Research Station. 259 pp.

Foti, T. L. and S. M. Glenn. 1991. The Ouachita Mountain landscape at the time of settlement. Pp. 49-65, in Henderson, D. and L. D. Hedrick, eds. Restoration of old growth forests in the Interior Highlands of Arkansas and Oklahoma. Ouachita National Forest and Winrock International Institute for Agricultural Development, Hot Springs, AR.

Foti, T. L. and J. M. Guldin. 1994. Multivariate analysis of the ground cover layer, shrub layer, midstory, and overstory of the Ouachita/Ozark national forests. Pp. 61 - 73, in J. B. Baker. Proc. Symposium on ecosystem management research in the Ouachita Mountains: pretreatment conditions and preliminary findings, October 26-27, 1993, Hot Springs, AR. Gen. Tech. Rept. SO-112. New Orleans, LA. USDA, Forest Service, Southern Forest Research Station. 259 pp.

Foti, T. L. and G. Hanson. 1992. Arkansas and the Land. University of Arkansas Press, Fayetteville, AR.

Foti, T. L., L. L. Richards, J. Andre, and J. E. Voeller. 1999. Chapter 2: Prehistoric and historic changes. In USDA, Forest Service. Ozark-Ouachita Highlands Assessment: V. Terrestrial vegetation and wildlife. 5 vols. Southern Region, USDA, Forest Service, Southern Research Station, Gen. Tech. Rept. SRS-35.

Fountain, M. S. 1991. Tree and non-tree dimensions of an old-growth shortleaf pine stand: Lake Winona research natural area. Pp. 147-152, *in* Henderson, D. and L. D. Hedrick, eds. Restoration of old growth forests in the Interior Highlands of Arkansas and Oklahoma - Proceedings of the Conference. Ouachita National Forest and Winrock International Institute for Agricultural Development, Hot Springs, AR.

Fountain, M. S. and J. M. Swenney. 1987. Ecological assessment of the Lake Winona Research Natural Area. USDA, Forest Service, Southern Forest Experiment Station. New Orleans, LA. Research Paper SO-235. 14 pp.

Fountain, M. S. and R. L. Willett. 1980. Status of wild American ginseng in Arkansas. Arkansas Farm Research, Univ. Ark. Agr. Expt. Stat., Jan.-Feb., 1980. P. 4.

Fuller, M. L. 1912. The New Madrid earthquake. Government Printing Office, Washington, DC. 64 pp.

Gandhi, K. N. and R. D. Thomas. 1989. Asteraceae of Louisiana. Sida, Botanical Miscellany No. 4. SMU Herbarium, Dallas, TX. 202 pp.

Gandy, L. C., C. R. Britton, R. S. Caldwell, R. K. Ford, C. R. Laurin, R. E. McDaniel, S. Noland, C. S. Spears, J. L. Spellman, and G. E. Tucker. 1993. Mount Magazine State Park, Final Environmental Impact Statement, FTN Associates, Ltd., Little Rock, AR. 468 pp.

Garren, K. H. 1943. Effects of fire on vegetation of the southeastern United States. Bot. Rev. 19:617-654.

Gerstacker, F. [trans. and ed. by J. W. Miller] 1991. In the Arkansas backwoods: tales and sketches. Univ. Missouri Press, Columbia, MO.

Getz, M. E. 1994. Vascular flora of Camp Joseph T. Robinson Military Base North Little Rock, Arkansas. M. S. thesis, University of Central Arkansas, Conway, AR.

Godt, M. J. and J. L. Hamrick. 1995. Allozyme diversity in the endangered shrub *Lindera melissifolia* (Lauraceae) and its widespread cogener, *L. benzoin.* Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR. 28 pp.

Golden, T. A. 1999. Noteworthy plants of southwestern Arkansas. Henderson State University J. 1999 Ark. Underg. Res. Conf. & Space Grant Symp. Pp. 83-87.

Golden, T. A. and D. L. Marsh. 1999. Variation in *Sphaerocarpos* (Marchantiopsida) in Arkansas. J. Ark Acad. Sci. 53:144.

Goldman, D. H. 1995. A new species of *Calopogon* from the midwestern United States. Lindleyana 10:37-42.

Gould, F. W. 1975. The grasses of Texas. Texas A & M University Press, College Station, TX. 653 pp.

Graham, A. 1999. Late Cretaceous and Cenozoic history of North American vegetation. Oxford Univ. Press, NY. 350 pp.

Graney, D. G. and E. R. Ferguson. 1971. Site-quality relationships for shortleaf pine in the Boston Mountains of Arkansas. Forest Science 17: reprint not page numbered.

Great Plains Flora Association. 1986. Flora of the Great Plains. University Press of Kansas, Lawrence, KS.

Gregg, H. R. and R. K. Weldon. 1935. A census of woody plants at Hot Springs National Park Auto Camp. Hot Springs National Park. Natural History Notes 2:1-3.

Guldin, J. M., J. B. Baker, and M. G. Shelton. 1994. Midstory and overstory plants in mature pine/hardwood stands of the Ouachita/Ozark national forests. Pp. 29-49, *in* J. B. Baker. Proc. symposium on ecosystem management research in the Ouachita Mountains: pretreatment conditions and preliminary findings, October 26-27, 1993, Hot Springs, AR. Gen. Tech. Rept. SO-112. USDA, Forest Service, Southern Forest Research Station, New Orleans, LA. 259 pp.

Guldin, J. M. and E. F. Loewenstein. 1999. Chapter 4: Silvicultural practices. *In* USDA, Forest Service. Ozark-Ouachita Highlands Assessment: V. Terrestrial vegetation and wildlife. 5 vols. Southern Region, USDA, Forest Service, Southern Research Station, Gen. Tech. Rept. SRS-35.

Guldin, J. M., F. R. Thompson, L. L. Richards, and K. C. Harper. 1999. Chapter 3: Status and trends of vegetation. *In* USDA, Forest Service. Ozark-Ouachita Highlands Assessment: V. Terrestrial vegetation and wildlife. 5 vols. Southern Region, USDA, Forest Service, Southern Research Station, Gen. Tech. Rept. SRS-35.

Haley, B. R., E. E. Glick, W. V. Bush, B. F. Clardy, C. G. Stone, M. B. Woodward, and D. L. Zachry. 1976. Geologic map of Arkansas. Arkansas Geological Commission and U. S. Geological Survey, Little Rock, AR.

Halls, L. K. and T. H. Ripley (eds.) 1961. Deer browse plants of southern forests. U. S. Forest Serv. South and Southeast Forest Expt. Stations. 78 pp.

Hardcastle, E. 1993. A natural area inventory of Lonoke County and ecological survey of Indian Lake Barrens. M. S. thesis, University of

Arkansas, Fayetteville, AR.
Hardcastle, E. and D. X. Williams. 2000. *Ptilimnium nodosum*, Arkansas status report 2000. Unpublished report submitted to the Arkansas Natural Heritage Commission, Little Rock, AR. 46 pp.
Hargis, A. E. 1995. A comparative study of the flora, fauna, and water quality of springs in the Ozark National Forest, Arkansas. Coop. Unit Publ. No. 25. Arkansas Cooperative Research Unit and University of Arkansas, Fayetteville, AR.
Hargis, A. E. 1995. A comparative study of the flora, fauna, and water quality of springs in the Ozark National Forest, Arkansas. M. S. thesis, University of Arkansas, Fayetteville, AR.
Harper-Lore, B. L., and M. Wilson. 2000. Roadside use of native plants. Island Press, Washington, DC.
Hattenbach, M. J., D. Zollner, and S. Simon. 2000. Arkansas Blackland ecosystem assessment. Unpublished report, submitted by Arkansas Field Office, The Nature Conservancy, Little Rock, AR, to Arkansas Natural Heritage Commission, Little Rock, AR. 30 pp. + appendices.
Hawkins, T. K. and E. L. Richards. 1995. A floristic study of two bogs on Crowley's Ridge in Green County, Arkansas. Castanea 60:233-244.
Hays, J. F. 1998. *Agalinis* (Scrophulariaceae) in the Ozark highlands. Sida 18:555-577.
Hays, J. F. 2000. A suvey of southern Arkansas for species of the plant genus *Agalinis* Raf. (Scrophulariaceae). Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.
Hedrick, L. 2000. A perspective on vegetational change in the Ouachita Mountains. Article prepared for USFS employee newsletter. Repository, Arkansas Natural Heritage Commission, Little Rock, AR.
Heikens, A. L. 1999. Savannas, barrens, and glade communities of the Ozark Plateaus Provence. Pp. 220-230, *in* Anderson, R. C., J. S. Fralish, and J. M. Baskin. (Eds.) Savannas, Barrens, and Rock Outcrop Communities of North America. Cambridge University Press, NY.
Henderson, D. and L. D. Hedrick, eds. 1991. Restoration of old growth forests in the Interior Highlands of Arkansas and Oklahoma - Proceedings of the Conference. Ouachita National Forest and Winrock International Institute for Agricultural Development. Univ. Chicago Press., Chicago, IL.
Hess, W. J. and N. A. Stoynoff. 1998. Taxonomic status of *Quercus acerifolia* (Fagaceae) and a morphological comparison of four members of the *Quercus shumardii* complex. Systematic Botany 23:89-100.
Hinterthuer, B. 1999. Survey of *Ptilimnium nodosum*. Unpublished report submitted to the Arkansas Natural Heritage Commission, Little Rock, AR. 33 pp.
Hoagland, B. W., I. H. Butler, and F. L. Johnson. 1999. The Cross Timbers. Pp. 231-248, in Anderson, R. C., J. S. Fralish, and J. M. Baskin. (Eds.) Savannas, Barrens, and Rock Outcrop Communities of North America. Cambridge University Press, NY.
Hoffman, R. and K. Kearns, eds. 1997. Wisconsin manual of control recommendations for ecologically invasive plants. Bureau of Endangered Resources, Dept. Natural Resources, Madison, WI. 102 pp.
Holmgren, N. H. 1998. Illustrated companion to Gleason and Cronquist's manual. Illustrations of the vascular plants of northeastern United States and adjacent Canada. New York Botanical Garden, Bronx, NY.
Hooyschuur, E. 1990. Electrophoretic analysis of genetic variation among clones and populations of pondberry, *Lindera melissifolia*. M. S. thesis, University of Central Arkansas, Conway, AR.
Hornberger, K. L. 1987. Systematics of the genus *Sisyrinchium* (Iridaceae) in the Southeastern United States. Ph. D. dissertation, University of Arkansas, Fayetteville, AR.
Hornberger, K. L. 1991. The blue-eyed-grasses (*Sisyrinchium*: Iridaceae) of Arkansas. Sida 14(4):597-604.
Hosman, R. L. 1982. Outcropping Tertiary units in southern Arkansas. USGS, Miscellaneous Investigations Series, MAP I-1405. United States Geological Survey, Denver, CO.
Hudson, E. 1996. Report on *Juglans cinerea* (butternut). Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.
Hunter, C. G. 1989. Trees, Shrubs, and Vines of Arkansas. Ozark Society Foundation, Little Rock, AR.
Hunter, C. G. 1995. Autumn leaves and winter berries in Arkansas. Ozark Society Foundation, Little Rock, AR.
Hurst, H. R., B. A. Huey, and R. J. Smith. 1974. Weeds of Arkansas rice fields. Pp. 122-123, in Proc. 27th Annual Meeting Southern Weed Science Society.
Hyatt, P. E. 1991. A survey of the vascular flora of Baxter County, Arkansas. M. S. thesis, University of Arkansas, Fayetteville, AR.
Hyatt, P. E. 1993. A survey of the vascular flora of Baxter County, Arkansas. Castanea 58:115-140.
Hyatt, P. E. 1994. Significant Collections. Castanea 59:78-79. [*Carex davisii*, new to Arkansas, and notes on *Waldsteinia fragarioides*.]
Hyatt, P. E. 1997. Conservation assessment for *Prenanthes barbata* (T. & G.) Milstead. Prepared for Kisatchie National Forest, U.S. Forest Service (Louisiana).
Hyatt, P. E. 1998. Arkansas *Carex* (Cyperaceae): a briefly annotated list. Sida 18:535-554.
Hyatt, P. E. 1998. *Carex* (Cyperaceae) of the Buffalo National River (Arkansas): a preliminary list. Castanea 63:174-179.
Hyatt, P. E. 2001. European chickweed invades Arkansas. Claytonia 21(3):6 - 7.
Iltis, H. H. 1955. A botanical excursion to the Buffalo River Valley and Jasper, Newton County, northwest Arkansas: A botanical commentary. 20 pp. Field Trip Handout, Southwestern Association of Naturalists Annual Meeting and Foray. University of Arkansas, Fayetteville, AR.
Isely, D. 1990. Leguminosae (Fabaceae). Vol. 3, Part 2, Vascular Flora of the Southeastern United States. University of North Carolina Press, Chapel Hill, NC.
Isely, D. 1998. Native and Naturalized Leguminosae (Fabaceae) of the United States (exclusive of Alaska and Hawaii). Monte L. Bean Life Science Museum, Brigham Young University, Provo, Utah.
Ison, C. F. 1996. Vascular flora of St. Francis National Forest of Arkansas. Castanea 61:49-61.
James, D. and J. Neal. 1986. Arkansas Birds: Their distribution and abundance. University of Arkansas Press, Fayetteville, AR.
Jansma, J. and H. Jansma. 1991. George Engelmann in Arkansas Territory. Arkansas Historical Quarterly 50:225-248.
Jansma, J. and H. Jansma. 1992. Engelmann revisits Arkansas, The new state. Arkansas Historical Quarterly 51:328-356.
Jenkins, S. E., R. Guyette, and A. J. Rebertus. Undated. Vegetation-site relationships and fire history of a savanna-glade-woodland mosaic in the Ozarks. Unpublished report to National Park Service. Repository, Arkansas Natural Heritage Commission, Little Rock, AR.
Jenkins, S. E. and M. A. Jenkins. 1996. Savanna and glade vegetation of Turkey Mountain, Arkansas: effects of a single prescribed burn. Unpublished report to the National Park Service, Harrison, AR. 30 pp.
Johnson, G. P. 1992. Noteworthy collections - Arkansas: *Quercus shumardii* Buckl. var. *acerifolia* Palmer (Fagaceae). Castanea 57:150-151.
Johnson, G. P. 1994. *Quercus shumardii* Buckl. var. *acerifolia* Palmer (Fagaceae). Castanea 59:78.
Johnson, G. P. 1999. Leaf and fruit variability in the maple-leafed oak, Quercus shumardii Buckl. var. *acerifolia* Palmer (Fagaceae). Castanea 64:194-199.
Johnson, G. P. 2000. An addition and a deletion to the Orchidaceae of Arkansas. North American Native Orchid Journal 6(2):140-141.
Jones, S. D. 1994. A new species of *Carex* (Cyperaceae): *Phaestoglochin*) from Oklahoma and Texas; typification of section *Phaestoglochin*, and notes on sections *Bracteosae* and *Phaestoglochin*. Sida 16:341-353.
Jones, S. D. and A. A. Reznicek. 1995. *Carex conjuncta* (Cyperaceae) verified

for Arkansas, and notes on the range of *Carex oklahomensis*. Sida 16(4):772-774.

Kartesz, J. T. and C. A. Meacham. 1999. Synthesis of the North American Flora, Version 1.0 North Carolina Botanical Garden, Chapel Hill. [CD-ROM].

Kellum, J. E., E. Sundell, and B. R. Lockhart. 1997. Ground flora composition following harvesting of a bottomland hardwood forest in the Mississippi River batture lands. J. Ark. Acad. Sci. 51:199-203.

Keys, J. E., Jr., C. A. Carpenter, S. L. Hooks, F. G. Koenig, W. H. McNab, W. E. Russell, and M.-L. Smith. 1995. Ecological units of the eastern United States: first approximation. USDA, Forest Service, Atlanta, GA. 82 pp. [map and booklet of map unit tables].

Kinch, J. A. 1996. The thin black crust. Nature Conservancy: July/August 1996. Pp. 8-9.

Kluender, R. A., L. C. Thompson, and G. W. Callahan. 1988. Analysis of wildfire occurrence in southeastern Arkansas, 1984-1987. Proc. Ark. Acad. Sci. 42:48-51.

Kluender, R. A., L. C. Thompson, R. J. McFarland, and D. M. Seigerwald. 1989. Arkansas incendiary wildfire record: 1983-1987. Proc. Ark. Acad. Sci. 43:49-51.

Kluender, R. A. and R. L. Willett. 1988. Arkansas timber resource: yesterday, today, and tomorrow. Proc. Ark. Acad. Sci. 42:48-51.

Kral, R. 1966. Observations on the flora of the southeastern United States with special reference to northern Louisiana. Sida 2:395-408.

Kral, R. 1973. Some notes on the flora of the southern states, particularly Alabama and middle Tennessee. Rhodora 75:366-410.

Kral, R. 1981. Further additions to some notes on the flora of the southern states, particularly Alabama and middle Tennessee. Rhodora 83:301-315.

Kral, R. 1981. Some distributional reports of weedy or naturalized foreign species of vascular plants for the southern United States, particularly Alabama and middle Tennessee. Castanea 46:334-339.

Kral, R. and V. Bates. 1991. A new species of *Hydrophyllum* from the Ouachita Mountains of Arkansas. Novon 1:60-66.

Kucera, C. L. 1998. The grasses of Missouri. University Missouri Press, Columbia, MO. 305 pp.

Kurz, D. 1999. Ozark Wildflowers. A field guide to common Ozark Wildflowers. Falcon Pub., Co., Billings and Helena, Montana.

Kurz, D. and S. E. Orsell. 1984. Ozark Swamps. Missouri Conservationist. August 1984, pp. 4-8.

Kyzer, J. W. and D. L. Marsh. 1999. Occurrences of *Petalophyllum* (Fossombroniaceae) in the Interior Highlands of Arkansas. J. Ark. Acad. Sci. 53:145-146.

Ladd, D. 2000. Lichens of Pine Bluff Arsenal, Arkansas. Unpublished report to Department of Defense. Repository, Arkansas Natural Heritage Commission, Little Rock, AR.

Ladd, D. and P. Nelson. 1982. Ecological synopsis of Missouri glades. Missouri Academy of Science Occ. Paper #7:1-20. Proc. Cedar Glade Symposium (E. A. McGrimes, ed.). Kirksville, MO.

Ladd, D. and F. Oberle. 1995. Tallgrass prairie wildflowers: a field guide. Falcon Press Publ. Co., Billings and Helena, MT. 264 pp.

Langtree, C. 1849. Langtree's new sectional map of the State of Arkansas. G. McCowan, Little Rock, AR.

Lee, J. 1976. Appearance of the Ouachita and Red River valleys to early Europeans. Ark. Archaeological Society Field Notes No. 141. Pp. 4-5.

Leichty, H. O., M. G. Shelton, and E. R. Lawson. 1997. Variability in forest floor mass and nutrient concentration of mature pine-hardwoods in the Ouachita Mountains. J. Ark. Acad. Sci. 51:121-124.

Lellinger, D. 1984. Ferns of North America. Smithsonian Institution, Washington, DC.

Lesquereux, M. L. 1860. Recent botany and general distribution of the plants of Arkansas. Pp. 295 -399, in D. D. Owen. Second report of a geological reconnoissance (sic) of the middle and southern counties of Arkansas made during the years 1859 and 1860. C. Sherman and Son, Printers. Philadelphia, PA. 433 pp.

Lichtenberg, J. S. 1999. Trophic interactions in an Ozark forest ecosystem. M. S. thesis, University of Arkansas, Fayetteville, AR.

Logan, J. M 1992. The glades of Buffalo National River, Arkansas. M. S. thesis, Botany Department, Iowa State University, Ames, Iowa. 120 pp.

Logan, J. M. 1994. A state record for *Cyperus grayoides* (Cyperaceae) in Arkansas. Sida 16:215-216.

Logan, J. M. 1995. Site report, Dortch Woods. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Logan, J. M. 1996. Results of a field survey for *Cyperus grayoides* (Cyperaceae) in Arkansas. Sida 17:283-286.

Logan, J. M. 1997. Report on *Calamagrostis porteri* ssp. *insperata* and *Calamovilfa arcuata* survey. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR. 31 pp.

Logan, J. 1997. Report on *Silene ovata* survey. Unpublished report submitted to the Arkansas Natural Heritage Commission, Little Rock, AR. 27 pp.

Long, A. A. 1989. Disjunct populations of the rare shrub *Neviusia alabamensis* Gray (Rosaceae). Castanea 54:29-39.

Lowman, L. P. 1975. A preliminary investigation of plant distribution within Pinnacle Mountain State Park. Planning Dept., Ark. State Parks, Little Rock, AR. 27 pp, plus appendices.

Lowman, L. P. 1980. Assessment of botanical communities on proposed phase I acquisition site adjoining Lake Poinsett State Park. Report submitted to Department of Planning, Arkansas State Parks, Little Rock, AR. 17 pp.

Luckow, K. 2000. Effects of shortleaf pine-bluestem ecosystem restoration on soil quality on the Ouachita National Forest and implications for improved water quality and watershead condition. U. S. Forest Service draft soil monitoring report submitted to Arkansas Natural Heritage Commission, Little Rock, AR.

MacRoberts, B. R., M. H. MacRoberts, L. M. Stacey, and D. C. Moore. 1998. The status of *Parnassia* (Saxifragaceae) in the west gulf coastal plain. Phytologia 83(1):53-57.

MacRoberts, D. T. 1977. New combinations in *Tradescantia*. Phytologia 37(5):451-452.

Magee, D. W. and H. E. Ahles. 1999. Flora of the Northeast. A manual of the vascular flora of New England and adjacent New York. University of Massachusetts Press, Amherst, MA.

Marbut, C. F. 19–. Soil reconnaissance of the Ozark region of Missouri and Arkansas. USDA, Bureau of Soils, Washington, DC. [undated, unpaged reprint]

Marsh, D. L. 1960. Relationship of *Phlox oklahomensis* to *Phlox bifida* complex: Including a new subspecies of *Phlox bifida*. Trans. Kansas Acad. Sci. 63:12-18.

Marsh, D. L. 1970. Observation of flowering in *Arundinaria gigantea* in Arkansas. Proc. Ark. Acad. Sci. 24:36-37.

Marsh, D. L. 1971. Studies of *Arundinaria*: Experimental induction of flowering and additional observation in the field. Proc. Ark. Acad. Sci. 25:40-42.

Marsh, D. L. 1986. The woodland trees of Clark County, Arkansas. Academic Forum 4:64-73.

Marsh, D. L. 1998. Synopsis of Anthocerotes, Hepatics, and Sphagna of Arkansas. Ark. Rare Plant Conf., Hot Springs National Park, August, 1998. 7 pp.

Marsh, D. L. and K. D. Golden. 1988. Additional woodland trees of Clark County, Arkansas. Henderson State University Academic Forum 6:37-45.

Marsh, D. L. and R. L. Golden. 1989. Occurrence of *Lepuropetalon spathulatum* and other interesting plants on a saline prairie remnant at Griffithtown, Arkansas. Henderson State University Academic Forum 7:62-65.

Marsh, D. L. and T. A. Golden. 1996. Plantain sunflower (*Helianthus occi-*

dentalis subsp. *plantagineus*) in Arkansas. Proc. Ark. Acad. Sci. 50:131-132.

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 ralfsiii* (*Fossombroniaceae*). J. Ark. Acad. Sci. 51:204.

Marsh, D. L. and B. A. Smith. 1993-1994. Honey locust relatives (*Gleditsia* L.) in Clark County, Arkansas. Henderson State University Academic Forum 11:17-20.

Martin, W. H., S. G. Boyce, and A. C. Echternacht [eds.] 1993. Biodiversity of the Southeastern United States. Upland Terrestrial Communities. John Wiley & Sons, NY.

Martin, W. H., S. G. Boyce, and A. C. Echternacht [eds.] 1993. Biodiversity of the Southeastern United States. Lowland Terrestrial Communities. John Wiley & Sons, NY.

Martsoff, J. and R. Wright. 1991. Photosynthetic efficiency of drought-induced leaves in *Neviusia alabamensis*. Proc. Ark. Acad. Sci. 45:61-63.

Masters, R. E. 1993. Effects of timber harvest and periodic fire on soil chemical properties in the Ouachita Mountains. So. J. App. For. 17(3):139-145.

Mattoon, W. R. 1915. Life history of the shortleaf pine. Bull. 244. USDA, Washington, DC. 46 pp.

Mayo, D. C. and P. L. Raines. 1978. Woody vegetation of the Crystal Mountains region. Proc. Ark. Acad. Sci. 40:48-51.

McDaniel, D. L., D. L. Marsh, and W. D. Crank. 1997. Rediscovery of *Parnassia asarifolia* Vent. (Parnassiaceae) in Arkansas. J. Ark. Acad. Sci. 51:208-209.

McInnis, N. C., L. M. Smith, and A. B. Pittman. 1993. *Geocarpon minimum* (Caryophyllaceae), new to Louisiana. Phytologia 75(2):159-162.

Meanley, B. 1967. Champion cypress knees. Atlantic Naturalist, Audubon Naturalist Society of the Central Atlantic States, Inc. Vol. 22 (3): [unpaged reprint].

Mohlenbrock, R. H. 1987. Alum Cove, Arkansas. Natural History. April 1987, pp. 60-62.

Montgomery, G. L. 1976. Natural history themes and an inventory of natural areas in the Mississippi Alluvial Plain and adjacent East Gulf Coastal Plain. M. S. thesis, Louisiana State University, School of Forestry and Wildlife Management, Baton Rouge, LA.

Moore, D. M. Undated. Some natural areas of Arkansas. Unpublished report, General Extension Service, Univ. of Arkansas, Fayetteville, AR. Repository, Ark. Dept. Natural Heritage, Little Rock, AR.

Moore, P. D. 2000. A list of exotic plant species occurring in Arkansas. Unpublished report compiled by Arkansas State Highway and Transportation Dept., Little Rock, AR, in cooperation with The Nature Conservancy. 23 pp.

Murphy, M. E. 1987. A survey of the vascular plants of Carroll County, Arkansas. M. S. thesis, Arkansas State University, College Station, AR. 58 pp.

Murray, E. 1978. *Acer* Notes No. 8. Kalmia 8:17-20.

Naczi, R. F. C. 1999. *Carex planispicata*, a widespread and frequent new species of *Carex* section *Griseae* (Cyperaceae) from the Eastern United States of America. J. Kentucky Acad. Sci. 60:37-44.

Naczi, R. F. C.and C. T. Bryson. 1990. Noteworthy records of *Carex* (Cyperaceae) from the southeastern United States. Bartonia 56:49-58.

Naczi, R. F. C., A. A. Reznicek, and B. A. Ford. 1998. Morphological, geographical, and ecological differentiation in the *Carex willdenowii* complex (Cyperaceae). Amer. J. Bot. 85:434-447.

Nelson, J. B. and J. E. Fairey, III. 1979. Misapplication of the name *Stachys nuttallii* (Lamiaceae) to a new southeastern species. Brittonia 31(4):491-494.

Nesom, G. L. 2000. Noteworthy collections from herbarium NCU. Castanea 65:80-83. [Reports state record of *Gamochaeta falcata* (Lam.) Cabrera (Asteraceae) from Arkansas.]

NRCS, National Resources Conservation Service. 1999. The PLANTS database. [http://plants.usda.gov/plants]. USDA, National Plant Data Center, Baton Rouge, LA.

Nuttall, T. [ed. Savoie Lottinville]. 1999. A journal of travels into the Arkansas Territory during the year 1819. Arkansas Classic, University of Arkansas Press, Fayetteville, AR. 361 pp.

Omernick, J. M. 1986. Ecoregions of the United States. US Environmental Protection Agency, Corvalis, OR. [Map].

Orzell, S. L. 1983. Natural area inventory and floristic analysis of fens in selected southeastern Missouri counties. M. S. thesis, Southern Illinois University, Carbondale, IL. 158 pp.

Orzell, S. L. 1983. Notes on rare and endangered Missouri fen plants. Trans. Missouri Acad. Sci. 17:67-71.

Orzell, S. L. 1984. Additional notes on rare, endangered, and unusual Missouri fen plants. Trans. Missouri Acad. Sci. 18:13-16.

Orzell, S. L. 1984. Preliminary annotated checklist of plants from Garrison Fen, Fulton County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 3 pp.

Orzell, S. L. 1984. Preliminary annotated checklist of plants from Graminoid Fen, Fulton County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 4 pp.

Orzell, S. L. 1984. Plants observed at Rose Pogonia Preserve, Jefferson County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 1 p.

Orzell, S. L. 1984. Preliminary annotated checklist of plants from Idlewild Wooded Acid Seep, Pulaski County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 4 pp.

Orzell, S. L. 1984. Preliminary checklist of plants from Hell Creek Cave Area, Stone County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 2 pp.

Orzell, S. L. 1984. Preliminary annotated checklist of plants from Hinson Road Wooded Acid Seep, Pulaski County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 4 pp.

Orzell, S. L. 1984. Preliminary checklist of plants from Ten Mile Creek Wooded Acid Seep, Garland County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 3 pp.

Orzell, S. L. 1984. Plant species of federal concern in Arkansas. Rept. to Ark. Dept. Nat. Heritage. 2 pp.

Orzell, S. L. 1984. Endangered and threatened plants of Arkansas. Rept. to Ark. Dept. Nat. Heritage. 4 pp.

Orzell, S. L. 1984. Moro Creek Bottoms, Cleveland and Calhoun counties, Arkansas, site descriptions and plant checklist. Rept. to Ark. Dept. Nat. Heritage. 6 pp.

Orzell, S. L. 1984. Preliminary checklist of the plants of Roaring Branch Research Natural Area, Polk County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 4 pp.

Orzell, S. L. 1985. Selected acid seep forests in the Ouachita National Forest: preliminary botanical assessment. Rept. to Ark. Dept. Nat. Heritage. 22 pp.

Orzell, S. L. 1985. Preliminary annotated checklist of the flora of Granite Mountain Glade, Pulaski County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 9 pp.

Orzell, S. L. 1985. Preliminary annotated checklist of the flora of a Ouachita Mountain Shale Glade, Montgomery County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 4 pp.

Orzell, S. L. 1985. Preliminary annotated checklist of the flora of three novaculite glades in the Ouachita Mountains of Arkansas. Rept. to Ark. Dept. Nat. Heritage. 7 pp.

Orzell, S. L. 1985. Site report for Moccasin Creek Fen, Marion County, Arkansas. Rept. to Ark. Dept. Nat. Heritage. 6 pp.

Orzell, S. L. 1985. Report from the field. Arkansas Nature Conservancy Newsletter 4(1):6-7.

Orzell, S. L. and D. Kurz. 1986. Floristic analysis of prairie fens in the southeastern Missouri Ozarks. Pp. 50-58, in G. C. Clamby and R. H. Pemble (eds.), Proc. Ninth North American Prairie Conference, North Dakota State Univ., Fargo, ND.

Owen, D. D., R. Peters, M. L. Lesquereux, and E. Cox. 1860. Second report of a geological reconnoissance (sic) of the middle and southern counties of Arkansas made during years 1859 and 1860. C. Sherman and Son, Printers, Philadelphia. 433 pp.

Owen, W. 1998. Conservation assessment for *Heuchera villosa* var. *arkansana.* Unpublished report submitted to Ouachita and Ozark-St.Francis National Forests, Arkansas.

Owen, W. 1998. Conservation assessment for *Iris verna* L. on the Ouachita National Forest, Arkansas. Unpublished report submitted to Ouachita National Forest, Hot Springs, AR.

Owen, W. 1998. Conservation assessment for *Polymnia cossatotensis.* Unpublished report submitted to Ouachita National Forest, Hot Springs, AR.

Owen, W. 1998. Conservation assessment for *Waldsteinia fragarioides* (Michx.) Tratt. Barren Strawberry for the Ozark National Forest, Arkansas. Unpublished report submitted to Ouachita National Forest, Hot Springs, AR.

Pagan, J. 1999. A report updating *Calopogon* sites in Arkansas. Unpublished report submited to Arkansas Natural Heritage Commission, Little Rock, AR. 7 pp.

Parman, D. L. 1998. Riding circuit in Arkansas, 1844-1845: an excerpt from the autobiography of Reverend William Graham. Ark. Hist. Quart. 57(3):309-339.

Peck, J. H. 1999. *Salvinia minima* in Arkansas. Amer. Fern J. 89: 215-216.

Peck, J. H. 2000. Floristic status of woodferns (*Dryopteris*) in Arkansas. J. Ark. Acad. Sci. 54:88-102.

Peck, J. H., J. R. Bray, D. L. Marsh, D. W. McMasters, C. Amason, and W. D. Crank. 1995. *Psilotum nudum* new to Arkansas. Amer. Fern J. 85:71.

Peck, J. H. and C. J. Peck. 1988. A bibliographic summary of Arkansas field botany. Proc. Ark. Acad. Sci. 41:58-73.

Peck, J. H. and C. J. Peck. 1988. Distribution, abundance, status, and phytogeography of log ferns (*Dryopteris*: Woodsiaceae) in Arkansas. Proc. Ark. Acad. Sci. 41:74-78.

Peck, J. H. and C. J. Peck. 1988. Seven clubmosses (*Lycopodium*) new to Arkansas. Amer. Fern J. 78:73-74.

Peck, J. H., C. J. Peck, S. L. Orzell, E. Bridges, and C. Amason. 1987. Discovery of *Lycopodium* communities in the Gulf Coastal Plain region of Arkansas. Proc. Arkansas Acad. Sci. 41:112-113.

Peck, J. H. and W. C. Taylor. 1995. Checklist and distribution of Arkansas pteridophytes. Proc. Ark. Acad. Sci. 49:130-137.

Peck, J. H., C. T. Witsell, and E. Hendrix. 2000. *Dryopteris goldiana* and its hybrid with D. celsa new to Arkansas. Amer. Fern J. 90:110-111.

Pecotte, A. J. 1981. Aspects of Crowley's Ridge in Arkansas. M. S. thesis, Texas A. & M. University, College Station, TX.

Peitz, D. G., P. A. Tappe, and M. G. Shelton. 1997. Effects of retained pine and hardwood basal areas on percent cover of plants utilized by bobwhite quail. J. Ark. Acad. Sci. 51:144-149.

Penick, J., Jr. 1976. The New Madrid earthquakes of 1811-1812. Univ. of Missouri Press, Columbia, MO. 181 pp.

Phipps, J. B. 1990. *Mespilus canescens,* a new rosaceous endemic from Arkansas. Syst. Bot. 15:26-32.

Pittman, A. B. 1988. Identification, survey, and evaluation of potential habitats of *Geocarpon minimum* Mackenzie in Arkansas. Report by Arkansas Natural Heritage Commission, Little Rock, AR. 111 pp.

Pittman, A. B. 1992. Agency draft Geocarpon minima MacKenzie recovery plan. Prepared for and distributed by Southeast Region, US Fish and Wildlife Services, Jackson, MS. 49 pp.

Pittman, A. B., V. Bates, and R. Kral. 1989. A new species of *Polymnia* (Compositae: Heliantheae) from the Ouachita Mountain Region of Arkansas. Sida 13:481-486.

Prather, J. W., K. G. Smith, M. A. Mlodinow, and C. M. Riley. 2000. Characteristics of some fruiting plant species in northwest Arkansas and the avian assemblages that feed on them. J. Ark. Acad. Sci. 54:103-108.

Priest, J. D. and R. Wright. 1991. Groundwater hydrology of a population of *Lindera melissifolia* in Arkansas. Proc. Ark. Acad. Sci. 45:84-87.

Quinn, J. H. Undated. Prairie mounds in Arkansas. Ark. Archeological Soc., Newsletter. 3(6):1-7.

Rabeler, R. K. and E. B. Smith. 1993. Noteworthy Collection: Arkansas. Castanea 58(2):156.

Rabeler, R. K. and J. W. Thieret. 1988. Comments on the Caryophyllaceae of the southeastern United States. Sida 13:149-156.

Rafferty, M. D. 1996. Rude pursuits and rugged peaks, Schoolcraft's Ozark Journal 1818-1819. Univ. Arkansas Press, Fayetteville, AR. 170 pp.

Rebertus, A. J. and S. E. Jenkins. 1994. Savanna and glade vegetation of Turkey Mountain, Arkansas. Unpublished report submitted to National Park Service. Repository, Arkansas Natural Heritage Commission, Little Rock.

Rebertus, A. J. and B. R. Burns. 1997. The importance of gap processes in the development and maintenance of oak savannas and dry forests. J. Ecol. 85:635-645.

Rettig, J. H. 1987. *Carex* locations for Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Reznicek, A. A. and P. W. Ball. 1980. The taxonomy of *Carex* section *Stellulatae* in North America north of Mexico. Contr. Univ. Mich. Herb. 14:153-203.

Reznicek, A. A. and P. E. Hyatt. 1996. Conservation assessment for *Carex hyalina.* Report submitted to Kisatchie National Forest, Pineville, LA.

Reznicek, A. A. and R. F. C. Naczi. 1993. Taxonomic status, ecology, and distribution of *Carex hyalina* (Cyperaceae). Contr. Univ. Mich. Herb. 19:141-147.

Reznicek, A. A. and P. E. Rothrock. 1997. *Carex molestiformis* (Cyperaceae), a new species of section Ovales from the Ozark Mountain region. Contr. Univ. Michigan Herb. 21:299- 308.

Rhodes, J. D. and F. H. Tainter. 1980. Precipitation extremes and tree growth. Arkansas Farm Research, Univ. Arkansas Agric. Expt. Stat., Jan.-Feb., 1980. P. 12.

Richardson, D. J., R. D. Wright, and S. Walker. 1990. Sexual dimorphism and intersexual differences in resource allocations of a dioecious shrub, *Lindera melissifolia* (Walt.) Blume. Proc. Ark. Acad. Sci. 44:100-103.

Roberts, J. L. 1979. The Arkansas Blackland region. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR. 69 pp.

Robertson, M. A. 1991. A native plant inventory and site analysis for Twentieth Century Gardens in Hot Springs, Arkansas. M.S. thesis, University of Arkansas, Fayetteville, AR.

Robison, H. W. and R. T. Allen. 1995. Only in Arkansas: A study of the endemic plants and animals of the state. University of Arkansas Press, Fayetteville, AR. 121 pp.

Robison, H. W. and T. Buchanan. 1988. Fishes of Arkansas. University of Arkansas Press, Fayetteville, AR.

Robison, H. W. and K. L. Smith. 1982. The endemic flora and fauna of Arkansas. Proc. Ark. Acad. Sci. 36:52-57.

Roedner, B. J., D. A. Hamilton, and K. E. Evans. 1978. Rare plants of the Ozark Plateau - a field identification guide. USDA, Forest Service, Northcentral Forest Experiment Station, St. Paul, MN. 238 pp.

Rolingson, M. A. 1991. Environment and vegetation of the Bayou Bartholomew locality. Pp. 7-26, in Archeology along Bayou Bartholomew, Southeast Arkansas. The Archeologist, Vol. 32. Fayetteville, AR.

Rothrock, P. E. 1991. The identity of *Carex albolutescens, C. festucacea,* and *C. longii* (Cyperaceae). Rhodora 93:51-66.

Rothrock, P. E. and A. A. Reznicek. 1996. A new species of *Carex* section *Ovales* (Cyperaceae) occurring in the Ozark Mountain region. Brittonia 48(1):104-110.

Rothrock, P. E. and A. A. Reznicek. 1998. Documented chromosome numbers 1998: 1. Chromosome numbers in *Carex* section *Ovales* (Cyperaceae): Additions, variations, and corrections. Sida 18:587-592.

Rothrock, P. E.and A. A. Reznicek. 2001. The taxonomy of the *Carex bick-*

nellii group (Cyperaceae) and new species for central North America. Novon 11:205-228.

Rouw, D. W. and G. P. Johnson. 1994. The vegetation of maple-leaved oak sites on Sugarloaf and Magazine Mountains, Arkansas. Proc. Ark. Acad. Sci. 48:154-157.

Rowan, D. 1994. Rediscovery of *Trifolium stoloniferum* in Missouri. Missouriensis 15(2):1-5. Rowland, E. R. 1930. Life, letters, and papers of William Dunbar. Miss. Hist. Soc., Jackson, MS.

Runkle, J. R. 1991. Natural disturbance regimes and the maintenance of stable regional floras. Pp. 31-47, in Henderson and Hedrick, eds. Restoration of old growth forests in the Interior Highlands of Arkansas and Oklahoma - Proc. of the Confer. Ouachita National Forest and Winrock International Institute for Agricultural Development, Hot Springs, AR.

Sagers, C. L. and J. Lyon. 1997. Gradient analysis in a riparian landscape: contrasts among forest layers. Forest Ecology and Management 96:13-26.

Sagers, C. L., J. Lyon, and E. E. Dale, Jr. 1996. Physical factors, functional groups, and phytosociology. Pp. 44-45, *in* K. F. Steele [ed.] Evaluating plant communities in the riparian zone of the Buffalo National River. Arkansas Water Resources Center Publ. No. MSC-195.

Saucier, R. T. 1994. Geomorphology and Quaternary geological history of the lower Mississippi Valley. U.S. Army Engineer Waterways Experiment Station. Vicksburg, MS. Vol. 1, 363 pp, plus appendices. Vol. 2, Atlas.

Schauwecker, T. 1996. A comparison of blackland prairie relicts in Mississippi and Arkansas. M. S. thesis, Mississippi St. Univ., Starkville, MS. 42 pp.

Sealander, J. A. and G. A. Heidt. 1990. Arkansas Mammals: Their natural history, classification and distribution. University of Arkansas Press, Fayetteville, AR.

Segelquist, C. A. and W. E. Green. 1968. Deer food yields in four Ozark forest types. J. Wildl. Manage. 32(2):330-337.

Shantz, H. L. and R. Zon. 1924. Natural vegetation. P. 5, *in* Atlas of American Agriculture, GPO, Washington, DC. [Map].

Shelford, V. E. 1926. Naturalist's guide to the Americas. Williams & Wilkins, Co., Baltimore, MY.

Shelton, M. G. and D. Cain. 1999. Structure and short-term dynamics of the tree component of a mature pine-oak forest in southeastern Arkansas. J. Torrey Bot. Soc. 126(1):32-48.

Shelton, M. G. and P. A. Murphy. 1991. Age and size structure of a shortleaf pine-oak stand in the Ouachita Mountains—implications of uneven-age management. Pp. 616-629, in S. S. Coleman and D. G. Neary. Proc. sixth biennial southern silvicultural conference, October 30-November 1, 1990, Memphis, TN. Gen. Tech. Rept. SE-70. USDA, Forest Service, Southeastern Forest Experiment Station, Asheville, NC. 2 vols., 868 pp.

Shepherd, W. M. 1987. Monitoring of *Geocarpon minimum* at Warren Prairie Natural Area in the spring of 1987. Report by Arkansas Natural Heritage Commission, Little Rock, AR. 24 pp.

Shepherd, W. M. 1988. Monitoring of *Geocarpon minimum* at Warren Prairie Natural Area. Report by Arkansas Natural Heritage Commission, Little Rock, AR. 6 pp.

Shepherd, W. M., C. R. Preston, and R. Steinauer. 1991. Five-year study of *Geocarpon minimum* at Warren Prairie Natural Area, Bradley County, Arkansas. Proc. Ark. Acad. Sci. 45:100-102.

Slaughter, C. R. 1993. Wild orchids of Arkansas. Published by author, Little Rock, AR.

Slaughter, C. R. 1995. Arkansas Calopogons: beautiful beard. North Amer. Native Orchid J. 1(4):306-312.

Small, J. K. 1938. Ferns of the Southeastern United States. Science Press, Lancaster, PA.

Smith, B. A. and D. L. Marsh. 1993. Occurrence of hybrid honey locust (*Gleditsia Xtexana* Sarg.) in southwest Arkansas. Proc. Ark. Acad. Sci. 47:149-150.

Smith, E. B. 1988. An atlas and annotated list of the vascular plants of Arkansas, 2nd ed. Kinko's Copies, Fayetteville, Arkansas. 448 pp.

Smith, E. B. 1989. Floristic notes on the Arkansas Cruciferae (Brassicaceae). Proc. Ark. Acad. Sci. 43:118.

Smith, E. B. 1994. Keys to the flora of Arkansas. University Arkansas Press, Fayetteville, AR. 363 pp.

Smith, E. B., P. E. Hyatt, and K. Golden. 1992. Documented chromosome numbers 1992: 1. Chromosome numbers of some Arkansas flowering plants. Sida 15:145-146.

Smith, K. L. 1986. Sawmill — The story of cutting the last great virgin forest east of the Rockies. University of Arkansas Press, Fayetteville, AR.

Smith, R. 1989. The Atlas of Arkansas. University of Arkansas Press, Fayetteville, AR.

Smith, T. E. 1998. The reintroduction of running buffalo clover (*Trifolium stoloniferum*) in Missouri, 1989-1998. Missouriensis 19:12-22.

Sparks, J. C. 1996. Growing season and dormant-season fire behavior and effects on vegetation in the Ouachita Mountains, Arkansas. M. S. thesis, Oklahoma State University, Stillwater, OK. 186 pp.

Stahle, D. W. and P. L. Chaney. 1994. A predictive model for location of ancient forests. Nat. Areas J. 14:151-158.

Starkey, D. A. , T. J. Haley, R. A. Fitzgibbon and L. L. Richards. 1999. Chapter 6: Biological threats to forest resources. *In* USDA, Forest Service. Ozark-Ouachita Highlands Assessment: V. Terrestrial vegetation and wildlife. 5 vols. Southern Region, USDA, Forest Service, Southern Research Station, Gen. Tech. Rept. SRS-35.

Stoynoff, J. and W. J. Hess. 1990. A new status for *Quercus shumardii* var. *acerifolia* Fagaceae). Sida 14:267-271.

Strausberg, S. and W. A. Hough. 1997. The Ouachita and Ozark-St. Francis National Forests: a history of the lands and USDA Forest Service tenure. Southern Research Station, New Orleans, LA. 45 pp.

Stroud, H. B. and G. T. Hanson. 1981. Arkansas Geography: The physical landscape and the historical-cultural setting. Rose Publ. Co, Little Rock, AR.

Stuckey, R. L. 1975. A bibliography of manuals and checklists of aquatic vascular plants for the conterminous United States. Sida 6:24-29.

Sullivan, J. J. and A. V. Brown. 1994. Aquatic macrophytes of two small northwest Arkansas reservoirs. Proc. Ark. Acad. Sci. 48:186-191.

Sundell, E. and R. D. Thomas. 1988. Four new records of *Cyperus* (Cyperaceae) in Arkansas. Sida 13:259-261.

Sundell, E., R. D. Thomas, C. Amason, R. L. Stuckey, and J. Logan. 1999. Noteworthy vascular plants from Arkansas. Sida 18:877-887.

Sundell, E., R. D. Thomas, and S. R. Hooks. 1989. *Asclepias obovatus* Ell. (Asclepiadaceae) rediscovered in Arkansas. Sida 13:376-378.

Taylor, C. E. and R. J. Taylor. 1986. *Solidago* (Asteraceae) of limited distribution in the central United States. Sida 11:334-339.

Taylor, W. C. 1976. Arkansas pteridophyta: description and distribution. Ph. D. diss., Southern Illinois University, Carbondale, IL.

The Nature Conservancy. 1995. Ecological Assessment: Forest Lands in Arkansas and Oklahoma proposed for inclusion into the Ouachita National Forest and Cossatot National Wildlife Refuge. Arkansas Field Office, The Nature Conservancy, Little Rock, AR.

The Nature Conservancy. 1995. Technical Assessment to: An ecological assessment of Forest Lands in Arkansas and Oklahoma proposed for inclusion into the Ouachita National Forest and Cossatot National Wildlife Refuge. Report by J. Campbell, S. Walker, and D. Zollner, Arkansas Field Office, The Nature Conservancy, Little Rock, AR.

The Nature Conservancy. 1996. Ecological Assessment: Alcoa bauxite natural areas in Arkansas. A report on the status of natural areas with stewardship recommendations. Prepared by the Nature Conservancy's Arkansas Field Office with support from Aluminum Company of America. Little Rock, AR. 57 pp.

The Nature Conservancy. 2000. Ecological assessment of Pulaski County, Arkansas. Report by Arkansas Field Office, The Nature Conservancy, Little Rock, AR. 117 pp. [Field work by Jeff Azerrad].

Thomas, R. D. and C. M. Allen. 1993. Atlas of the vascular flora of Louisiana. Vol. 1: Ferns and fern allies, conifers, and monocotyledons. Natural Heritage Program, Louisiana Department of Wildlife and Fisheries & The Nature Conservancy, Louisiana Field Office, Baton Rouge, LA.

Thomas, R. D. and C. M. Allen. 1996. Atlas of the vascular flora of Louisiana. Vol. II: Dicotyledons: Acanthaceae - Euphorbiaceae. Natural Heritage Program, Louisiana Department of Wildlife and Fisheries and The Nature Conservancy, Louisiana Field Office, Baton Rouge, LA.

Thomas, R. D. and C. M. Allen. 1998. Atlas of the vascular flora of Louisiana. Vol. III: Dicotyledons: Fabaceae - Zygophyllaceae. Natural Heritage Program, Louisiana Department of Wildlife and Fisheries & The Nature Conservancy, Louisiana Field Office, Baton Rouge, LA.

Thomas, R. D., E. B. Smith, E. Sundell, P. E. Hyatt, and C. Amason. 1991. Additions to the flora of Arkansas. Sida 14:483-491.

Thompson, F. R., D. Zoeller, G. Bukenhofer, S. Hensley, and G. Houf. 1999. Chapter 5: Plant and animal populations. In USDA, Forest Service. Ozark-Ouachita Highlands Assessment: V. Terrestrial vegetation and wildlife. 5 vols. Southern Region, USDA, Forest Service, Southern Research Station, Gen. Tech. Rept. SRS-35.

Thurman, C. M. and E. E. Hickey. 1989. A Missouri survey of six species of federal concern (*Tomanthera auriculata, Asclepias meadii, Geocarpon minimum, Lesquerella filiformis, Platanthera praeclara,* and *Boltonia decurrens*). Report by Missouri Dept. Conservation to United States Fish and Wildlife Service. 100 pp.

Timme, S. L. and P. L. Redfearn. 1997. Checklist of the liverworts and hornworts of the Interior Highlands of North America in Arkansas, Illinois, Missouri, and Oklahoma. Evansia 14:89-105.

Tucker, G. C. 1987. The genera of Cyperaceae in the southeastern U. S. J. Arnold Arbor. 68:361-445.

Tucker, G. E. 1973. Rare and endangered plants of Arkansas: a preliminary draft. Report submitted to Arkansas Planning Commission, Little Rock, AR. 58 pp.

Tucker, G. E. 1988. In Memorium: Maxine Clark, 1911-1988. Proc. Ark. Acad. Sci. 42:15.

Tucker, G. E. 1988. In Memorium: Delzie Demaree, 1889-1987. Proc. Ark. Acad. Sci. 42:16-17.

Tucker, G. E. 1989. A survey of the botanical features of Magazine Mountain on the slopes and plateau surface. Report submitted to U.S. Forest Service. 26 pp.

Tumlison, R. and D. L. Marsh. 1994. Biological evaluation: Compartments 1406, 1407, and 1408: Winona Ranger District, Perry County, Arkansas. Report to USDA Forest Service, Ouachita National Forest, Hot Springs National Park, Arkansas.

Tyrl, R. J., S. C. Barber, P. Buck, J. R. Estes, P. Folley, L. K. Magrath, C. E. S. Taylor, and R. A. Thompson. 1998. Identification of Oklahoma plants. A taxonomic treatment comprising of keys and descriptions for the vascular plants of Oklahoma. Flora of Oklahoma, Inc., Stillwater, OK.

USDA, Forest Service. 1984. Sensitive plants of the Ozark-St. Francis National Forests. USDA, Forest Service, South Region. 28 pp.

USDA, Forest Service. 1999. Ozark-Ouachita Highlands Assessment: V. Terrestrial Vegetation and Wildlife. 5 Vols. Southern Region, USDA, Forest Service, Southern Research Station, Gen. Tech. Rept. SRS-35.

USDA, Soil Conservation Service, and Univ. Arkansas Agri. Ext. Expt. Stat. 1982. General soil map, State of Arkansas. Univ. Arkansas Cooperative Extension Service, UA Division of Agriculture, USDA, and County Governments, Little Rock, AR.

Vanderpool, S. S. 1984. A comparative study of the vascular plants from selected bogs and conifer swamps with a comparison to fens. Canad. J. Bot. 59:842-853.

Vanderpool, S. S. and E. L. Richards. 1998. A floristic inventory of three bogs on Crowley's Ridge in northeast Arkansas. J. Ark. Acad. Sci. 52:99-109.

Veatch, M. S. 1906. Geology and underground water resources of northern Louisiana and southern Arkansas. U. S. Geological Survey, Prof. Paper No. 46. Washington, DC. 422 pp.

Walck, J. L., J. M. Baskin, and C. C. Baskin. 1996. Sandstone rockhouses of the eastern United States with particular reference to the ecology and evolution of the endemic plant taxa. Bot. Rev. 62:311-362.

Walker, S. A. 1997. First record of *Psilocarya scirpoides* and a new record of *Eleocharis* (Cyperaceae) in Arkansas. Southw. Nat. 42:118.

Walker, S. A. and J. Campbell. 1997. A floristic survey and annotated checklist of the Pine Bluff Arsenal. J. Ark. Acad. Sci. 51:178-187.

Walker, S. A. and G. P. Johnson. 1991. A survey and annotated checklist of the late summer flora of the moist soil units at Holla Bend National Wildlife Refuge. Proc. Ark. Acad. Sci. 45:111-113.

Ward, D. B. 1987. North American collections of *Lepuropetalon spathulatum* (Saxifragaceae). Phytologia 63(1):15-37.

Waterfall, U. T. 1988. Keys to the flora of Oklahoma. 6th ed. Flora of Oklahoma, Inc., Stillwater, OK.

Watson, L. E. 1989. Status survey of *Calamovilfa arcuata*, Cumberland sandgrass, in Oklahoma. Report submitted to USFWS Ecological Services, Tulsa, OK.

Watson, L. E. 1989. Status survey of *Tradescantia ozarkana*, Ozark spiderwort, in Oklahoma. Report submitted to USFWS Ecological Services, Tulsa, OK.

Watson, L. E. 1991. Population biology and reproductive ecology of *Eriocaulon kornickianum*, dwarf pipewort, in Oklahoma. Unpublished report to U. S. Fish and Wildlife Service, Albuquerque, NM. 29 pp. + maps.

Watson, L. E. 1995. Morphological and genetic divergence among disjunct populations of *Eriocaulon kornickianum*, dwarf pipewort. Unpublished report to U. S. Fish and Wildlife Service, Albuquerque, NM.

Watson, L. E., G. E. Uno, N. A. McCarthy, and A. B. Kornkven. 1994. Conservation biology of a rare plant species, *Eriocaulon kornichianum* (Eriocaulaceae). Amer. J. Bot. 81:980-986.

Weih, R. 1999. Natural State Digital Database, CD Version 1.0 Beta, UTM Zone 15, NAD27. Spatial Analysis Laboratory, School of Forestry, Arkansas Forest Resource Center, University of Arkansas at Monticello, Monticello, AR.

Werth, C. R. 1991. Isozyme studies on the *Dryopteris spinulosa* complex. I. The origin of the Log Fern *D. celsa*. Syst. Bot. 16:446-461.

Werth, C. R., A. M. Evans, and D. M. E. Ware. 1988. The southern woodfern *Dryopteris Xaustralis* in Tennessee and Virginia. Castanea 53:263-271.

Wherry, E. T. 1937. Southern occurrences of *Dryopteris clintoniana*. Amer. Fern J. 27:1-5.

White, D., S. Walker, and B. Fields. 1999. Effects of land management practices on *Trifolium stoloniferum* (running buffalo clover) at the Bluegrass Army Depot. Final Report. Unpublished report submitted to Department of Defense. Repository, Arkansas Natural Heritage Commission, Little Rock, AR.

Wilkes, S. 1999. Report describing location and habitat type for *Valerianella nuttallii* (T. & G.) Walp. in Arkansas. Unpublished report submitted to Arkansas Natural Heritage Commission, Little Rock, AR.

Williams, J. F. 1890. The distribution of timber: its relation to the underlying rock formation. Ark. Geol. Survey 2:167-170.

Wilson, J. H. (ed.) 1984. Rare and endangered species of Missouri. Missouri Dept. Conservation, Jefferson City, MO. 171 pp.

Witsell, C. T. 2000. Ecological assessment of Iron Mountain Natural Area and surrounding lands, Polk County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Preliminary checklist of the plants of Iron Mountain Natural Area, Polk County, Arkansas. Unpublished report to

Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Preliminary checklist of the plants of Falcon Bottoms Natural Area, Columbia and Lafayette counties, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Preliminary checklist of the plants of Konecny Grove Natural Area, Prairie County, Arkansas. Unpublished report submitted to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Preliminary checklist of the plants of Potlatch's Lost 40, Calhoun County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Preliminary checklist of the plants of savanna woodlands in the Grand Prairie of Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Preliminary checklist of the plants of Smoke Hole Natural Area, Lonoke County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Site report for Fernwood Seep, Polk County, Oct. 26, 2000. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Site report for Turkey Mountain Savanna, Lower Buffalo Wilderness, Buffalo National River, Marion County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Updated checklist of the plants of Arkansas Oak Natural Area, Nevada County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Updated checklist of the plants of Big Creek Natural Area, Cleburne County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Updated checklist of the plants of Fernwood Seep, Polk County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Updated checklist of the plants of Iron Mountain Natural Area, Polk County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. 2000. Updated checklist of the plants of Mill's Park Natural Area, Saline County, Arkansas. Unpublished report to Arkansas Natural Heritage Commission, Little Rock, AR.

Witsell, C. T. and W. M. Shepherd. 1998. Rediscovery of *Marsilea vestita* subsp. *vestita* in Pulaski County, Arkansas, after 162 years. J. Ark. Acad. Sci. 52:142-143.

Wood, C. E., Jr. 1975. The Balsaminaceae in the southeastern United States. J. Arnold Arboretum 56:413-426.

Wright, R. D. 1988. Pondberry in Arkansas: an environmental analysis. Report to Arkansas Dept. of Natural Heritage. Univ. Central Arkansas, Conway, AR. 21 pp.

Wright, R. D. 1989. Reproduction of *Lindera melissifolia* in Arkansas. Proc. Ark. Acad. Sci. 43:69-70.

Wright, R. D. 1989. Species biology of *Lindera melissifoia* (Walt.) Blume in northwest Arkansas. Pp. 176-179, in Ecosystem Management: rare species and significant habitats. R. S. Mitchell, C. J. Sheviak, and D. J. Leopold, eds. Proc. 15th Annual Natural Areas Assoc. Conf., New York State Museum, Albany, Bull. 471, 314 pp.

Wright, R. D. 1990. Photosynthetic competence of an endangered shrub, *Lindera melissifolia*. Proc. Ark. Acad. Sci. 44:118-120.

Wright, R. D. 1994. Sex ratio and success, an assessment of *Lindera melissifolia* in Arkansas. Proc. Ark. Acad. Sci. 48:230-233.

Wyatt, T. W., Jr. 1972. Vascular plants of Mississippi County, Arkansas. M. S. thesis, Dept. Biology, Arkansas State University, State University, Arkansas.

Yatskievych, G. 1999. Steyermark's Flora of Missouri. Vol. 1. Pteridophytes, Gymnosperms, and Monocots, revised edition. Missouri Dept. Conservation and Missouri Botanical Garden, St. Louis., MO.

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Survey of *Salvinia* (Salviniaceae) in Eastern Arkansas

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Abstract

Salvinia, water spangles, is a genus of 10 species of free-floating heterosporous aquatic ferns with two species introduced to North America. *S. minima* Baker was introduced into the eastern United States by at least 1814 and occurs mainly across the southeastern United States. *S. molesta* Mitchell was recognized as a distinct species in the 1970s, was introduced into the United States as a water-garden plant in the 1980s, and has escaped and spread across the southeastern United States in the 1990s. It is recognized by federal agency as noxious aquatic weed. *S. minima* Baker was discovered in Arkansas in 1998. A status survey of eastern Arkansas was undertaken from 1998 - 2000 to determine the distribution and abundance of *S. minima* and *S. molesta*. A search of 33 Arkansas counties led to the discovery of *S. minima* at 21 localities in 11 counties: Arkansas, Ashley, Chicot, Desha, Jefferson, Lee, Lincoln, Monroe, Phillips, Prairie, and Pulaski. No populations of *S. molesta* were located in 33 counties. Search efforts must extend to southwestern Arkansas in the Red River watershed to complete the survey.

Introduction

Salviniaceae (water spangles) is a monogeneric fern family of 10 species of free-floating heterosporous aquatic ferns classified in genus *Salvinia* (Reed, 1954, 1965; Nauman, 1993; Schneller, 1990). They are most distinctive ferns with a peculiar adaptive vegetative morphology (Forno, 1983; Moran, 1992). Lacking true roots, they compensate for this with one submerged dimorphic frond which is highly dissected and functions as an absorption organ that also provides counter-balance to two companion floating-leaves on the surface of the water (Croxdale, 1978, 1979, 1981). All species have a propensity for vegetative expansion (Mitchell and Tur, 1975), making them potentially invasive and weedy species (Gaudet, 1973; Oliver, 1993; Dickinson and Miller, 1998). Two species occur in North America, *S. minima* and *S. molesta* (Nauman, 1993).

Salvinia minima Baker (water spangles) was discovered in Guiana (South America) in the middle of the eighteenth century and named in 1775. Small (1938) noted *S. minima* was first reported from North America in New York in1814, with later discoveries of it in southern states. It was discovered in Florida as late as 1928, with most of these stations considered to be introductions where the species has naturalized (Small, 1938). Small (1938) reported that "how it was introduced...is not known". Nauman (1993) recognized *S. minima* Baker as native to North America, reporting its known range as Georgia, Florida, Alabama, Louisiana, Mexico, West Indies, and Central America. In the 1980s and 1990s this species expanded its known range westward in the Gulf States as well as into the southwestern United States. It was first reported west of the Mississippi River in Louisiana (Landry, 1981) and then in Texas (Hatch, 1995). Its known range expanded northward from Georgia to South Carolina (Johnson, 1995). *S. minima* was discovered in Lonoke Co., Arkansas, in 1998 and in three additional locations in two more counties in 1999 (Peck, 1999). The populations persisted through the mild winter of 1998-1999 at these localities, suggesting that they were naturalized or well established introductions.

Nauman (1993) reported that *Salvinia molesta* Mitchell, giant water spangles was commercially cultivated in Florida and sent across the southern one-half of the United States for the water-garden trade. Nauman (1993) recognized that this represented a potential risk of escape and establishment. Nauman's prediction proved correct. Within a decade, escaped and well established infestations of *S. molesta* were discovered in Florida northward to South Carolina (Johnson, 1995), westward to Alabama (Haynes and Jacono, 2000), and across the Mississippi River to Louisiana and Texas (Jacono, 1999a,b). Ominously, more propagation sites that might foster more escapes are known to occur as far north as Virginia in the East and from California north to Washington in the West, indicative of future problems on a national scale. Infestations in Louisiana may spread northward to Arkansas in two watersheds, resulting in the establishment of this noxious aquatic weed in southeastern or southwestern Arkansas.

Salvinia molesta is the notorious "African Kariba water weed" that formed a dense carpet covering 1,000 square kilometers in three years (Schelpe, 1961; Mitchell and Tur, 1975) and was originally identified as *S. auriculata* Aublet. Noting that *S. auriculata* Aublet was a fertile species that did not cause such infestations in its native Brazil, Mitchell

(1972) recognized this aggressive, sterile weedy clone as a distinct species in Africa, a pentaploid of hybrid origin, possibly from Brazil (Moran and Smith, 1999). The current reported range of this pantropical weed includes Zimbabwe, Botswana, Kenya, South Africa, Zambia, Madagascar, Ceylon, Indonesia, Papua New Guinea, Western Australia, Queensland, Brazil, and now the United States. It forms such dense concentrations that it physically blocks commercial navigation, harms fisheries stock by depleting night-time dissolved oxygen levels, and promotes disease-carrying mosquito populations (Forno and Harley, 1979; Thomas and Room, 1986; Room, 1990; Oliver, 1993). Research is being conducted to seeking safe and effective biological management (Gallardo, et al., 1998, 1999)

A preliminary field survey of *Salvinia* across eastern Arkansas was conducted to determine the extent of its distribution, the magnitude of local abundance, and whether there are limits to its persistence or vigor. The ultimate objective of this survey was to provide data to determine whether either species of *Salvinia* warrants a legal status in Arkansas as a state listed non-indigenous, invasive, or noxious weed.

Methods

A field survey was conducted from 1998 through 2000 in 33 counties in eastern Arkansas, including Arkansas, Ashley, Bradley, Chicot, Clay, Cleveland, Craighead, Crittenden, Cross, Desha, Drew, Faulkner, Grant, Greene, Independence, Jackson, Jefferson, Lawrence, Lee, Lincoln, Lonoke, Mississippi, Monroe, Phillips, Poinsett, Prairie, Pulaski, Randolph, Saline, St. Francis, Sharp, White, and Woodruff. The survey was ground-based, restricted to driving public roads and inspecting accessible waterways, impoundments, and ditches; observation during the survey was enhanced with binoculars. Rather than attempt to locate all populations or as many as possible, surveying ceased in a county once one population was discovered. No more than three days were spent searching in any single county. Thus, the survey was managed to emphasize the greatest geographic spread of work effort. Vouchers were collected and deposited at the UALR Herbarium (LRU). Estimates of aerial extent and abundance as well as names of associated vegetation were recorded. Selected samples were maintained in log phase growth at the UALR greenhouse to provide an index of maximum density that might be expected in the field.

The genus is readily identified by their floating leaves that are rounded with the top surface bearing whie, coarse, stiff hairs and by the submerged leaves that are green, branched, and filiform. They are separated from each other easily with a hand-lens. *S. minima* has smaller leaves (dia. less than 0.5 cm) with hairs tipped with four prongs that flair apart. *S. molesta* has larger leaves (dia. greater than 1 cm) with hairs tipped with four prongs that fuse together at the tip, resembling an old hand-cranked egg beater.

Results and Discussion

Plants of *Salvinia minima* Baker were found at 21 localities in 11 counties, adding 17 localities and 8 counties to the original reported state range (Peck, 1999). Currently Arkansas County has four localities, Prairie County has three, and Jefferson, Lee, Lonoke, Monroe, and Phillips counties have two localities each; four remaining counties have one locality. All populations were similar to those initially found (Peck, 1999); they were small (less than 0.1 meter square), sparse to thinly stocked, not forming multiple layers of crowded plants, and were present with other floating-leaved aquatic plants, including *Azolla mexicana* Presl, *Lemna minor* L., *Spirodela polyrhiza* (L.) Schleid., *Wollfia columbiana* Karst., and *Wolfiella gladiata* (Hegelm.) Hegelm.

All field populations occurred at stocking densities less than 1% of wet weight and dry weight of the index maximum established under greenhouse conditions. In no instance was an infestation evident, based on aerial extent or stocking density of the population. No population of *Salvinia molesta* Mitchell was located. The failure to find any population of *S. minima* in 22 counties or *S. molesta* in any of the 33 counties surveyed does not mean that these counties are free of these species. Search time, manner, and mode were severely constrained; this preliminary survey should not be considered a complete examination of any entire watercourse nor any watershed.

Voucher Specimens: *Salvinia minima* Baker.–U.S.A.: ARKANSAS: Arkansas Co.: Mill Bayou drainage, 5 mi w DeWitt, T4S R4W S34, Peck 99003 LRU; Grand Cypress Lake, Bayou Meto WMA, T5S R6W S14, Peck 99004 LRU; La Grue Bayou, 3 mi n Casscoe on Co 146, T2S R3W S17, Peck 20184 LRU; Cypress Bayou, 1 mi w of Tichnor on Ark 44, T6N R 2W S30, Peck 20185 LRU; Chicot Co.: Lake Boggy Bayou, 1 mi se of Dewey, T14S R1W S30, Peck 20214 LRU; Desha Co.: Silverlake Watershead, 10 mi ne Dumas, T8S R3W S31, Peck 99574 LRU; Jefferson Co.: Langford Lake watershead, 3 mi w Reydell, T6S R6W S13, Peck 99562 LRU; Wabbaseka Bayou, 1 mi s of Wabbaseka along US 78, T4S R 7W S18/19, Peck 20109 LRU; Lee Co.: Big Creek Drainage, 5 mi w Moro, T2N R1W S12, Peck 99583 LRU; L'Anguille River Slough, 0.5 mi N of Wrightland on AR 2, T3N R3E S28, Peck 20138 LRU; Lincoln Co.: Mud Lake watershead, 8 mi e Gould, T8S R4W S13, Peck 99570 LRU; Lonoke Co.: Buffalo Ditch drainage, 1 mi e Geridge, T2N R6W S7, Peck 98002 LRU, Peck 99001 LRU; Bayou Two Prairie, wetland e of Co. 21, 1 mi n of Lonoke, T2N R8W S11, Peck 20152 LRU; Monroe Co.: Big Cypress Creek drainage, 1 mi e Cross Roads, T3S R1E S18, Peck 99588 LRU; Maddox Bay Oxbow, 1 mi w Lawrenceville on Ark 146, T2S R2W S23, Peck 20101 LRU; Phillips Co.: Big Creek drainage, 3 mi e Maple Corner on US 49, T2S R3E S1, Peck 20237 LRU; Little Cypress Creek drainage, 3 mi w Hickville, T1S R1E S18, Peck 99579 LRU; Prairie Co.: Honey Creek drainage, 6 mi s DuValls Bluff, T1N R4W S17, Peck 99592 LRU; Bayou Meto drainage, along Beck Rd, 6 mi w Stuttgart, T2S R6W S26, Peck 20250 LRU; Minnow Pond ditches, 2 mi s DuValls Bluff on Ark 33, T2N R4W S19/30, Peck 20249 LRU; Pulaski Co.: Old River Oxbow slough, on Ar 161 and Co5, T1S R11W S12, Peck 99650 LRU.

U. S. Public Law 101-646 of 1990 (Nonindigenous Aquatic Nuisance Prevention and Control Act) was passed to enable programs to be developed that prevent the unintentional introduction of aquatic nuisance species and to allow the development of state aquatic nuisance species management plans. Federal agencies are actively involved in this program, including the U.S. Army Corps of Engineers Aquatic Plant Control Research Program, the U.S. Geological Survey Nonindigenous Aquatic Species Program, the U.S. Department of Agriculture National Biological Control Institute, and the U.S. Environmental Protection Agency. Currently, *Salvinia molesta* is listed as a federal noxious weed, meaning that importation into the United States or transportation across state lines is prohibited by Federal law, based on the application of the commerce clause in the U. S. Constitution. Distribution within a state of such a federally listed plant is permitted, unless specifically prohibited by an individual state and listed as a state noxious weed, thus linking state enforcement to that of federal authorities. Texas and Florida (Harvey, 1998) have enacted state legal authority. Additionally, NAS-USGS also lists water spangles, *S. minima*, as a "nonindigenous aquatic fern" based on the fact that this non-native species has been introduced beyond its natural range, whether or not it formed permanent populations or failed to persist.

The evidence so far does not suggest a need to list *Salvinia minima* as a noxious weed in Arkansas. It may be prudent for the state of Arkansas to join with other states (Florida and Texas) and federal authorities in banning the sale, transport, and cultivation of *S. molesta*. This action may reduce or prevent future infestations that may negatively impact commerical aquaculture of plants and animals in Arkansas and cause other unwanted environmental impacts.

While *Salvinia minima* is known to occur and persist to some extent within Arkansas, at present its state distribution or potential range of occurrence is imperfectly known. At present our observations on its local vigor are quite limited. The extreme drought in 2000 followed by an extreme winter event in 2000-2001 may have disfavored its occurrence as much as the mild winter of 1998-1999 and 1999-2000 may have favored its persistence. Whether *S. minima* arrived in Arkansas by natural means (waterfowl) or by human intervention is not known. How it has spread across multiple watersheds within the state also remains unknown, but both waterfowl or human activities may have contributed. As for spread within watersheds, passive movement by currents, waterfowl, and human activity might all have played a role. Thus our prospects for predicting or evaluating *Salvinia* persistence or expansion into weedy growth in Arkansas are imperfectly and insufficiently known.

Salvinia molesta Mitchell has not yet been found in Arkansas, but seemingly suitable habitat and conditions exist in the southeastern and southwestern regions in the state. With *S. minima* now known from 21 localities in 11 counties in southeastern Arkansas, the potential likelihood that *S. molesta* might also occur in Arkansas and might then become an infestation is viewed as a very real risk in the near future, particularly from populations in Louisiana or Texas. Both species have similar mechanisms for dispersal and survival. Further search in southeastern and southwestern Arkansas counties is warranted. Additionally, it is advised that all field biologists (agronomic, forestry, wildlife, or botanists) in Arkansas be trained to identify and be vigilant for the presence of this non-indigenous, invasive, and noxious plant in Arkansas.

Literature Cited

Croxdale, J. G. 1978. *Salvinia* leaves. I. Origin and early morphogenesis of floating and submerged leaves. Can. J. Bot. 56:1982-1991.

Croxdale, J. G. 1979. *Salvinia* leaves. II. Morphogenesis of the floating leaf. Can. J. Bot. 57:1951-1959.

Croxdale, J. G. 1981. *Salvinia* leaves. III. Morphogenesis of the submerged leaf. Can. J. Bot. 59:2065-2072.

Dickinson, M. B. and **T. E. Miller.** 1998. Competition among small, free-floating, aquatic plants. Amer. Midl. Nat. 140:55-67.

Forno, I. W. 1983. Native distribution of the *Salvinia auriculata* complex and keys to species identification. Aquatic Bot. 17:71-83.

Forno, I. W. and **K. L. S. Harley.** 1979. The occurrence of Salvinia molesta in Brazil. Aquatic Bot. 6:185-187.

Gallardo, M. T., J. R. Ascher, M. J. Colier, B. B. Martin, and D. F. Martin. 1999. Effect of cattail (*Typha domingensis*) extracts, leachates, and selected phenolic compounds on rate of oxygen production by salvinia (*Salvinia minima*). J. Aqua. Plt. Manag. 37:80-82.

Gallardo, M. T., B. B. Martin, and **D. F. Martin.** 1998. Inhibition of water fern *Salvinia minima* by cattail (*Typha domingensis*) extracts and by 2-chorophenol and salicylaldehyde. J. Chem. Ecol. 24:1483-1490.

Gaudet, J. J. 1973. Growth of a floating aquatic weed *Salvinia* under standard conditions. Hydrobiologia 41:77-106.

Harvey, W. D. 1998. Harmful or potentially harmful fish, shellfish, and aquatic plants. *In:* Texas Administrative Code. Title 31, Part 2 (Texas Parks and Wildlife Department regulations). Chapter 57, subchapter A, section 57.111-112.

Hatch, S. L. 1995. *Salvinia minima* new to Texas. Sida 16:595.

Haynes, R. R. and **C. C. Jacono.** 2000. Status of *Salvinia* (Salviniaceae) in Alabama. Castanea 65(3):225-227.

Jacono, C. C. 1999a. *Salvinia molesta* D. S. Mitchell invades the United States! Aquatics 21:4-9.

Jacono, C. C. 1999b. *Salvinia molesta* (Salviniaceae) new to

Texas and Louisiana. Sida 18:927-928.

Johnson, D. 1995. Giant *Salvinia* found in South Carolina. Aquatics 17:22.

Landry, G. P. 1981. *Salvinia minima* new to Louisiana. Amer. Fern J. 71:95.

Mitchell, D. S. 1972. The Kariba weed: *Salvinia molesta.* Brit. Fern Gaz. 10:251-252.

Mitchell, D. S. and N. M. Tur. 1975. The rate of growth of *Salvinia molesta* (*S. auriculata* Aubl.) in laboratory and natural conditions. J. Applied Ecology 12:213-226.

Moran, R. C. 1992. The story of the molesting *Salvinia.* Fiddlehead Forum 19:26-28.

Moran, R. C. and **A. R. Smith.** 1999. *Salvinia* adnata Desv. versus S. molesta D. D. Mitch. Amer. Fern J. 89:268-269.

Nauman, C. E. 1993. Salviniaceae Reichenbach. Pp. 336 - 337, *In* Flora of North America Editorial Committee. Flora of North America North of Mexico, Vol. 2, Oxford University Press.

Oliver, J. D. 1993. A review of the biology of giant salvinia (*Salvinia molesta* Mitchell). J. Aqua. Plt. Manag. 31:227-231.

Peck, J. H. 1999. *Salvinia minima* in Arkansas. Amer. Fern J. 89:215-216.

Reed, C. F. 1954. Index Marsileata et Salviniata. Boletim Sociedade Broteriana, Coimbra 28:5- 61.

Reed, C. F. 1965. Index Marsileata et Salviniata, supplement. Boletim Sociedade Broteriana, Coimbra 39:259 - 302.

Room, P. M. 1990. Ecology of a simple plant-herbivore system: biological control of *Salvinia.* Trends Ecol. Evol. 5:74-79.

Schelpe, E. A. C. L. E. 1961. The ecology of *Salvinia auriculata* and associated vegetation on Kariba Lake. J. South. Afr. Botany 27:181-187.

Schneller, J. J. 1990. Salviniaceae. Pp. 256-258, *In* K. U. Kramer and P. S. Green. Pteridophytes and Gymnosperms, Vol. 1, *In* K. Kubitzki. The Families and Genera of Vascular Plants. Springer-Verlag, New York.

Small, J. K. 1938. Ferns of Southeastern United States. Science Press Printing, Lancaster, PA. Thomas, P. A. and P. M. Room. 1986. Taxonomy and control of *Salvinia molesta.* Nature 320:581-584.

Decomposition Rate Comparisons between Frequently Burned and Unburned Areas of Uneven-aged Loblolly Pine Stands in Southeastern Arkansas

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Abstract

Although fire has been used extensively over long periods of time in loblolly pine (*Pinus taeda* L.) ecosystems, little is known concerning the effects of frequent fire use on nutrient cycling and decomposition. To better understand the long-term effects of fire on these processes, foliar litter decomposition rates were quantified in a study investigating prescribed fire and uneven-aged loblolly pine management in the Upper Coastal Plain in Arkansas. Part of the study area had been burned on a 2- to 3-year cycle since 1981, whereas another portion had not received any prescribed fires. Decomposition rates were determined by placing foliar litter from each area in litterbags, installing these bags in the field within each area, and monitoring the litter mass loss over a 10-month period. During this period, no differences were found in decomposition rates between the burned and unburned areas. However, an initial increase in decomposition was found in litterfall collected from the burned areas when compared with litterfall collected from unburned areas.

Introduction

The dependence of the pine forest upon recurring fires in the southern pine belt of the southeastern United States is well known (Barnes et al., 1998). Although fire was once considered a destructive agent with few benefits, it is now apparent that fires are important in maintaining and establishing forests. The use of prescribed fire has now become a well accepted silvicultural practice (Barnes et al., 1998). Prescribed fire is often used to reduce fuels; prepare sites for regeneration; dispose of logging debris; improve wildlife habitat; manage for competing vegetation and disease; improve aesthetics, access, and grazing; perpetuate fire dependent species; and to manage for endangered and other species (Wade and Lunsford, 1989). Fuel burned by prescribed fires includes dead trees, logs, slash, needles, leaves, and other litter (McCullough et al., 1998).

The effects of fire on forest ecosystems are complex and can be beneficial or detrimental depending on fire intensity, stand structure, and community composition (Barnes et al., 1998). Positive benefits of fire can include increased nutrient uptake, accelerated tree growth, enhanced nutrient cycling (Clinton et al., 1996), and improved nutrient availability (Shoch and Binkley, 1986). Negative effects of prescribed fire may include forest floor and organic matter destruction, nutrient and soil loss, erosion, decreased soil aeration and penetrability, and vegetation mortality (Wade and Lunsford, 1989).

While some of the more direct impacts of fire have been documented, less is known of the indirect affects of fire on forest ecosystem processes, such as decomposition. With this in mind, we superimposed a litter decomposition study within an ongoing study of the silvicultural effects of fire in uneven-aged loblolly pine (*Pinus taeda* L.) stands in southeastern Arkansas. The objectives of the study were to determine if 1) pine foliar litterfall on burned areas decomposes at a different rate than litterfall on unburned areas and 2) pine foliar litterfall collected from burned areas decomposes at a different rate than litterfall collected from unburned areas. These objectives were quantified by examining pine litterfall decomposition as well as foliar litter nutrient concentrations.

Methods

Study Area.--The study was located on compartments 11, 24, and 55 of the Crossett Experimental Forest in Ashley County, Arkansas at 32°02'N mean latitude and 91°56'W mean longitude. The study area is 53 m above mean sea level and has nearly level topography. Annual precipitation averages 140 cm. Soils are predominantly Bude and Providence silt loams (fine-silty, mixed, thermic, Glossaquic and Typic Fragiudalfs, respectively) that have an impervious layer at a depth of 50-100 cm which impedes internal drainage and root growth (Gill et al., 1979). Soil reactivity varies from medium acid to very strongly acid (Gill et al., 1979). Site index for loblolly pine is 27 m at age 50 (Cain, 1993).

Treatments.--The study sites were managed using uneven-aged silviculture with single-tree selection and the complete exclusion of fire starting in the late 1930's until the late 1960's (Cain, 1993). After the late 1960's, no harvesting or vegetativion control was performed until 1980. The initial burn treatments began in January of 1981. The burn treatments consisted of 1) an unburned control, 2) an irregular winter burn [every 2-3 years], 3) a winter burn every five years, and 4) a winter burn every 10 years (Cain et al., 1998). Each of the 16-ha compartments was divided into sixteen 1-ha plots. Each 1-ha plot had an interior measurement plot of 0.65 ha that was surrounded by a 10-m wide isolation strip. Four contiguous 1-ha plots comprised a 4-ha burn treatment in each compartment. For the purposes of this study, only the unburned control and irregular burn treatments were used. Within these treatments, there was one 1-ha measurement plot that was maintained at a residual basal area of 14 m^2/ha. Timber harvests have been applied on a 6-year cutting cycle. To reduce hardwood competition, the unburned (check) plots were treated in 1992 with a broadcast application of Arsenal AC herbicide (1.7 kg a.i) in 113 L of water/ha using articulated rubber-tired skidders in swaths 9 m wide. Because the herbicide had been applied 8 years earlier, we were not concerned with the herbicide directly affecting the results of the decomposition study.

A total of six 1-ha plots were used in the study, one unburned control and one irregularly burned plot in each of the three compartments. Within each 1-ha plot, three 4- x 4-m subplots were installed for installation of litter bags.

Litterbag Sampling.--The litterbag method is well recognized and has been used for many decomposition studies (Mellilo et al., 1982; Lockaby et al., 1995). Each bag is 30 cm x 30 cm with a mesh size of 5 mm on the top and 2 mm on the bottom. In the fall of 1999, pine foliar litterfall was collected from all plots within each treatment. The litter was dried, mixed by treatment, and stored for later use inside of the litterbags.

Vegetation was trimmed to ground level in three strips (approximately 40 cm wide) within each of the 4- x 4-m subplots on each treatment plot. Litterbags containing 20 g of air-dried litter collected from the burned areas and litterbags containing 20 g of air-dried litter collected from the unburned areas were placed in rows on each subplot. Litter collected from the two treatments was kept separate by treatment so comparisons in decomposition rates could be made between 1) litterfall placed on the burned and unburned treatments and 2) litterfall collected from each treatment. One litterbag of each litter source (burned or unburned areas) was collected from each subplot after 0.5, 1, 2, 5, 7, and 10 months. The litterbags were transported in plastic bags to the laboratory where all foreign material was removed. The litter was dried at 70° C, and mass loss was determined. Loss on ignition was used to calculate ash free masses. Ash free masses, which are free from contamination by mineral soil, were used in the analysis. In addition, a correction factor was applied to adjust the initial air-dried mass of the litter to an oven-dried basis.

Litter Quality.--Initial litter quality of loblolly pine litterfall was assessed for each treatment. Several studies have used litter quality as a variable to assess decomposition rates (Fogel and Cromak, 1977; Taylor et al., 1989). The litter collected for litterbags was dried, ground, and analyzed for macro-nutrient concentrations by the University of Arkansas Soil Test Laboratory, Fayetteville, Arkansas. Nutrient data were used to determine C/N ratios and to compare initial litter quality for the decomposition study.

Statistical Design.--The ash free mass loss data were analyzed using ANOVA with a split-plot through space and time design. The litter quality data were analyzed using a paired *t*-test. All tests were performed at an α level of 0.05.

Results and Discussion

After 10 months, there was no evidence that 20 years of prescribed fires had altered decomposition rates at these sites. The ash free pine litterfall masses did not significantly differ between the burned and unburned treatments for any of the collection dates. As can be seen in Figure 1, pine litterfall masses were similar for the two treatments throughout the 10 months.

In contrast, mass loss was significantly different at all

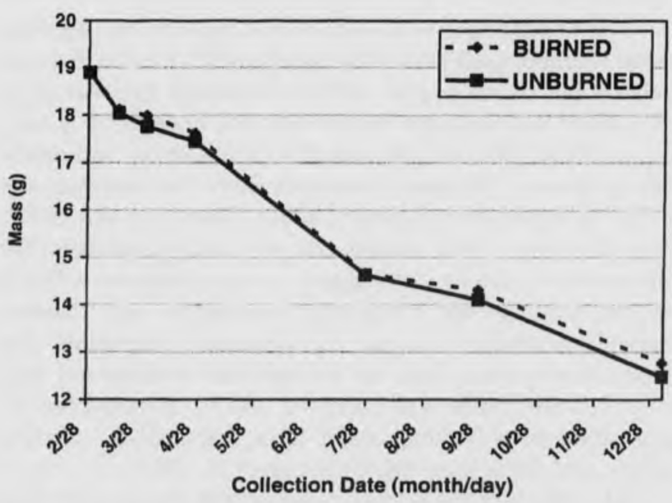

Fig. 1. The loss of mass from decomposing foliar litter located in burned and unburned areas of uneven-aged loblolly pine stands.

dates between the litterfall collected from the burned and unburned treatments (Fig. 2). It is apparent that long-term prescribed fire can affect mass loss indirectly. The litterfall collected from the burned areas either decomposed faster or experienced rapid leaching after only two weeks. At the two week collection period, litterfall collected from burned areas had lost 56% more mass than litterfall collected from

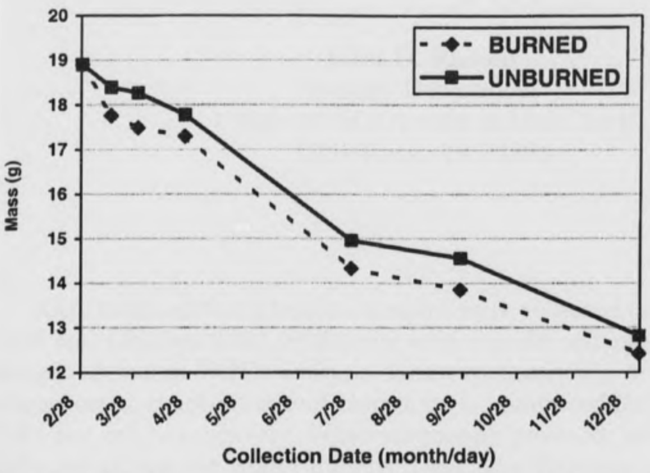

Fig. 2. The loss of mass from decomposing foliar litter collected from burned and unburned areas of uneven-aged loblolly pine stands.

unburned areas. After the first 2 weeks, decomposition rates were similar for the subsequent 9.5 months. Masses of the two litterfall sources remained significantly different throughout the 10 months.

Nutrient analysis showed significant differences in K, Ca, Mg, and C concentrations between the burned and unburned areas. There were no significant differences for N, P, or S (Table 1) or C/N ratios. Litterfall collected from the burned treatment contained higher concentrations of K, Ca and Mg but lower concentrations of C than foliar litterfall from the unburned treatments. These differences in nutrient concentrations could be partially responsible for the initial increase in mass loss in litterfall from the burned areas. However, these differences in nutrient concentrations were not enough to fully explain the differences in mass loss. It is possible that these differences would be better explained by examining nutrient content in combination with cellulose, lignin concentrations, or soluble sugar concentrations.

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Literature Cited

Barnes, B. V., D. R. Zak, S. R. Denton, and **S. H. Spurr.** 1998. Forest ecology. Fourth edition. John Wiley and Sons Inc. 774 pp.

Cain, M. D. 1993. A 10 year evaluation of prescribed winter burns in uneven-aged stands of *Pinus taeda* L. and *P. echinata* Mill.: woody understory vegetation response. Internat. J. Wildl. Fire 3:13-20.

Cain, M. D., T. B. Wigley, and **D. J. Reed.** 1998. Prescribed fire effects on structure in uneven-aged stands of loblolly and shortleaf pines. Wildl. Soc. Bull. 26:209-218.

Table 1. Initial nutrient concentration of foliar litter collected from burned and unburned areas in uneven-aged loblolly pine stands.

Nutrient	Litterfall Source	Mean Concentration (%)	Standard Error
N	Burned	0.43 a[1]	0.006
	Unburned	0.43 a	0.012
C	Burned	47.84 a	0.083
	Unburned	48.21 b	0.104
P	Burned	0.02 a	0.001
	Unburned	0.02 a	0.002
K	Burned	0.13 a	0.004
	Unburned	0.11 b	0.007
Ca	Burned	0.37 a	0.006
	Unburned	0.33 b	0.011
Mg	Burned	0.09 a	0.002
	Unburned	0.08 b	0.003
S	Burned	0.04 a	0.001
	Unburned	0.04 a	0.001

[1]Means for a nutrient concentration followed by different letters were significantly different at $\alpha = 0.05$.

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Clinton, B. D., J. M. Vose, and **W. T. Swank.** 1996. Shifts in above-ground and forest floor carbon and nitrogen pools after felling and burning in the southern Appalachians. For. Sci. 42:431-440.

Fogel, R., and **K. Cromak.** 1977. Effect of habitat and substrate quality on Douglas fir litter decomposition in western Oregon. Can. J. Bot. 55:1632-1640.

Gill, H. V., D. C. Avery, F. C. Larance, and **C. I. Fultz.** 1979. Soil survey of Ashley County, Arkansas. USDA Soil Conservation Service, forest service, in cooperation with the Arkansas Agricultural Experiment Station. 174 pp.

Lockaby, B. G., J. H. Miller, and **R. G. Clawson.** 1995. Influences of community composition on biogeochemistry of loblolly pine (*Pinus taeda*) systems. Amer. Mid. Nat. 134:176-184.

McCullough, D. G., R. A. Werner, and **D. Neumann.** 1998. Fire and insects in northern and boreal forest ecosystems of North America. Ann. Rev. of Entom. 43:107-127.

Mellilo, J. M., J. D. Aber, and **J. F. Muratory.** 1982. Nitrogen and lignin control of hardwood leaf litter dynamics. Ecology 63:621-626.

Shoch, P., and **D. Binkley.** 1986. Prescribed burning increased nitrogen availability in a mature loblolly pine stand. For. Ecol. Manage. 14:13-22.

Taylor, B. R., D. Parkinson, and **W. F. J. Parsons.** 1989. Nitrogen and lignin contents as predictors of litter decay rates: a microcosm test. Ecology 70:97-104.

Wade, D. D., and **J. D. Lunsford.** 1989. A guide for prescribed fire in southern forests. USDA For. Serv. Tech. Pub. R8-TP 11. 56 pp.

A Survey of the Macrobenthic Community in Ferguson Lake, Saline County, Arkansas

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Abstract

One hundred thirty benthic samples were collected on 33 visits to Ferguson Lake, Saline County, Arkansas, between May 1997 and October 2000. Sediments were visually examined and described, and some were returned to the lab for sediment oxygen demand (SOD) analysis. Fourteen taxa, representing five phyla of invertebrates, were identified. In all samples, oligochaetes, chaoborids, and chironomids comprised the majority of individuals, reaching densities up to 7449, 14,208, and 8783 per m^2, respectively. When seasonally grouped, largest total abundances and greatest abundances of most taxa were collected during the winter months (December-February). A minor abundance peak occurred in July due to a mid-year generation of *Chaoborus*. Some significant differences in abundance between seasons were present. The number of taxa collected per sample was also highest in winter but not significantly different from other seasons. Community diversity indicators were lowest in summer. Sediments over most of the lake consisted of a variable thickness (1 to 4 cm) layer of woody detritus above a deeper, rich, thinly divided mix of organic muck and inorganic particulates. Too little variation in sediments existed to test for macrobenthos preferences. The SOD tests revealed a nearly complete oxygen depletion in the chamber in 24 hours.

Introduction and Study Area

Ferguson Lake is a privately-owned country club/recreation lake located in eastern Saline County, Arkansas (Fig. 1). Rickett and Floyd (1999) gave a brief history and an introductory description of the lake and reported on the morphometry and limnology of the lake. The current paper describes the macrobenthic community.

Based on characters described in the literature, Rickett and Floyd (1999) concluded that Ferguson Lake was midway between a "blackwater" environment and the more usual small watershed impoundment. We therefore called it a "brownwater" environment with several swamp-like features such as low pH, brown-colored water (humic acids), much undecomposed plant material on the sediments, and summer hypoxia immediately above the substrate.

Materials and Methods

We conducted thirty-three sampling trips between May 1997 and October 2000 and collected 65 macrobenthic samples at each of two stations in Ferguson Lake (Fig. 1). Although sampling frequency was slightly concentrated in the spring months, all months were represented. Station 1 was located in the channel of Clear Creek, approximately 400 m upstream from the dam, whereas station 2 was in mid-lake, approximately 500 m farther upstream. In a large area around station 2, the lake bottom was flat due to the long-term settling of solids, making the original channel of Clear Creek difficult to locate.

The macrobenthic community was sampled with a standard 6 x 6-inch (15.2 x 15.2-cm) Ekman grab and small amounts of sediment with organisms were preserved in FAA (15% [by volume] conc. formalin, 5% acetic acid, 15% ethanol [95%] and 65% dH_2O) for transportation to the lab. In the lab, the remaining sediment was removed with a 250-micron sieve, but at this point most of the remaining sediments were larger chunks of plant detritus. Organisms were picked from aliquots placed in petri dishes and preserved permanently in 70% ethanol. Since the area sampled by the grab encompassed approximately 232 cm^2, each count was multiplied by 43.1, and numbers/m^2 were recorded.

Sediment characteristics were visually assessed and recorded during each sampling trip. A series of 24-hour sediment-oxygen-demand (SOD) analyses were conducted to illustrate the probable major cause of the usual mid-summer hypoxia above the sediments (Rickett and Floyd, 1999). Approximately 11.3 L of sediment was collected, returned to the lab and placed, with as little disturbance as possible, in a sealable plexiglas chamber. An equal volume of lake water was added to the chamber; the chamber was sealed and a small recirculating pump was activated. A probe attached to a YSI Model 50B D.O. meter was inserted through the top with a sealed gasket, and a measurement was recorded every hour for 24 hours.

With the F-statistic, t-tests, and Mann Whitney-U tests, significant differences between the two sampling stations and between any two seasons for each of the eight "major" taxa were noted. March, April and May were considered spring; June, July and August were considered summer, and so on. Correlation of any change in taxa present in the sam-

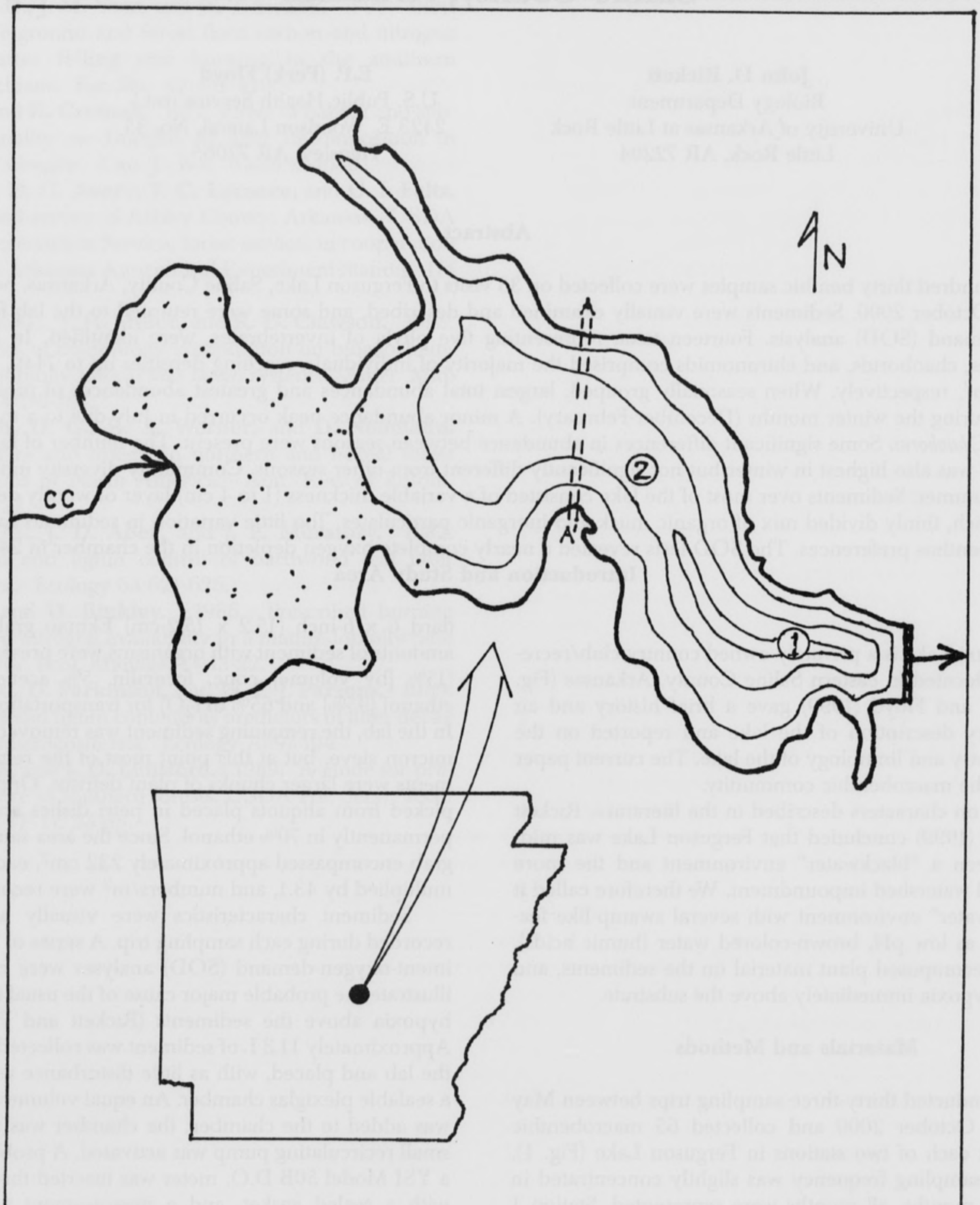

Fig. 1. Location of Ferguson Lake, Saline County, Arkansas.
Stippling: swamp dominated by tupelo gum, *Nyssa aquatica* A-A': original dam from "high" point (A) to "low" point (A')
CC: Clear Creek
Depth contours: 1 m intervals

Table 1. Benthic taxa collected in Ferguson Lake, May 1997-October 2000

(Code: N43/S2/4-30-98 = 43/m^2 organisms were collected at sta. 2 on 30 Apr 98)

Nematoda (N43/S2/4-30-98; N21.5/S2/5-19-99; N21.5/S1/3-21-00; N21.5/S2/4-27-00; N21.5/S2/10-17-00)
Nematomorpha (N21.5/S2/6-24-97; N21.5/S1/1-23-98; N21.5/S1/3-24-98; N21.5/S2/10-29-98; N21.5/S1/10-1-99; N64.5/S2/10-1-99)
Annelida
- Oligochatea

Mollusca
- Bivalvia
  - Sphaeriidae
    - *Sphaerium* (fingernail clam)

Arthropoda
- Arachnida
  - Hydracarina (N43/S2/1-23-98; N21.5/S2/2-13-98; N21.5/S2/12-3-98)
- Copepoda
- Cladocera
- Ostracoda
- Insecta
  - Ephemeroptera (mayflies)
    - Caenidae
      - *Caenis* (N21.5/S1/3-24-98)
  - Trichoptera (caddisflies)
    - Polycentropidae
      - *Nyctiophylax* (N21.5/S1/4-23-98; N21.5/S1/4-30-98; N21.5/S2/5-19-98)
  - Megaloptera
    - Sialidae (fishflies)
      - *Sialis* (N21.5/S1/1-23-98)
  - Diptera (flies)
    - Chaoboridae (phantom midges)
      - *Chaoborus*
    - Chironomidae (midges)
    - Heleidae (biting midges)

ples or abundance of those present with the occasional applications of lime and fertilizer to the lake was also attempted.

Results and Discussion

Taxa and abundances.--Organisms were identified using Edmondson (1959), Edmunds (1976), Merritt and Cummins (1978), Pennak (1978), Thorp and Covich (1991), and Wiggins (1977). Fourteen taxa representing five phyla were identified (Table 1). Nematoda, Nematomorpha, Hydracarina, *Caenis* sp., *Sialis* sp. and *Nyctiophylax* sp. were seldom found and constituted small portions of the samples. The remaining eight taxa were collected frequently and are discussed later.

Of the six times Nematoda were collected, five occurred in the spring months; the other time was in October. Nematomorpha were collected three times in October and once each in January, March, and June. Water mites (Hydracarina) were collected three times in December, January, and February, whereas the caddisfly, *Nyctiophylax* sp., was collected twice in April and once in May. The fish-fly, *Sialis* sp., and mayfly, *Caenis* sp., were collected once each in January and March.

Figure 2 shows mean total numbers of organisms per sample throughout the study. Numbers exceeding 10,000 per square m were collected in February 1998, January and March 2000, whereas mid-year samples generally showed the lowest abundances. However, Figure 3 illustrates a numerical surge in July due to a mid-year generation of *Chaoborus* sp. Lowest monthly abundances occurred in May and September. Figure 4 shows the greatest abundance in winter and the lowest during the summer months due to the annual cycle of pupation and emergence of adults.

Figure 5 shows that the largest mean number of taxa per sample (8.7) was collected in March and the lowest number (5) was collected in August and September with a relatively smooth annual cycle. Figures 6 and 7 exhibit the taxonomic composition of samples by percent. The "other 1" category from Figure 6 is expanded in Figure 7 to give percents of cladocera, ostracods, heleids, and sphaeriids. The "other 2" category in Figure 7 includes the nematodes, nematomorphs, and others listed above. *Chaoborus* sp. comprised 23-91% of samples, exhibiting two distinct modes--one in August and a smaller one in January. Chironomids comprised 2-39% and exhibited a cyclic periodicity opposite that of *Chaoborus* sp., that is, when *Chaoborus* sp. comprised their largest percents, chironomids comprised their smallest. Sample components made up by oligochaetes ranged from 3-29%, and in general, followed the same pattern as that of the chironomids. The percent composition of copepods ranged between one and 18%, also showing two cycles.

Chaoborus sp. larvae were more abundant (1000-6000/m^2) than chironomid larvae (100-3200/m^2). *Chaoborus* sp. exhibited their greatest abundance in July at nearly the same time chironomids were at their lowest. Oligochaetes were most numerous (2400/m^2) in March and least abundant (100-500/m^2) from June through August. Semi-benthic copepods were most abundant (about 600/m^2) from April through June and least abundant (60/m^2) in September.

Semi-benthic cladocerans were most abundant (64/m^2) in March and absent from all samples from June through August (Fig. 7). Fingernail clams (*Sphaerium* sp.) were most abundant (150/m^2) in November and absent in September, whereas in other months the clams exhibited much irregularity of abundance. Ostracods were absent from May through August and virtually absent in April and September but exhibited a peak abundance of $504/m^2$ in November (Fig. 7). Heleids exhibited low numbers ($0-10/m^2$) from June through August and a peak of $250/m^2$ in December (Fig. 7).

The percent of samples comprised by ostracods ranged from zero in June and August to 6.3% in November (Fig. 7). The same for heleids was zero (June) to 3.5% (December), whereas cladocera were not present June through August and November and comprised 0.82% in April. The 0% in November doesn't fit the cycle and may have been due to sampling error. The month-to-month percents comprised by *Sphaerium* sp. exhibited too much irregularity to identify a pattern.

Somewhat unusual was the large number of (semi-) benthic copepods and cladocera in most of the samples. We were not able to determine if these organisms were actually on the surface of the sediment or in the water just above. The first author collected macrobenthos samples using the same methodology from Dardanelle Reservoir for many years and reported no copepods or cladocera in the samples (Rickett and Watson, 1994). In Ferguson Lake, copepods were collected in all months, but cladocera were absent during the summer months. The usually benthic ostracods (Pennak, 1978) (= eubenthos, according to Hutchinson, 1993) were also absent or nearly so from April through September. The summer absence of these latter two groups was probably due to the annual hypoxia (<1 mg/l) near the bottom of the water column (Rickett and Floyd, 1999), which was undoubtedly caused largely by a rather strong sediment oxygen demand (discussed later in this paper).

Figures 8 and 9 show seasonal percent composition of samples in the same interpretative pattern as Figures 6 and 7. *Chaoborus* sp. certainly dominated the summer samples and comprised nearly half of fall and winter samples (Fig. 8). Chironomids and oligochaetes together comprised only slightly more than 10% of the summer samples, but they

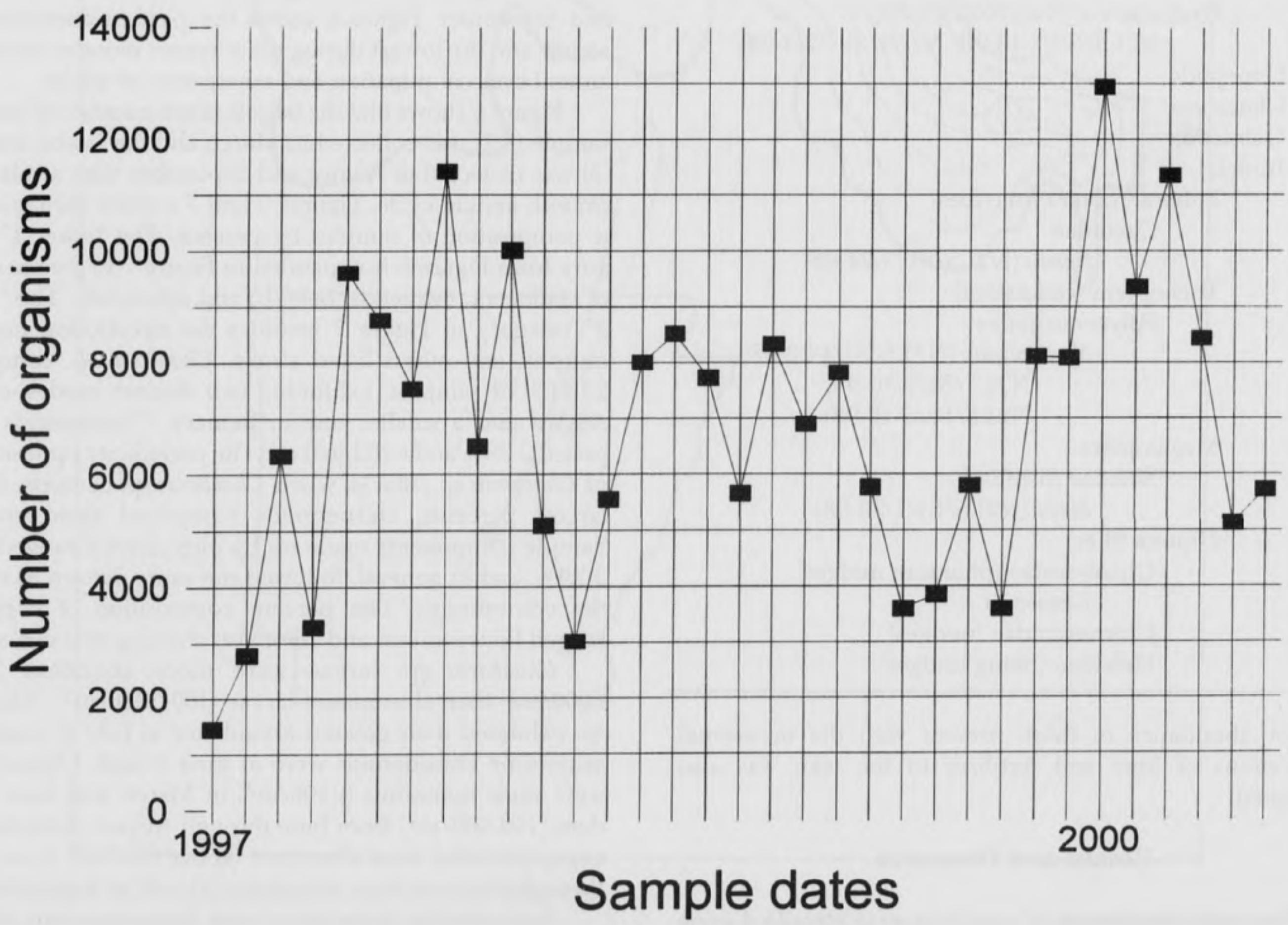

Fig. 2. Mean total numbers (per m^2) of macrobenthic organisms, Ferguson Lake, Saline County, Arkansas, 1997-2000.

omprised 40-60% in the other seasons. Copepods made up bout 5% in fall and winter samples and about 10% during pring and summer.

Ostracods comprised over half of the 5.6% made up by ne remaining taxa in the fall samples and virtually none of he summer samples (Fig. 9). Cladocerans were absent and eleids virtually so in the summer samples, but *Sphaerium* p. made up about 90% of the "other" taxa from Fig. 8.

Figures 10 and 11, respectively, show monthly and seasonal variations in three popular diversity indicators--taxonomic diversity, Margalef's richness, and Shannon-Weaver heterogeneity. Taxonomic diversity was relatively low all year but highest in April and lowest during July through September. Little difference was observed among the seasons. Margalef's richness was highest in March and April and lowest in August and September. Winter exhibited, by a slight margin over spring, the highest richness, whereas summer showed the lowest. With the exception of a slight secondary peak in December, both diversity and richness exhibited a smooth, single annual cycle (high in spring and low in summer). The Shannon-Weaver heterogeneity index fluctuated considerably by month but was highest in November, April, and January and lowest in August, July, and October. When months were combined into seasons (Fig. 11), this index exhibited a smooth one-cycle-per-year fluctuation with a peak in winter (only slightly higher than in spring) and a low in summer. Shannon-Weaver heterogeneity indices for the macrobenthic community in Dardanelle Reservoir ranged mostly between 0.6 and 1.0 (Rickett and Watson, 1994).

Table 2 contains critical values for tests examining for differences between sampling stations. For six of the eight taxa, the F-statistic revealed too much (significant) internal variation to place full faith in a subsequent t-test, so Mann Whitney-U tests were also conducted. No significant differences were found between sampling stations. The t-test on

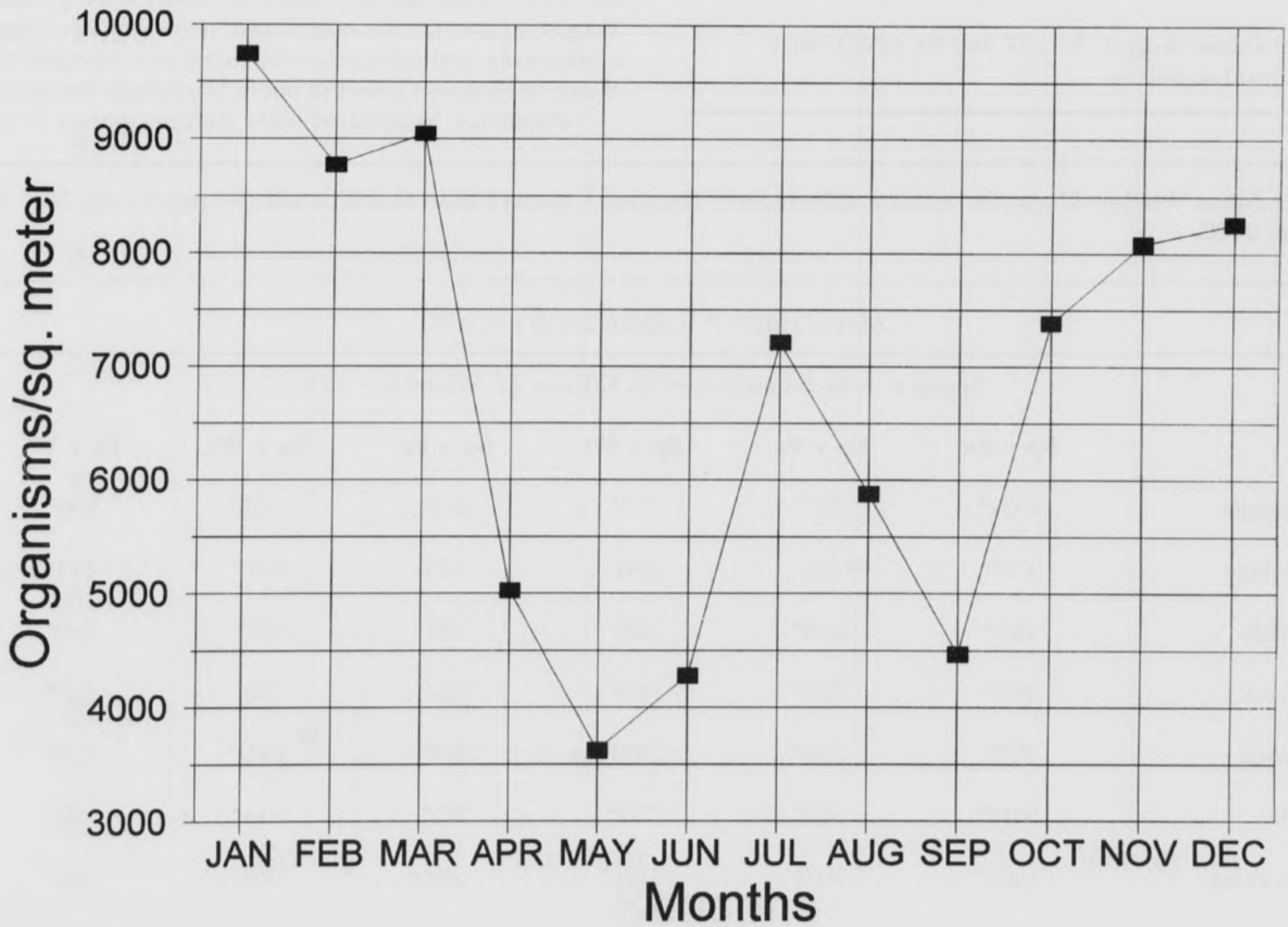

Fig. 3. Monthly mean number of organisms per square m, Ferguson Lake, Saline County, Arkansas, 1997-2000.

Table 2. Tests for significant difference between sampling stations, Ferguson Lake, Saline County, Arkansas.

taxa	F-value*	t-value*	MW-U*
Sphaeriidae	5.89**	2.30**	615
Oligochaeta	2.08**	0.32	431
Copepoda	4.79**	1.68	618
Cladocera	4.54**	0.13	551
Ostracoda	3.40**	0.78	526
Heleidae	3.57**	0.45	464
Chaoboridae	1.57	0.63	
Chironomidae	1.82	1.05	

*critical values: n-1=31; F=2.07, t=2.04, MW-U=630
**significant at p=0.05

Sphaeriidae most likely indicates a false significance. Having determined no significant difference between sampling stations overall, we then combined all samples in specified months to test for differences between any two seasons and found 36 of the 48 possible season-pairs with respect to individual taxa to be significantly different (Table 3).

The major macrobenthic taxa (oligochaetes, *Chaoborus* sp. and chironomids) present and abundance of oligochaetes in Ferguson Lake were approximately the same as in Dardanelle Reservoir, but abundances of *Chaoborus* sp. and chironomids were greater in Ferguson Lake. Margalef's richness and Shannon-Weaver heterogeneity indices between the two lakes were similar (Rickett and Watson, 1994). The total number of taxa present in Ferguson Lake was somewhat fewer than in Dardanelle Reservoir, and considerable variation occurred in the list of minor taxa between the two areas. For example, no hydras (*Hydra* sp.), bryozoans (*Urnatella* sp., *Pectinatella* sp.), snails (*Pleurocera* sp., Planorbidae), Asiatic clams (*Corbicula fluminea*), leeches (Hirudinea), amphipods (*Hyalella* sp., *Corophium* sp.), odonates (Odonata), or beetles (Elmidae) were present in Ferguson Lake. On the other hand, semi-benthic copepods, cladocerans, and ostracods were found in noticeable abundance in Ferguson Lake but not in Dardanelle Reservoir.

Wapanoca National Wildlife Refuge appears to be a

Table 3. Mann Whitney-U tests for seasonal differences in abundance of major macrobenthos taxa, Ferguson Lake, May 1997-October 2000.

MW-U values (* = significant at p = 0.05)						
Spring n = 38; Summer n = 32; Fall n = 24; Winter n = 36						
	Sp v Su	Sp v Fa	Sp v Wi	Su v Fa	Su v Wi	Fa v Wi
Oligochaeta	1032*	575*	757*	663*	1066*	598*
Sphaeriidae	637*	466	641	420	651*	444*
Copepoda	628*	1160*	579	319	621*	540*
Cladocera	864*	559*	765*	432	768*	523*
Ostracoda	797*	536*	1009*	568*	1002*	556*
Heleidae	1046*	565*	759*	582*	944*	472
Chaoboridae	1062*	707*	1121*	274	526	256
Chironomidae	1081*	485	696*	646*	1038*	444

type of aquatic habitat similar to the upper end of Ferguson Lake. Using dip nets and light traps, Harp and Harp (1980) collected many more taxa (163 taxa in four phyla, including nine orders of Insecta) than we did, but most of their collecting effort was in the littoral zone of the swampy area, whereas all of our collections were taken with an Ekman grab from sediments in or near the middle of the impoundment. A macroinvertebrate study of St. Francis Sunken Lands by Cochran and Harp (1990) yielded 243 taxa collected qualitatively with dip nets mostly in littoral zones of swampy areas. Likewise, Chordas et al. (1996) collected 219 taxa by dip nets and light traps in the White River National Wildlife Refuge. We are confident of recording many more taxa from the upper part of Ferguson Lake when time permits sampling that area.

Sediment Oxygen Demand.--The sediment was a non-uniform mix of finely-divided silt particulates and granular inorganic pieces. Overlying the sediment was a thick layer (1-4 cm) of slowly decomposing plant products (bark, tupelo and cypress foliage, and some tupelo seed pods), the accumulation of which apparently exceeded its decomposition. This detritus layer was slightly heavier at station 2 (closer to the upper end of the lake) than at station 1. The specific composition of the bottom material was also non-uniform horizontally.

SOD results are given in Figs. 12 and 13. Figure 12 shows dissolved oxygen in the chamber declined from 6.0 to 0.4mg/l in 24 hours when sediment from station 1 was tested. Correspondingly, readings over station 2 sediment declined from 7.9 to 0.5mg/l in a similar period. Except for the first hour, the rate of decline was very uniform. Figure 13 gives the amount of oxygen used per volume of sediment. During the first hour, sediment from station 2 used twice as much oxygen, and throughout the remainder of the 24-hour test, station 2 sediment continued to use slightly more oxygen than sediment from station 1.

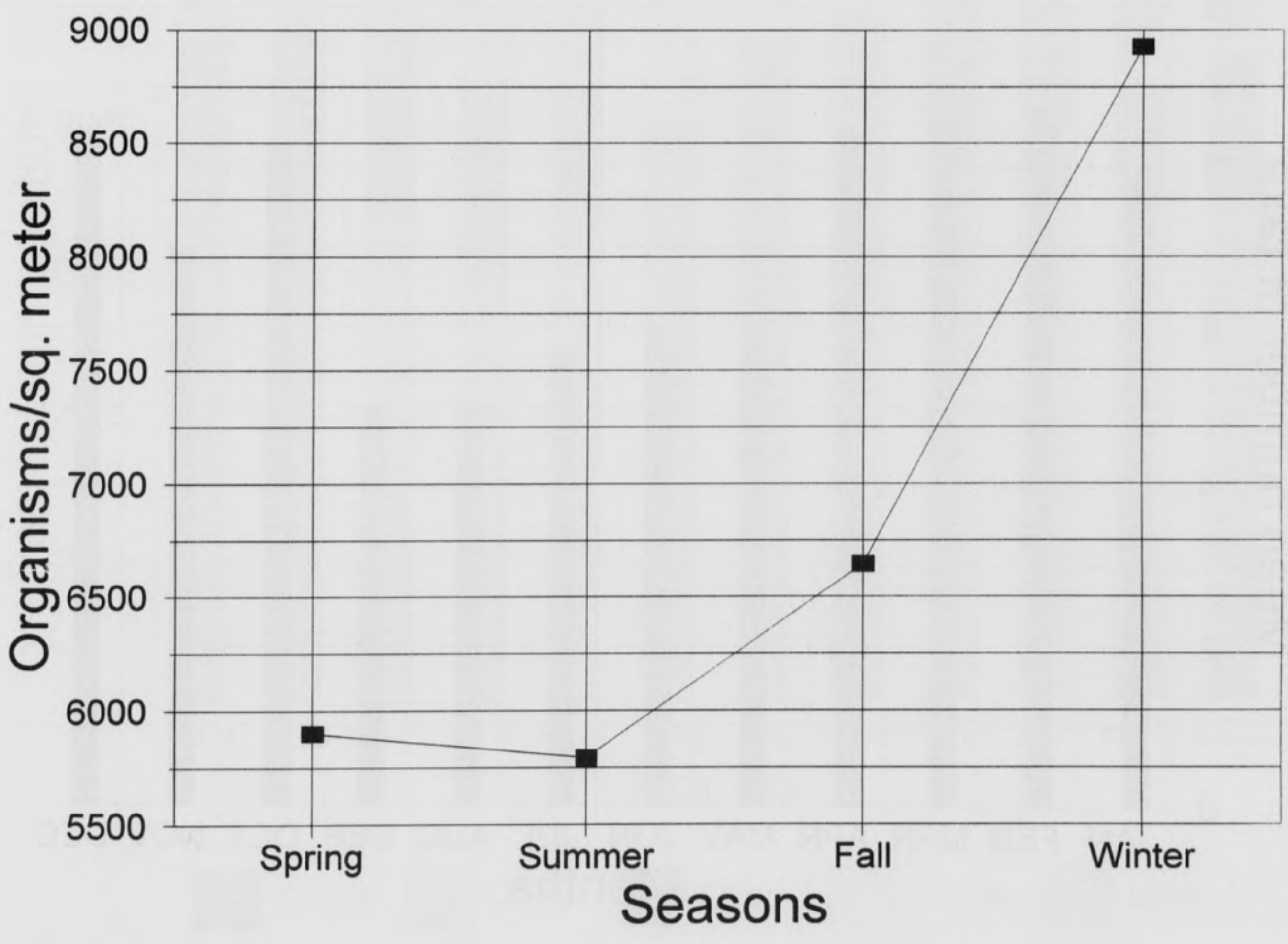

Fig. 4. Seasonal mean number of organisms per square m, Ferguson Lake, Saline County, Arkansas, 1997-2000.

Rickett and Edelman (1980) reported winter/spring SODs in Fourche Creek, Pulaski County, Arkansas to be 1.75 $g/m^2/day$, whereas summer SODs were 2.03 $g/m^2/day$, using the square measure of sediment in the chamber to represent a correspondingly representative square measure of stream sediment. If we let the 29.6 x 29.6-mm (876.16 mm^2) inside area of our SOD chamber to represent an equivalent area of Ferguson Lake substrate, we obtain 0.834 and 1.053 $g/m^2/day$ for stations 1 and 2, resepctively (mean: 0.944 $g/m^2/day$). This comparison indicates Fourche Creek sediment contained approximately twice the semi- and un-decomposed organic material as the sediment Ferguson Lake, but the water of a flowing stream would not be expected to contain as many organic acids as that of a body of standing water. The depression of pH normally associated with organic acids (such as in Ferguson Lake) would limit the rate of decomposition and therefore, the rate of oxygen consumption by the sediments.

Possible relation to lime and fertilizer applications.-- During our sampling period, attempts were made by others to stimulate fish production by the addition of lime (to raise the pH) and fertilizer (to stimulate plankton production). Two hundred fifty (U.S.) tons of agricultural, slow-release lime was added during late January and early February 1998. Correspondingly, pH rose from 6.1 to 7.0 in the following two months (Rickett and Floyd, 1999), rose sharply in May to 9.7 and declined steadily back to about 6.0 by December 1998. Since early 1999 the pH has fluctuated between 6.2 and 7.0, except for slight increases above 7.0 during the summers of 1999 and 2000 (Rickett and Floyd, unpubl. data). Rickett and Floyd (1999) also noted a long-term increase in pH (6.3 [1979-1989] to 7.0 [1997-1999] not apparently associated with liming. Liming has had little or no effect on permanemtly raising the pH.

Fertilizer was applied twice. In April 1999 nine (U.S.) tons of fertilizer (assay unavailable) was applied by plane.

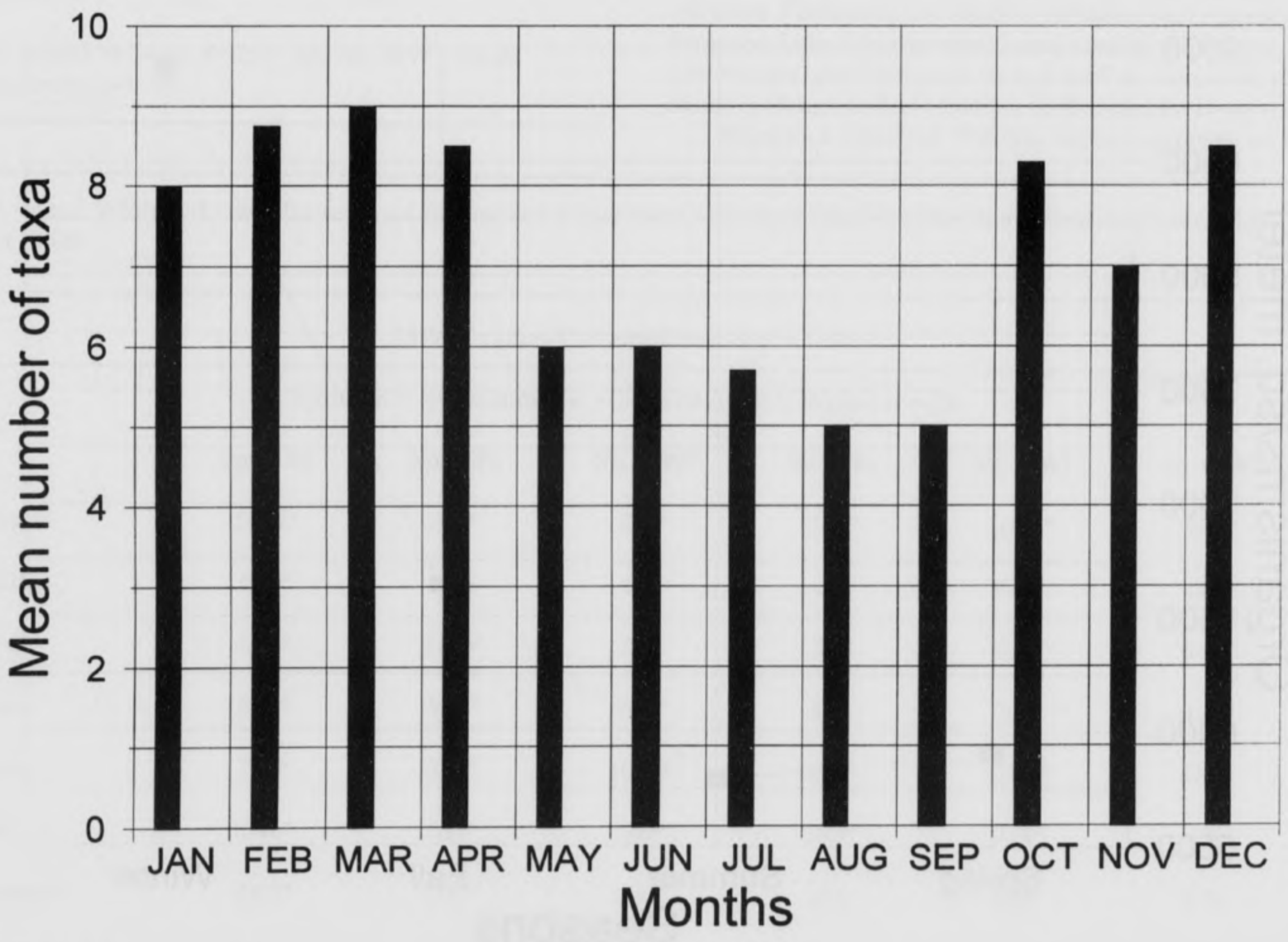

Fig. 5. Monthly mean number of macrobenthic taxa, Ferguson Lake, Saline County, Arkansas, 1997-2000.

Two days later most of it went over the spillway following a heavy rain. In April 2000 another 7.5 (U.S.) tons of fertilizer (18-46-0) was applied by plane. We would not expect fertilizer to have a direct effect on the macrobenthos community but probably on the planktonic community. A future paper will report on the plankton samples taken during this time period.

Summary

Fourteen taxa representing five phyla were collected in Ferguson Lake. Arthropoda was the most often represented phylum by taxa and numbers. *Chaoborus* sp. was the most abundant taxon followed by Chironomidae and Oligochaeta. These three taxa along with Heleidae, *Sphaerium* sp., and the semi-benthic copepods, cladocera, and ostracods comprised from 85-98% of all samples, with significant seasonal variation. All taxa exhibited seasonal cycles of abundance with lows in the summer and highs in late winter and early spring. All taxa but *Chaoborus* sp. and, perhaps, copepods demonstrated generally one high and low per year. *Chaoborus* sp. showed two highs and lows per year due to the appearance of a mid-summer generation. *Sphaerium* sp. showed the weakest seasonal cycle.

Lake sediments of silt and granular inorganics were overlain with heavy deposits of plant detritus, which apparently encouraged occupation by unusually large numbers of semi-benthic copepods, cladocerans, and ostracods. The decomposition of this detritus also caused significant hypoxia in summer in the water column 0.5 m above the sediments, and the organic enrichment of the silty/granular component was the basis of a rather strong sediment oxygen demand.

Community diversity indices (taxonomic diversity,

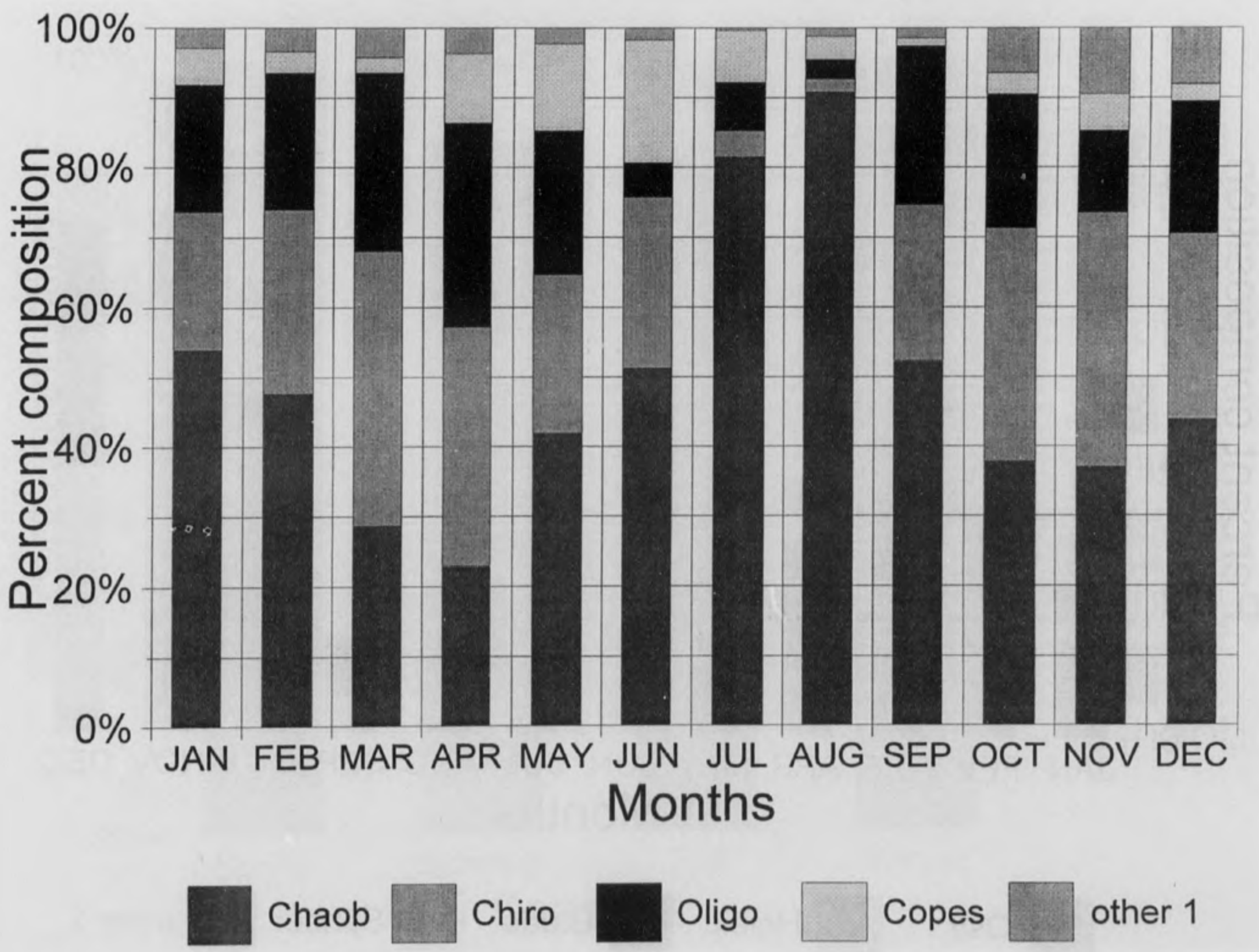

Fig. 6. Monthly taxonomic composition of samples by percent I, Ferguson Lake, Saline County, Arkansas, 1997-2000.

Margalef's richness, and Shannon-Weaver heterogeneity) indicated rather low diversity, but not significantly different diversity from other benthic communities in the region (e.g. Dardanelle Reservoir).

Literature cited

Chordas, III, S. W., G. L. Harp and **G. W. Wolfe.** 1996. The aquatic macroinvertebrates of the White River National Wildlife Refuge. Proc. Arkansas Acad. Sci. 50:42-51.

Cochran, B. G. and **G. L. Harp.** 1990. The aquatic macroinvertebrates of the St. Francis Sunken Lands in northeast Arkansas. Proc. Arkansas Acad. Sci. 44:23-27.

Edmondson, W. T., ed. 1959. Freshwater Biology, 2nd ed. John Wiley, New York.

Edmunds, G. F., Jr., S. L. Jensen and **L. Berner.** 1976. The mayflies of North and Central America. Univ. Minnesota Press.

Harp, G. L. and **P. A. Harp.** 1980. Aquatic macroinvertebrates of Wapanoca National Wildlife Refuge. Proc. Arkansas Acad. Sci. 34:115-117.

Hutchinson, G. E. 1993. Treatise on Limnology, vol. IV: The zoobenthos. John Wiley & Sons, New York, pp. 7-8.

Merritt, R. W. and **K. W. Cummins,** eds. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Publ., Dubuque, Iowa.

Pennak, R. W. 1978. Fresh-water invertebrates of the United States, 2nd ed. John Wiley & Sons, New York.

Rickett, J. D. and **P. Edelman.** 1980. An investigation of the streambed oxygen demand of Fourche Creek, Pulaski County, Arkansas. Proc. Arkansas Acad. Sci. 34:127-129.

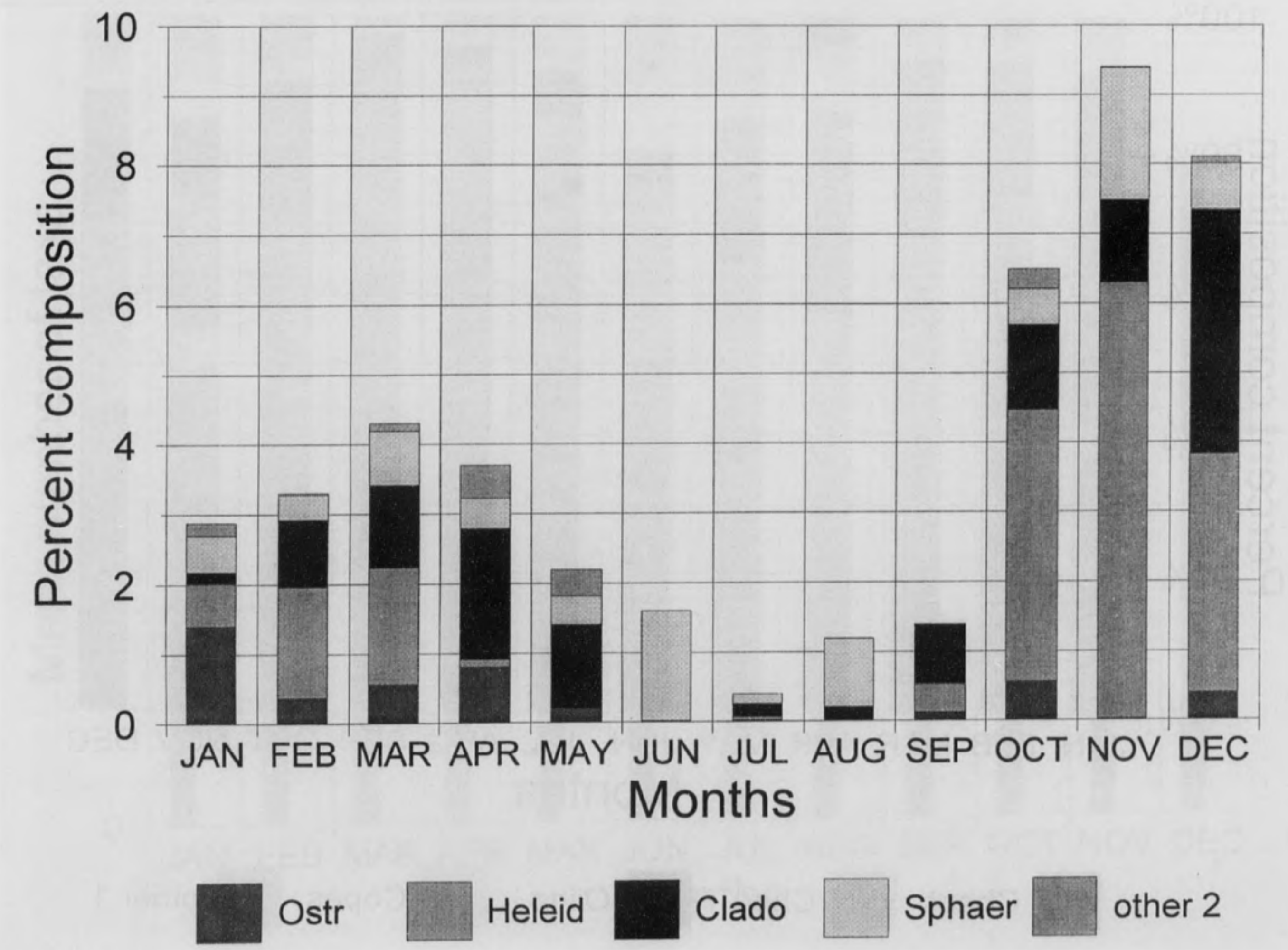

Fig. 7. Monthly taxonomic composition of samples by percent II, Ferguson Lake, Saline County, Arkansas, 1997-2000.

Rickett, J. D. and **E. P. Floyd.** 1999. Morphometry and Limnology of Ferguson Lake, Saline County Arkansas. J. Arkansas Acad. Sci. 53:101-107.
Rickett, J. D. and **R. L. Watson.** 1994. A long-term study of benthos in Dardanelle Reservoir. Proc. Arkansas Acad. Sci. 48:144-150.
Thorp, J. H. and **A. P. Covich,** eds. 1991. Ecology and classification of North American freshwater invertebrates. Academic Press, New York.
Wiggins, G. B. 1977. Larvae of the North American caddisfly genera (Trichoptera). Univ. Toronto Press.

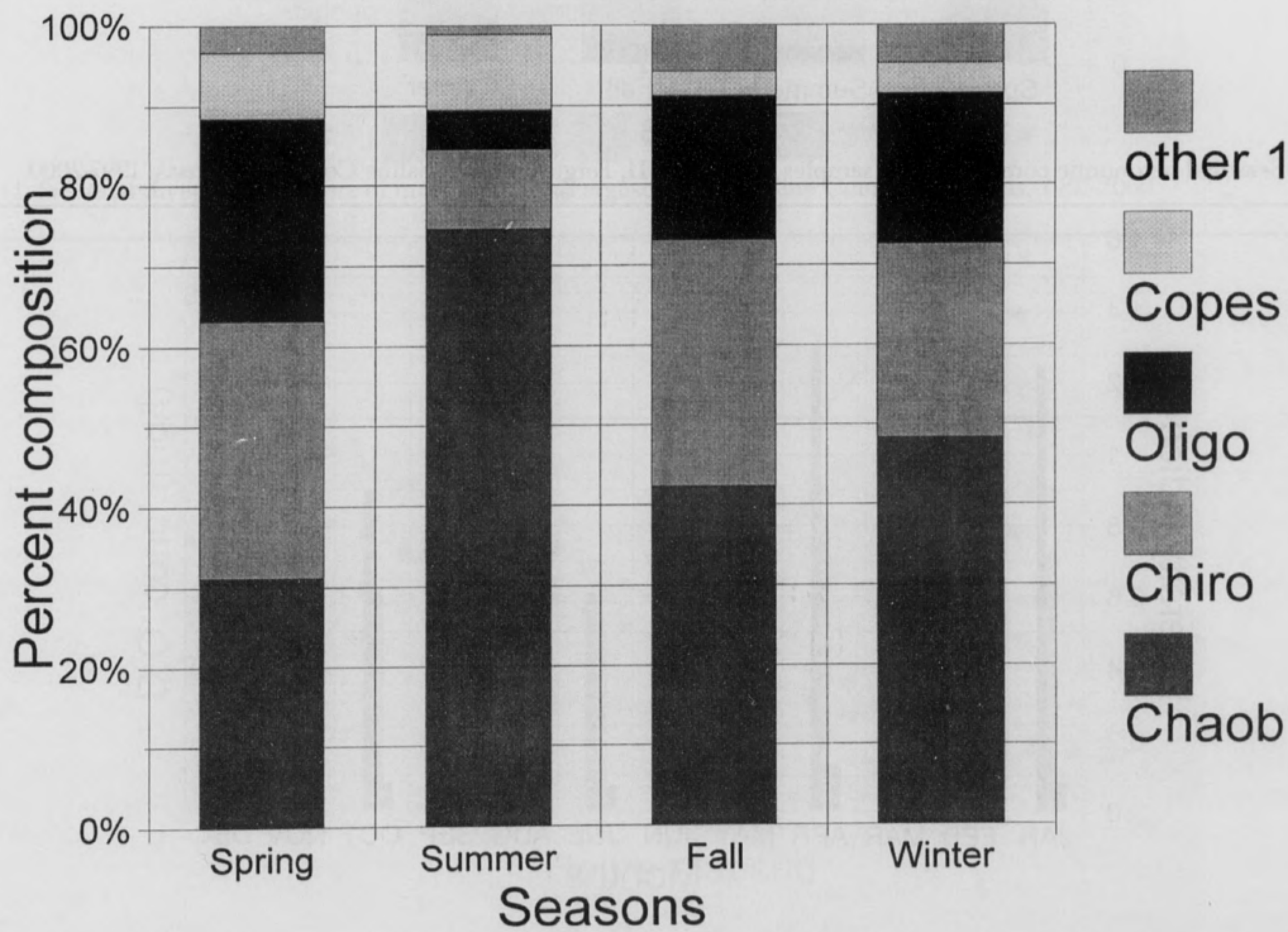

Fig. 8. Seasonal taxonomic composition of samples by percent I, Ferguson Lake, Saline County, Arkansas, 1997-2000.

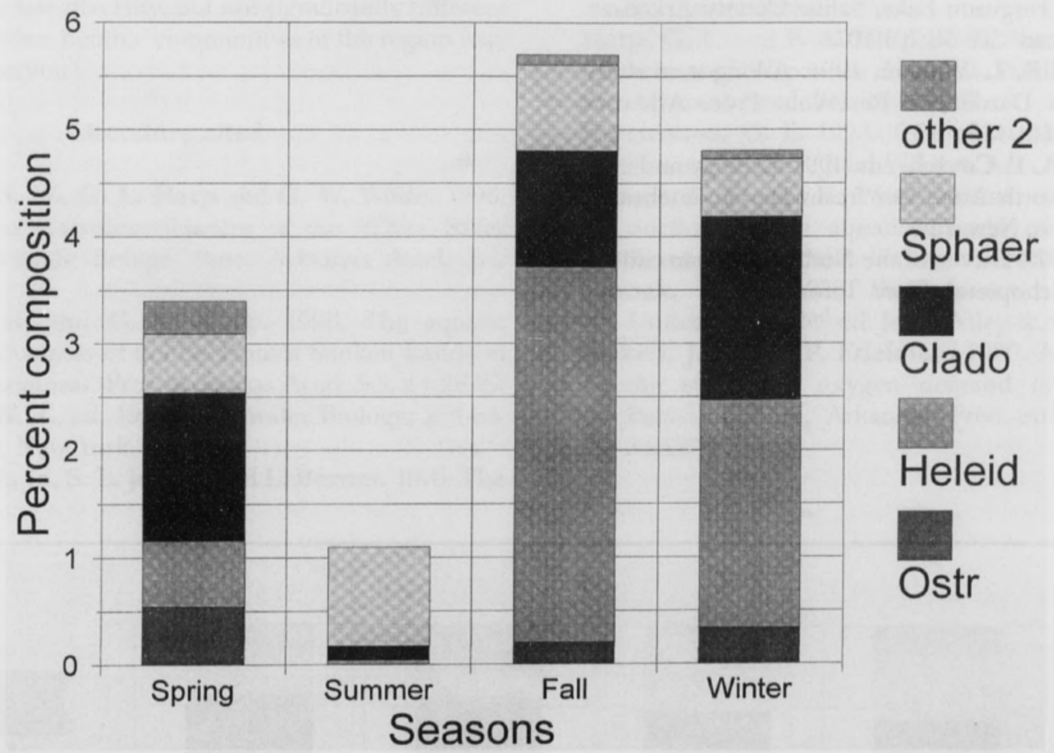

Fig. 9. Seasonal taxonomic composition of samples by percent II, Ferguson Lake, Saline County, Arkansas, 1997-2000.

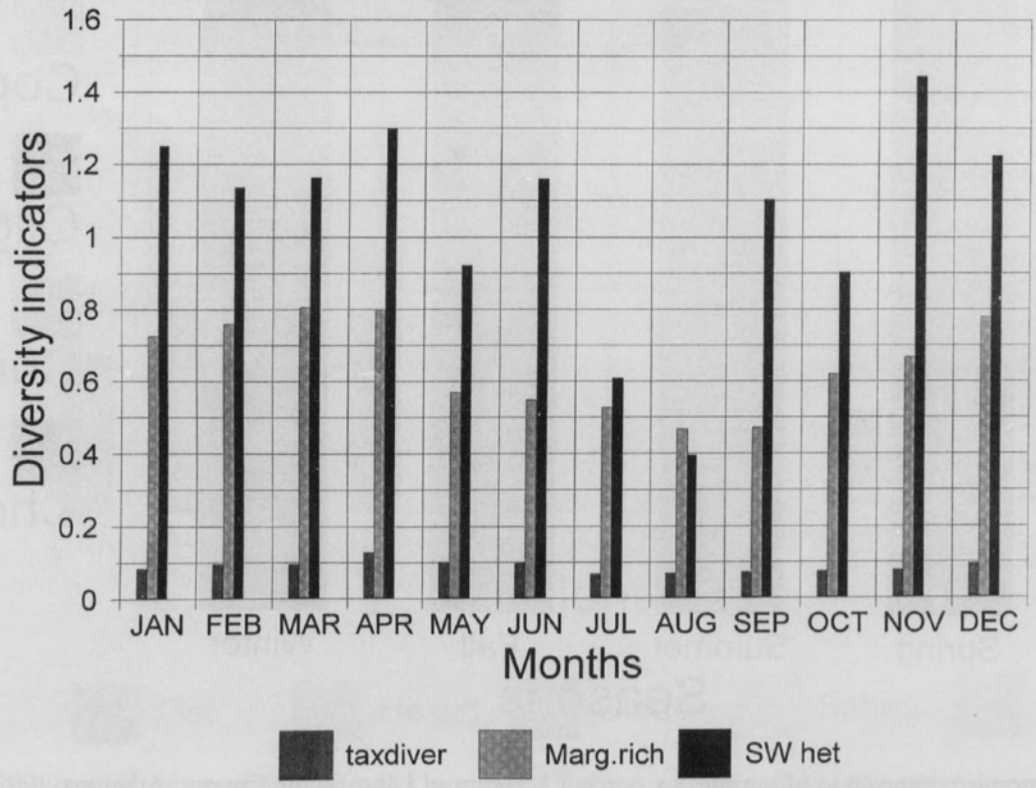

Fig. 10. Monthly diversity indicators of macrobenthos, Ferguson Lake, Saline County, Arkansas, 1997-2000.

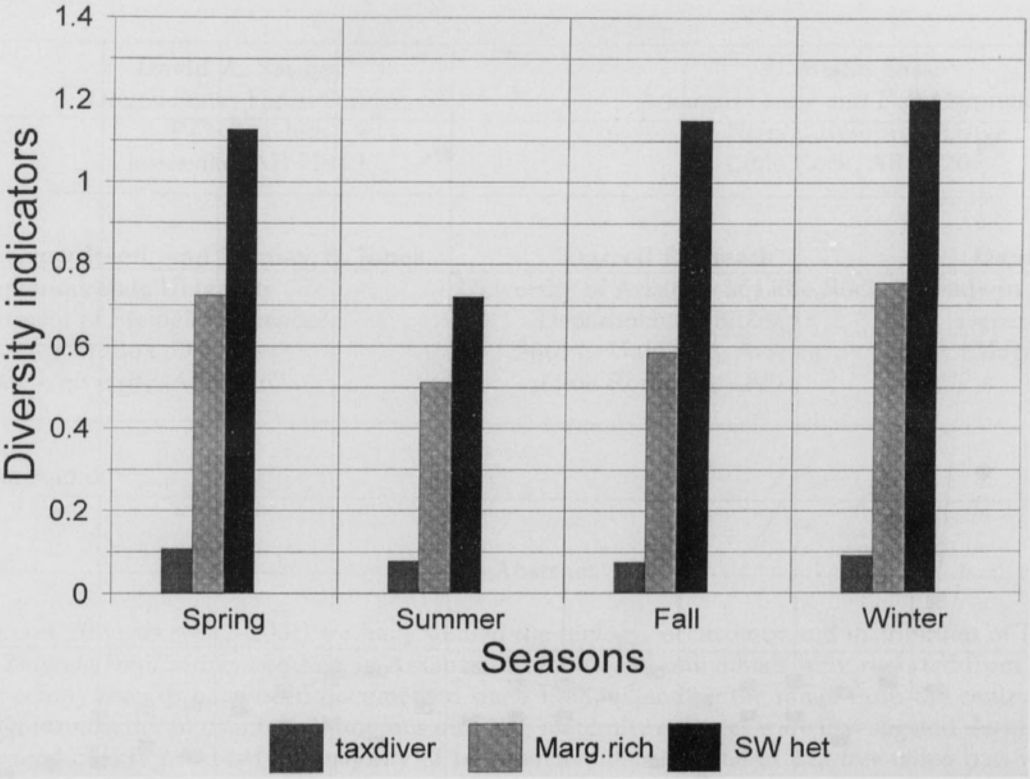

Fig. 11. Seasonal diversity indicators of macrobenthos, Ferguson Lake, Saline County, Arkansas, 1997-2000.

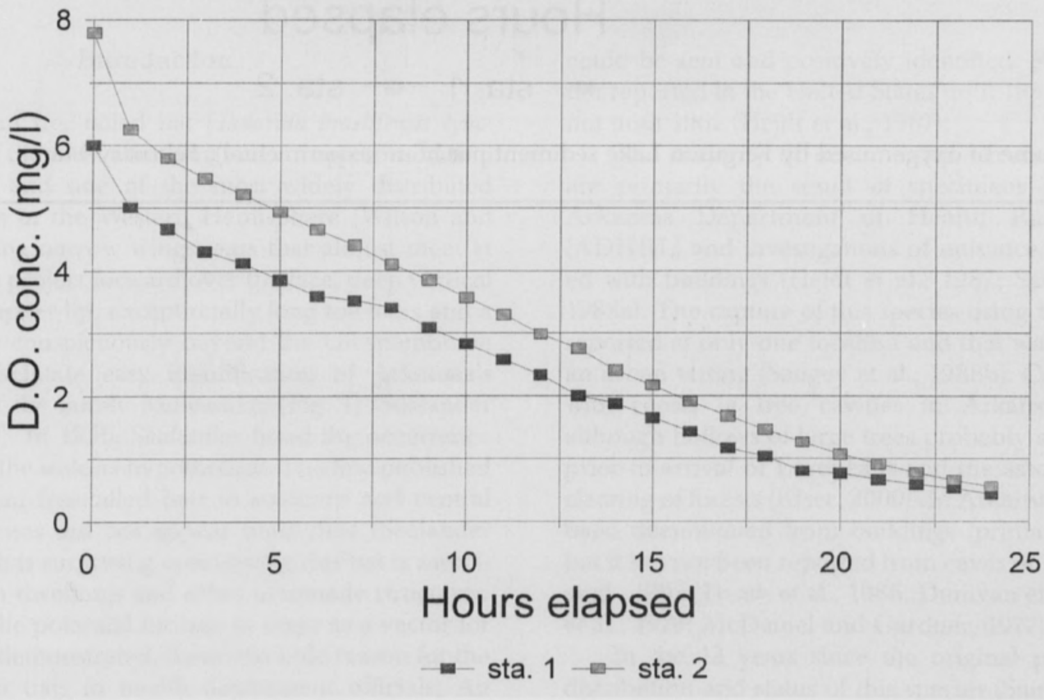

Fig. 12. Mean sediment oxygen demand (SOD) curves (experimental), Ferguson Lake sediment, February-March, 2000.

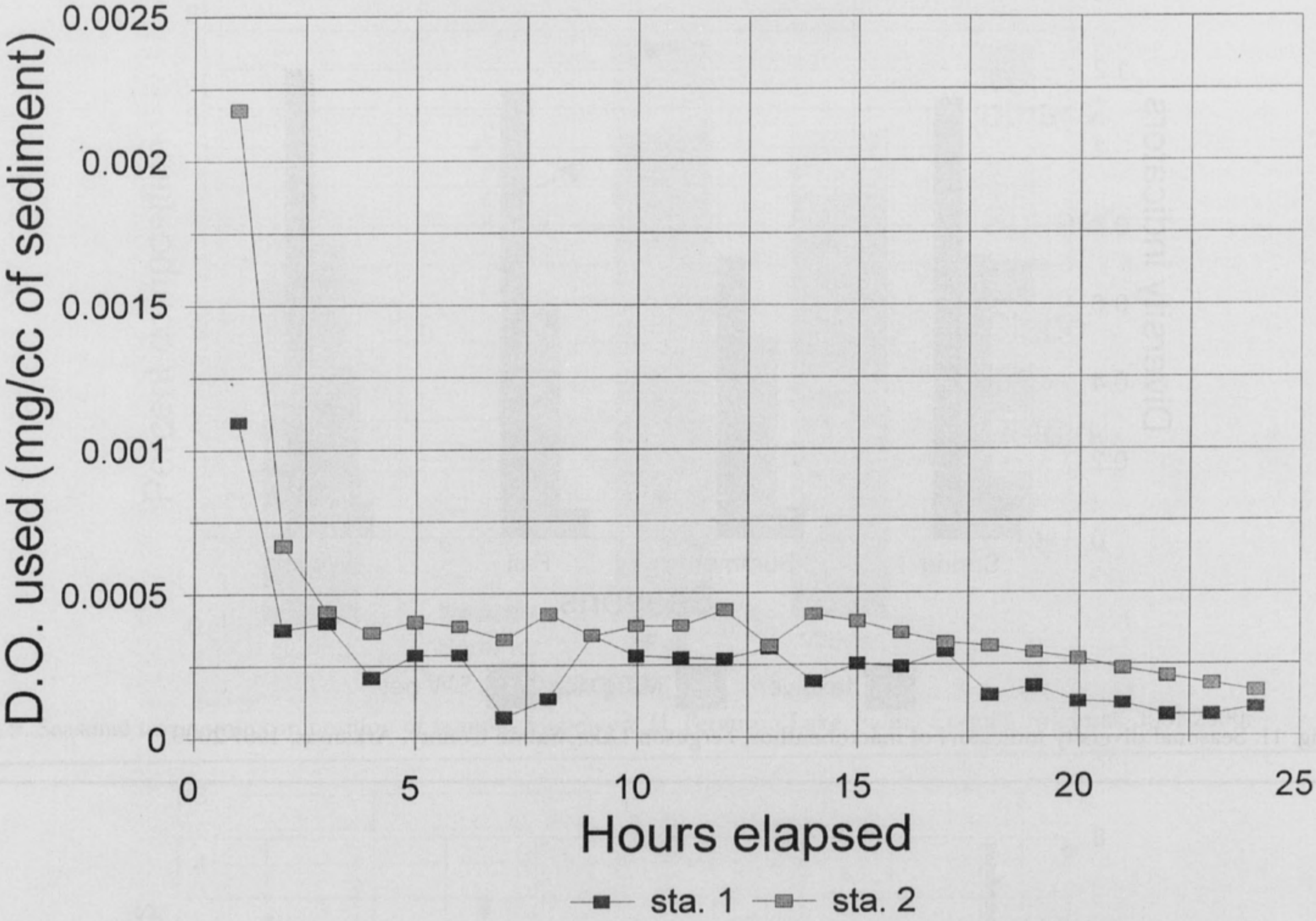

Fig. 13. Mean volume of oxygen used by Ferguson Lake sediment per hour (experimental), February-March, 2000.

Distribution of LeConte's Free-tailed Bat (*Tadarida brasiliensis cynocephala*) in Arkansas, with Notes on Reproduction and Natural History

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Abstract

During the past 20 years (1982–2001) we have studied the biology, occurrence and distribution of LeConte's (Brazilian) free-tailed bat, *Tadarida brasiliensis cynocephala*, in Arkansas. Colonies and individuals were reported from manmade structures only. Four new county records have been documented since 1988, extending the range from the central part of the state to Arkansas's northern-most tier of counties. Numerous nuisance maternity colonies were investigated during exclusion activities and one, year-round colony provided the majority of reproductive data. A total of 152 free-tailed bats was submitted to the Arkansas Department of Health Rabies Laboratory (1982–2001); most during February through April, a period that corresponded to annual mating activity. Pregnant bats had single embryos only in the right uterine horn and parturition occurred in mid-June. Seven specimens tested positive for rabies.

Introduction

The Brazilian free-tailed bat (*Tadarida brasiliensis cynocephala*) is one of the most abundant and conspicuous bats in North America and one of the most widely distributed mammal species in the Western Hemisphere (Wilson and Ruff, 1999). Long narrow wings, ears that almost meet at the mid-line and project forward over the face, deep vertical grooves on the upper lip, exceptionally long toe hairs and a tail that extends conspicuously beyond the tail membrane (uropatagium) facilitate easy identification of Arkansas's only member of the family Molossidae (Fig. 1) (Sealander and Heidt, 1990). In 1956, Sealander listed the occurrence of the species in the state as hypothetical. The first published report of Brazilian free-tailed bats in southern and central regions of Arkansas did not appear until 1964 (Sealander and Price), which is surprising considering this bat is associated with human dwellings and other manmade structures. However, until the potential for bats to serve as a vector for rabies had been demonstrated, there was little reason for the public to submit bats to health department officials. An additional factor may have been the virtual absence of biologists in the state with interests in bats to whom specimens could be sent and positively identified. Rabies in bats was not reported in the United States until 1953 and in Arkansas not until 1961 (Heidt et al., 1987).

The majority of documented occurrences of *Tadarida* are primarily the result of specimens submitted to the Arkansas Department of Health Rabies Laboratory (ADHRL) and investigations of nuisance colonies associated with buildings (Heidt et al., 1987; Saugey et al., 1983, 1988a). The capture of this species using mist-nets has been reported at only one location and that was in a park within an urban setting (Saugey et al., 1988b). Colonies associated with roosts in tree cavities in Arkansas are unknown although hollows of large trees probably served this species prior to arrival of Europeans and the associated large-scale clearing of forests (Kiser, 2000). In Arkansas, this species has been documented from buildings (primarily) and bridges, but it has not been reported from caves or mines (McAllister et al., 1995; Heath et al., 1986; Dunivan et al., 1982; Saugey et al., 1978; McDaniel and Gardner, 1977).

In the 13 years since the original publication of the distribution and status of this species (Saugey et al., 1988a), we had expected specimens to be submitted to the ADHRL from all major cities, particularly those adjacent to major

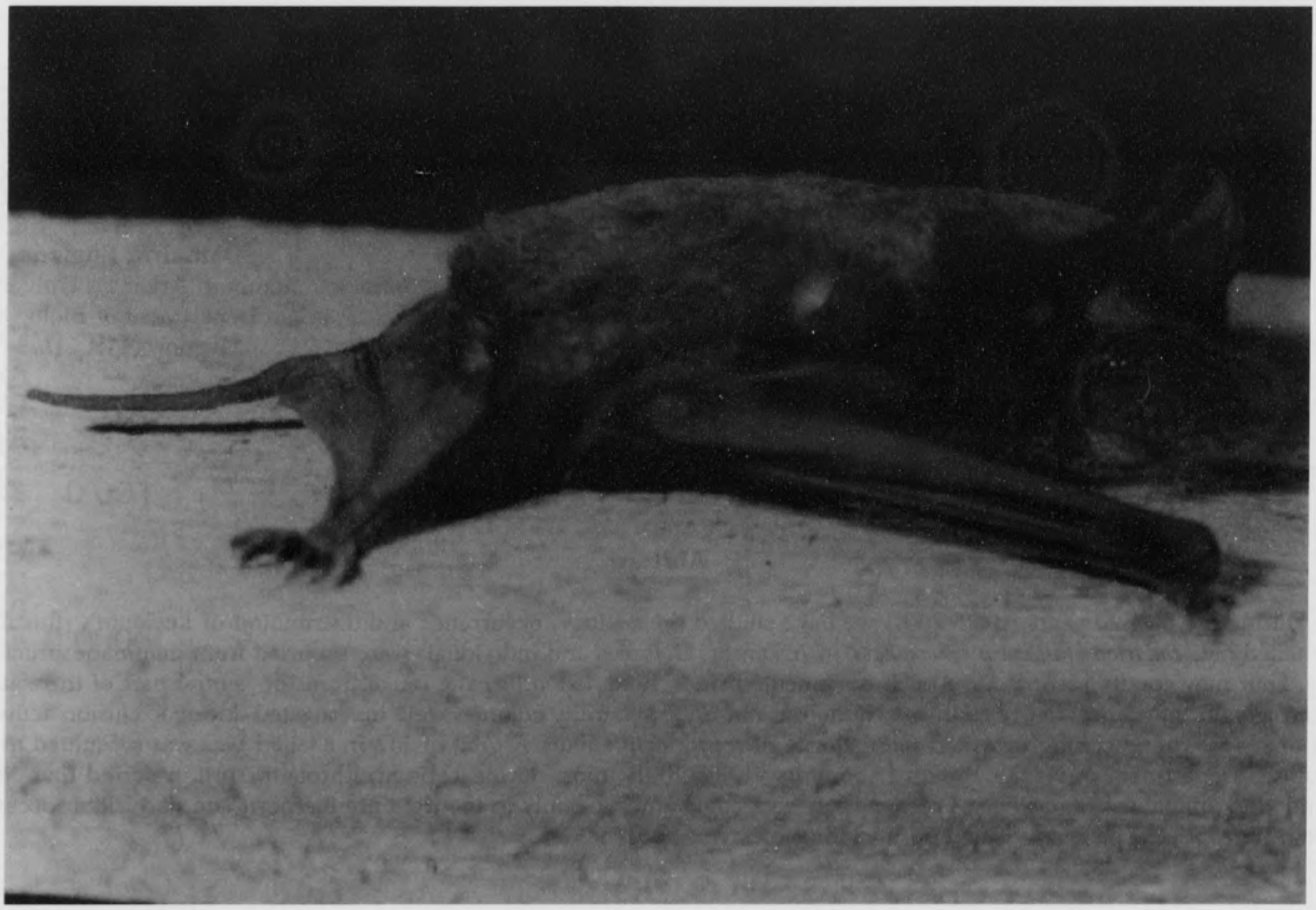

Fig. 1. Adult Brazilian free-tailed bat.

waterways, but this has not been the case. One would have thought public awareness of bats as potential vectors of rabies would have increased the incidence of reporting colonies of bats to public health officials and resulted in additional locality records.

Through the years, bats have been wing-banded using metal bands issued by the U.S. Fish and Wildlife Service and split-ring plastic bands purchased from A.C. Hughes Company. Bats recaptured from colonies in buildings are few because most were banded at the time of exclusion and have dispersed. A few individuals banded at a bridge in Ouachita County and at a house and bridge in Pike County have been recaptured but these colonies have been infrequently checked due to long travel distances. The purposes of this study were to determine the present distribution of *T. b. cynocephala* in Arkansas and summarize natural history and behavior observations.

Materials and Methods

Identification of specimens submitted to the ADHRL were made two or three times annually. Due to various stages of deterioration of submitted specimens and damage that occurred to skulls when tested for rabies, none were deposited in museum collections and should be considered "sight records." Investigations of nuisance colonies occurred when building owners requested assistance through extermination companies who passed information along to one of us or to the Arkansas Game and Fish Commission. The nuisance colony at Daisy and the observations at Self Creek bridge (both in Pike County) were made in conjunction with studies on the southeastern bat (*Myotis austroriparius*).

Bats were captured by hand and in traps when excluded from buildings using methods described by Greenhall (1982). Measurements of mass, length of body and length of left forearm (LFA) were taken to the nearest 0.1 g, 1 mm, and 0.1 mm respectively. Young-of-the-year bats were determined using a combination of closure of phalangeal epiphyses, overall size and color of fur. The position of the embryo in the uterus and rump-crown length also were recorded.

Results

Distribution.--*Tadarida* previously had been reported from 14 counties in an area encompassing the southern two-thirds of the state (Saugey et al., 1988a). We report four new county records as a result of submissions to the ADHRL (Boone, Baxter, Pike) and investigations of nuisance colonies of bats (Pike, Yell) (Fig. 2). Typically, little information accompanied bats submitted to the ADHRL with regard to conditions under which they were obtained. On 14 September 1990, a rabid male (ADHRL 297) was submitted from the city of Harrison, Boone County. Six juvenile females (ADHRL 67-72) were submitted from Mountain Home, Baxter County, on 8 July 1998. The fact these bats were juveniles and estimated to have been submitted within 30 days of their births clearly indicated the presence of an established maternity colony. A female (ADHRL 407) was submitted from Glenwood, Pike County, on 10 November 1999. An additional observation in Pike County occurred on 15 June 2001 when a maternity colony with about 45 bats was discovered in the attic of a home 5 kilometers (km) west of Daisy, Pike County. Pregnant *Tadarida* were observed roosting in a mixed colony with the big brown bat (*Eptesicus fuscus)* that had already given birth. In Alabama, Henry et al. (2000) also reported that parturition occurred slightly earlier in *Eptesicus* than in *Tadarida*. Four pregnant *Tadarida* had an average mass of 15.9 g (15–16.5) and LFA of 43 mm (41.8–44.9). A total of 6 bats, including one adult male, was banded and released. Four days later, one of the *Tadarida* banded at Daisy was accompanied by a number of non-

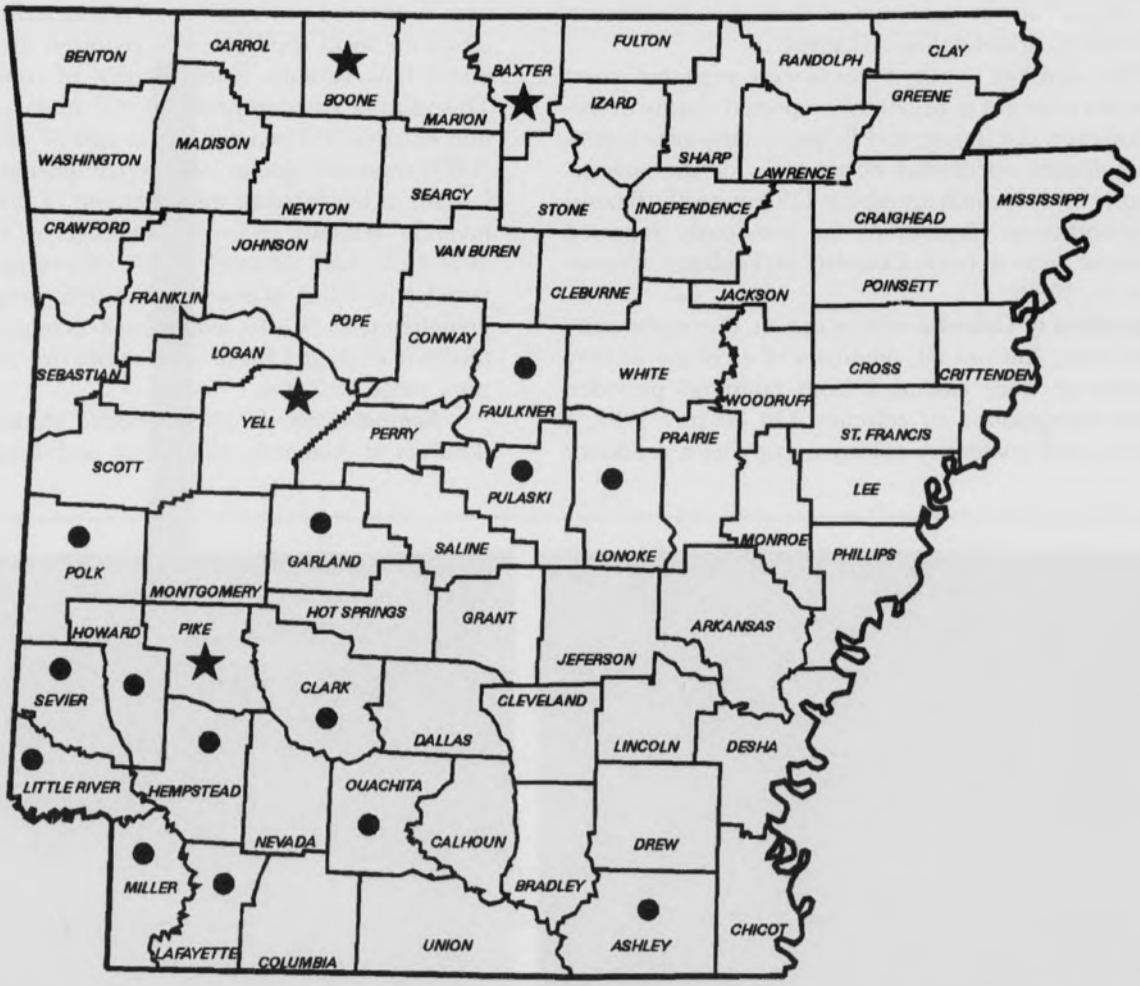

Fig. 2. Distribution of the Brazilian free-tailed bat in Arkansas. Solid circles are previously published county records. Stars represent new county records.

banded individuals day-roosting in a narrow space beneath a metal platform on the State Highway 70 bridge at Self Creek (Pike County). Self Creek bridge spans a portion of the U.S. Army Corps of Engineers' Lake Greeson Project and is home to a large (400-500) maternity colony of the southeastern bat. Individual *Tadarida* also were observed roosting in clusters of southeastern bats that occupied expansion joints in portions of the bridge located over water.

During late August 2001, male and female *Tadarida* were observed day-roosting with *Eptesicus* in an old classroom building at Plainview-Rover School in Plainview, Yell County. The colony roosted on the brick surface of an old chimney and in adjacent locations of the attic. Bats exited the structure through narrow spaces between wooden blocks placed between rafters at the roof's edge. *Tadarida* and *Eptesicus* in mixed colonies have been reported previously (Kiser, 2000; Henry et al.; 2000, Saugey et al., 1988a). Two males were collected for preparation as museum specimens for deposit in the mammal collection at Henderson State University, Arkadelphia, Arkansas.

The Pike and Yell county records were expected given their locations adjacent to previously reported county occurrences. However, the Baxter and Boone county sites constituted a significant northward occurrence for the species. Interestingly, both records are about 139 km north (Baxter) and north-northwest (Boone) of the previously reported northern-most record from Conway in Faulkner County (Saugey et al., 1983).

Composition of Colonies.--On occasion, the opportunity to capture some, but not all, members of a colony as they exited roosts or were excluded from buildings provided insight into composition of colonies. On 30 July 1993, a sample of a small maternity colony occupying a residence yielded 58 adult females, 41 juvenile females, 44 juvenile males, but no adult males. The colony was located in a brick home and used a small opening about 2.5 centimeters (cm) square to access the structure where they lived in a wall-space, not in the attic. A larger sample of 641 animals was collected and released from a maternity colony located in Hot Springs (Garland County) on 17 July 1999. The colony, which contained more than 2,000 animals, was in the attic and walls of a large, three-story wooden house originally constructed in 1913. The building, now owned by a church, had been covered with metal siding in recent years, but gaps between the siding and the original surface allowed easy access for bats. The colony primarily occupied the air space (chase) adjacent to both sides of the fireplace chimney that extended from the basement through the attic. Bats frequently were observed to roost directly on the chimney's brick surface, but would access the air space between the attic and upper floor when disturbed. The accumulation of crystallized guano along the attic ridgeline and support timbers confirmed observations of maintenance personnel and long-time local residents who reported the house had harbored bats virtually since its date of completion (Fig. 3). This sample was composed of 207 adult females, 184 juvenile females, 213 juvenile males and 37 adult males. LaVal (1973) reported similar colony compositions in Louisiana. Length of left forearm measurement of these bats revealed juvenile females (n = 10, average = 41.8 mm, range 40.9–42.8) had attained 98.1% of average LFA of adult females (n = 130, average = 42.6 mm, range 40–44.7), and juvenile males (n = 10, average = 41.5 mm, range 38.9–42.1) 98.3% of average LFA of adult males (n = 23, average = 42.2 mm, range 39.2–44).

Reproduction.--Unlike extended studies of colonies of *Tadarida* in Alabama, Louisiana, and Texas (Henry et al.,

Fig. 3. Free-tailed bat colony roosting in an attic (left) and accumulation of guano (feces) on rafters.

2000; LaVal, 1973; Spenrath and LaVal, 1974), conducting long-term studies of individual colonies of this species has proven problematic because owners and occupants of buildings are intolerant of their presence and want them immediately removed due to accumulation of guano and the excessively musky odor associated with colonies. However, we were able to engage in a protracted study (March 1983 – January 1984) of a large maternity colony located in an old dormitory building on the campus of Central Baptist College, Conway, Faulkner County (Saugey et al., 1983, 1988a). The roost structure was scheduled for demolition in early spring 1984 and the owners decided against exclusion. The dormitory was occupied by a small number of students who were, for the most part, absent on weekends and holidays. As a result, on winter days when students were absent, the building was heated to just above freezing to prevent rupture of water pipes and restroom facilities. The two-story building was constructed of double brick walls with a space in-between. The attic had a high ceiling, was large, and situated over an auditorium. The roost was shared with a colony of *Eptesicus.* The following observations and reproductive data are from the Conway location, unless otherwise noted, with information from other maternity colonies summarized and synthesized chronologically by month, regardless of year, to provide a partial picture of the biology of Brazilian free-tailed bats in Arkansas.

Examination of Fig. 4 indicates there are two periods in *Tadarida's* annual cycle when activity occurred at elevated levels and bats were submitted (submission event) to the ADHRL. We have defined a "submission event" as one or more specimens of *Tadarida* submitted to the ADHRL from the same locality on the same date. The majority of these submission events were represented by single specimens, but on occasion have included as many as 32 individuals. Interestingly, the major activity period occurred February through April when most vespertilionid bats are still deep in

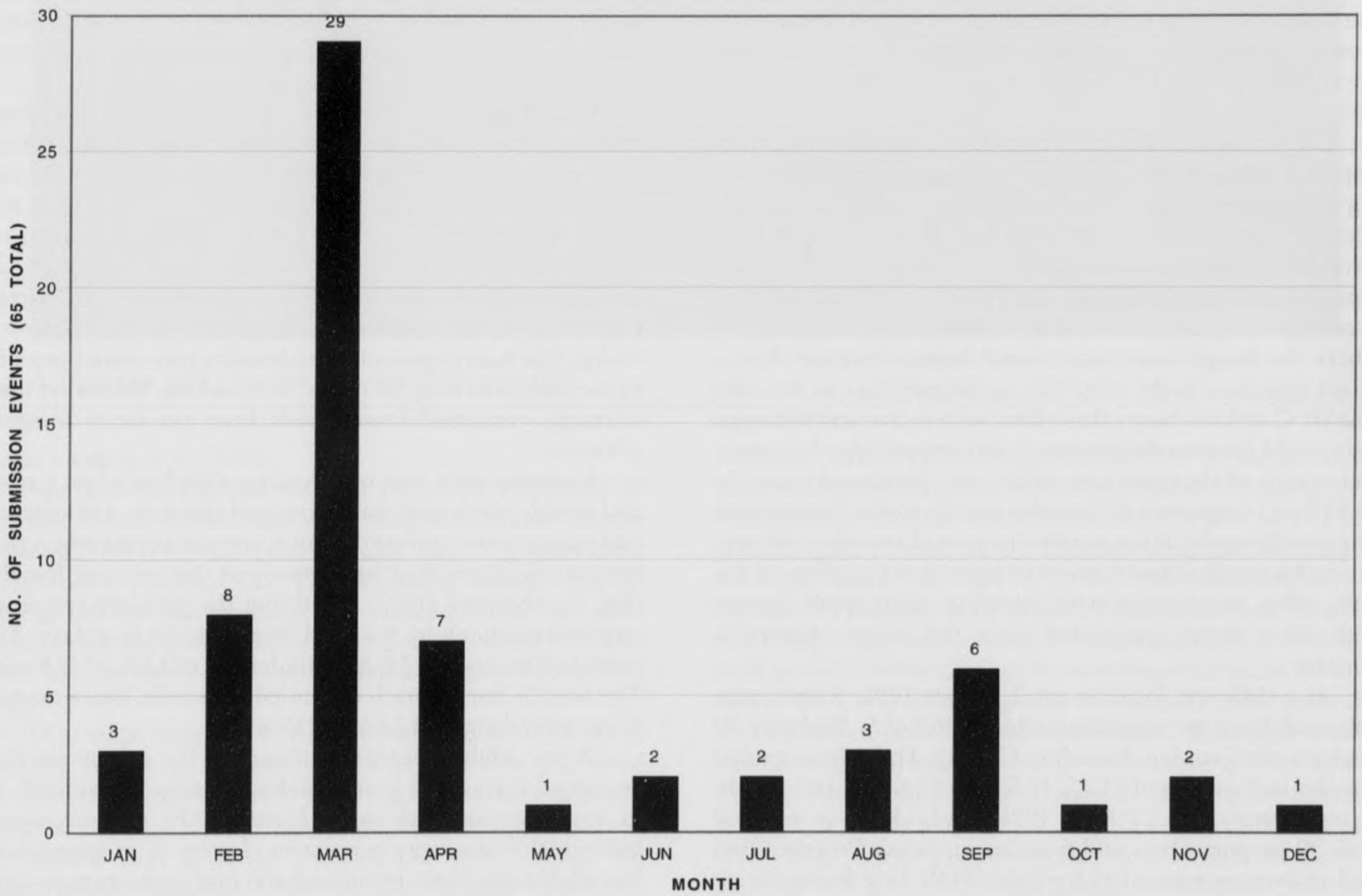

Fig. 4. Submissions of free-tailed bats to the Arkansas Department of Health Rabies Laboratory show two peaks. The February through April submissions probably are associated with breeding activity. The peak in September may result from increased activity as bats prepare for hibernation.

hibernation and inactive or have just begun to leave hibernacula for summer habitats. Although we did not observe copulation, this peak period was presumed to have corresponded with increased activity associated with mating (Sherman, 1937; LaVal, 1973; Henry et al., 2000). As discussed by Krutzsch (2000), this period of early spring activity is the monoestrous breeding season for temperate-dwelling molossids with male libido and female oestrous occurring concurrently. The male reproductive cycle is characterized by late winter-early spring recrudescence, spermatogenesis, and androgenesis. Oestrous females are inseminated during this period with fertilization following immediately and birth occurring during early summer. Sperm storage in interfemoral caudae epididymides, typical of temperate vespertilionids, does not occur.

Because most of the buildings colonized by *Tadarida* are human abodes, the incidence of submissions to the ADHRL are tied directly to periods when human/bat interactions are most likely to occur. We found the lower rate of submission events during the parturition period and when young were learning to fly, interesting. One might logically assume the number of human/bat interactions would be higher because the colony would have doubled in size, but this was not the case.

On 5 March 1983, we initiated our study at Central Baptist College where many *Eptesicus* were observed roosting along rafters with a few males of *Tadarida* interspersed. Female *Tadarida* were virtually absent from the open attic having moved through a small opening into an airspace between two brick walls. The area of congregation was near a corner along the south and west sides of the building where the temperature was several degrees warmer due to direct exposure to the sun. The air temperature in the attic was 20°C at 1330 hours (hrs). Bats were active and although they could be seen their capture was impossible. An extensive search of the open area of the attic produced a sample of 30 bats composed of 7 females and 23 males. Subsequent samples throughout the maternity period revealed the tendency for single males to roost in more open portions of the attic, often side-by-side with *Eptesicus*, or in small clusters with other males segregated from the larger clusters of females.

At a different location on 2 March 1991, 5 bats were collected from an expansion joint in the U.S. Highway 79 bridge near Camden, Ouachita County. Three females and 2 males had masses of 11.25, 12.5, and 13 g, and 11.5 and 16 g, respectively. On 27 April 1991, the bridge was revisited with 39 pregnant bats and 5 males captured. Pregnant bats had an average mass of 12.6 g (10.8–13.8). Five females were sacrificed and single fetuses removed. All fetuses were implanted in the right uterine horn. Rump-crown length averaged 14.4 mm (13–15.8), length of LFA averaged 5.4 mm (4.4–6.5), and mass averaged 0.4 g (0.3–0.5). Sex of fetuses was not determined. Average body measurements of sacrificed adult bats were total length 100 mm; length of tail 34 mm; length of foot 10 mm; length of ear 19 mm; length of tragus 4.5 mm; and length of LFA 41 mm. Mass of males averaged 11.4 g (10.8–12.8). On 4 May 2000, at the same location, mass of 6 pregnant bats averaged 12.8 g (12.0–13.3) and a single male 11.3 g, and on 11 May 1991, mass of 8 pregnant bats averaged 14.9 g (14.3–15.5) and 5 males averaged 12.9 g (12.5–13.5).

At the Conway site, on 4 June 1983, there were 1500-2000 *Tadarida* (primarily females) distributed among several large clusters scattered about the attic on the south and west walls. Numerous individuals also continued to occupy the airspace between brick walls. A thorough examination of these clusters and the attic in general did not reveal any neonates. Several small clusters of *Eptesicus* with neonates contained one to several pregnant *Tadarida*. Thirty-six pregnant *Tadarida* had an average mass of 16.1 g (15.0–19.0). Temperature and relative humidity in the attic were 35.5°C and 48%, respectively. Unlike observations by LaVal (1973) in Louisiana, and mentioned elsewhere in this document, we did not observe clusters of *Tadarida* hanging from open areas in the attic at the Conway site.

On 10 June, the majority of females were pregnant. Clusters of females previously described were intact, although more bats appeared to have moved into the airspace between brick walls. Females were more active on this day and attempted to retreat when a light was shown on them. Many females were visually examined with 28 weighed. Average mass was 17.1 g (15.0-19.0). Three lactating bats were examined and had masses of 12.5, 12.8, and 13.5 g. The heavy mass of some females may have been due to our early morning (0730 hrs) visit and the likelihood their stomachs contained insect foods from pre-dawn foraging activities.

Neonates were first observed on this date when a male and female, both with umbilicus and placenta still attached and moist, were removed from a crevice containing a portion of the cluster that had contained the lactating females (Fig. 5). Sherman (1937) noted that the placenta remained attached to young by the cord from 8 hours to 2 days. The male had a mass of 3.0 g and a length of LFA of 17.8 mm. The female, her stomach distended with milk, had a mass of 3.5 g and a length of LFA of 17.7 mm.

A few adult males were present in the colony site, but remained segregated from females, roosting individually or in small groups with male *Eptesicus*. On rare occasions, individual males were present in clusters of pregnant bats. Six adult males were examined and had an average mass of 13.9 g (13.0–14.8). Although exact ratios were not determined, females greatly outnumbered males. LaVal (1973) found females to outnumber males on all occasions

Fig. 5. Neonate with placenta and umbilicus attached.

by as much as a 5:1 ratio.

We returned the next day (11 June) and examined 10 females from a cluster. Nine were pregnant with an average mass of 15.4 g (14.5–17.3), considerably less (1.7 g) than those weighed the previous day. The remaining female weighed 11.8 g, and was not pregnant nor lactating. Only one additional newborn with umbilicus attached was observed. The male neonate had a mass of 3.0 g and a length of LFA of 17.7 mm.

One week later, on 18 June, we arrived at 0845 hrs to find the colony active and noisy. Pregnant bats and those having already given birth were segregated into different clusters, although a few pregnant individuals were observed in clusters with lactating females and their young. We observed an estimated 1,000 juvenile *Tadarida* ranging in age from several days to those recently born evidenced by the presence of attached umbilicae and placentae that were still moist and pliable. A majority of newborns appeared to be only hours old. About 50% of females had given birth by this date. LaVal (1973) reported about 50% of females in his study had given birth by 4 June. In Oklahoma, young were born during the latter part of June and the first part of July (Glass, 1958; Twente, 1956). Thirteen pregnant bats had an average mass of 16.3 g (14.5–17.5). Fifty-two juveniles (27 females – 25 males) were weighed, examined, and released. All young had been nursing, their stomachs distended with milk clearly visible through their abdominal walls. In both sexes, there was a small group of distinctly older juveniles that had been born several days earlier. The older female newborns (n = 3) had an average mass of 6.6 g (6.0–7.0) and average length of LFA of 23.9 mm (23–24.4), while younger females (n = 24) averaged 4.29 g (3.5–5.3) and 19.6 mm (18.4–21.5). Older juvenile males (n = 3) had an average mass of 6.9 g (6.5–7.3) and length of LFA of 24.9 mm (24.3–25.8). Younger juvenile males (n = 22) averaged 4.2 g (3.5–4.5) and 19.4 mm.

During our visit on 26 June, most adults and all juveniles were in the airspace or deep within crevices where ceiling beams entered brick walls. Clusters were not observed and areas on brick walls where clusters had occurred were devoid of bats. Whether this action was in response to our weekly visits or a deliberate attempt to take advantage of the cooler temperatures and breeze within the airspace was not known. LaVal (1973) observed similar behavior and indicated the site chosen for the nursery colony by *Tadarida* was especially favorable because it was immediately adjacent to the only opening of a concealed inter-roof space into which females and young could retreat if danger threatened or temperatures were cool. We have observed *Tadarida* selecting similar roost locations within three different colony sites. Interestingly, *Eptesicus* continued to roost in the vaulted area of the attic and in maternity clusters as previously described. Parturition was about 95% complete based on the large number of young seen in recessed areas and in the airspace, and the paucity of observable pregnant bats. Only one 15.0 g pregnant bat was observed in a small group of lactating females. Collection of juveniles was virtually impossible due to the small size of the opening into the air space, large enough to accommodate a human head and one hand holding a light. Hundreds of juveniles were observed with four collected from the surface of mortar between rows of bricks. Masses and lengths of LFA were as follows: males – 4.5 g/22.2 mm, 5.25 g/24.3 mm, 5.5 g/24.2 mm; female – 4.0 g/19.6 mm. The period of parturition for this colony was 10 – 28 June with the majority of young born on or near 18 June.

On 3 July 1983, many adult females were again clustered along the south and west walls. Numerous females were examined with none pregnant. A sample of 20 lactating bats was examined and had an average mass of 14.0 g (13.0–15.3). Mammary tissue was greatly enlarged and copious quantities of milk were easily expressed from elongated teats. The skin area around teats was completely devoid of fur due to nursing activity. Juveniles were not seen in the attic proper, but were observed in previously described inaccessible areas. Juveniles appeared agile and scurried and scampered about the brick surface, retreating farther from the opening when a light was introduced into the airspace. Juveniles were not captured. Observable mortality among juveniles in the open attic area was deemed negligible considering the size of the colony. The carcasses of only 5 individuals were seen atop fresh piles of guano that lay beneath clustering sites along the south and west walls. Juveniles dislodged at these locations would have fallen about 1 meter (m) and could have climbed the wall or been retrieved by their mothers. However, mortality of juveniles within the air space was probably much higher due to the 10 m drop from the attic to ground level. Juveniles falling from this height probably would have died on impact, been difficult to retrieve, and exposed to a variety of insect predators. Three adult male *Tadarida* removed from a cluster of *Eptesicus* had masses of 12.8, 13.3, and 13.5 g.

A colony located in a residence in Little Rock (Pulaski County) was examined on 6 July 1989. Fourteen lactating bats were captured. Three females apparently were entering post-lactation as fur re-growth around teats had begun and the quantity of milk expressed from mammary glands was far less than from other females. These bats had an average mass of 14.0 g (13.0–15.0). Interestingly, exactly 2 years later (6 July 1991), a maternity colony in a home in Hot Springs was examined. Ten adult females and one adult male were captured. All females were lactating and had an average mass of 13.4 g (11.5–14.8). The male had a mass of 12.3 g. *Tadarida* shared this roost with a maternity colony of the evening bat, *Nycticeius humeralis.*

On 13 July 1987, a building in Hot Springs that contained nursery colonies of *Tadarida* and *Eptesicus* was examined. The open area of the attic was unused by either species with both colonies located behind facia boards along the warmer, southern edge of the structure. Both species used the same access point and were seen simultaneously exiting the roost. Of 25 females captured, 24 were lactating. These lactating females had an average mass of 12.0 g (11.0–13.5).

A maternity colony sharing its roost with *Eptesicus* was reported from Hot Springs on 4 August 1989. Both species occupied a small space between a brick veneer wall and concrete blocks in a school building. Fifty-four *Tadarida* were captured as they exited the building to forage. Juveniles were easily distinguished from brown colored adults by their gray fur and generally smaller size and mass. Nine juvenile males had an average mass of 10.6 g (9.3–11.3) and an average length of LFA of 42.7 mm (41.5–43.5), 101% of the adult male average length of LFA, but within the normal range for adult males. Juvenile females (n = 10) had an average mass of 10.3 g (8.8–11.8) and an average length of LFA of 42.2 mm (41–43.8), 99% that of adult females. Post-lactating females (n = 12) had an average mass of 13.3 g (12.0–14.8), while lactating females (n = 15) averaged slightly less at 13.1 g (12.0–14.3). Eight adult males had an average mass of 12.0 g (11.5–13.3).

On 30 August 1987, an additional mixed maternity site for *Tadarida* and *Eptesicus* was discovered in Hot Springs that provided for interesting observations of behavior. A hopper style bat trap (Greenhall, 1982) was erected at the primary roost exit with a bag attached to the bottom to retain captured bats. The trap was erected several hours before sunset and all other known exits previously used by the colony had been thoroughly sealed. After the evening exodus had begun and bats became entrapped in the bag, small "swarms" composed of 10-15 bats would descend on the colony site at 30-45 minute intervals. Members of these swarms repeatedly flew to, landed upon, and crawled about the surface of the bag in apparent response to distress calls from bats within. Observations of similar behavior by red bats (*Lasiurus borealis*) have been reported by Baker and Ward (1967) and Saugey et al. (1988b, 1989).

An additional observation seemed to indicate the possibility that members of these colonies used multiple roosts. As swarms of bats descended on the building, they attempted to enter the structure by way of previously used, but now sealed, access points. The arrival of bats from other locations attempting to enter this roost structure suggested that small, scattered colonies in the area may have been subunits of larger, freely intermingled populations of *Tadarida* and *Eptesicus*, and that use of multiple roosts a common occurrence. We have documented the use of multiple roosts by *Nycticeius* in the Hot Springs area when bats banded at one location were recovered at later dates from three different homes within the city by Hot Springs Animal Control personnel.

The Conway location was revisited on 5 November 1983. The bats were quiet, exhibited little activity, were cool to the touch, and appeared to be in torpor. Temperature in the attic was 22.2°C with a relative humidity of 52%. Females were clustered on walls in the same locations as when pregnant and lactating in the summer. A sample of 47 females was examined that probably contained a mix of adults and young-of-the-year. Average mass was 17.3 g (14.0–19.8). A single male was found roosting within clusters of females. All other males were found roosting with male *Eptesicus* scattered along ceiling joists throughout the attic. Six males were fat and had an average mass of 16.6 g (14.5–18.5).

On 4 December, the colony was quiet and inactive. The temperature was 16.9°C and the relative humidity was 64%. Females continued to cluster along the south and west walls and in the airspace. Twenty-four females were examined and weighed. Average mass was 14.3 g (13.0–16.0), 3.0 g lighter than the November group. Males exhibited a similarly reduced average mass of 13.9 g (13.0–16.3), 2.7 g lighter than November. Possible causes for such a reduction in average masses may have included a greater percentage of young-of-the-year bats in the December sample, and the extremely cool temperatures from mid-November to early December coupled with a reduced level of building heat. Lowered roost temperatures probably would have required additional energy expenditure by bats. Because bats were not wing-banded, individual loss of mass was impossible to determine.

The last observation at Conway occurred on 5 January 1984. The outside air temperature was –3°C, and, although the temperature in the attic was not recorded, it was well below freezing as evidenced by the accumulation of ice on the interior attic walls. All major sources of heat in the building had been reduced during the holiday break with only small, gas, space-heaters in bathrooms. Examination of a tightly packed cluster of *Tadarida* on the west wall revealed all but one of the 102 individuals frozen. A thorough search of the entire attic produced 20 live *Tadarida* in the air-space between walls. Eight bats, three females and five males, were weighed. Females had masses of 12.8, 14.3, and 14.3 g. Males had masses of 12.3, 13.0, 13.5, with two at 14.0 g each. *Eptesicus* was not observed anywhere in the attic. The building was demolished in summer 1984.

Rabies.--During the study period, a total of 152 specimens of *Tadarida* was submitted to the ADHRL from Arkansas and nearby Texarkana, Texas. This total includes those specimens reported in 1988a (Saugey et al.). Ninety-five females and 57 males have been examined and of these, seven bats (4 males, 3 females) tested positive for rabies and represent 4.6% of submissions. Arkansas counties with rabid specimens included Boone, Clark, Garland (2), and Pulaski (2). The months in which these specimens were submitted were March, April (2), and September (3). The Texarkana, Texas, specimen was a female submitted in June.

Conclusions

All of the colonies of *Tadarida* that occurred in buildings during this study have been excluded, except for the Conway site that was destroyed. The members of this colony were reported to have spread throughout the city of Conway in search of suitable roost locations. One of us (DAS) received many calls during the week following demolition requesting information on what could be done to remove bats roosting directly on exterior surfaces of buildings in full view, in ventilation louvers, and in various types of out-buildings – areas not routinely used by this species during our study. Clearly, suitable alternative roost locations are not always known or readily available to some or all members of a colony, exposing them to additional predation pressures and destruction by humans. And as expected, the original solution to infestation problems proposed by virtually all property owners was unanimous – extermination.

Kiser (2000) observed that continued loss of established roosts through renovation of buildings, bat-proofing, and razing of old buildings (habitat loss), does not bode well for populations of Brazilian free-tailed bats. Bellwood (1992) stated the nature of this species to congregate in large numbers where they may become a nuisance and the relatively few locations in which they occur offer special problems in conservation. Both of these statements are applicable to populations of Brazilian free-tailed bats in Arkansas. *Tadarida* appears to be abundant where older or poorly maintained buildings are readily available, but exclusion, enhanced maintenance, and construction of new buildings using improved methods and materials also are gradually reducing the number of structures available as summer maternity sites and suitable over-wintering quarters.

Fortunately, it is unlikely this species will soon be extirpated from larger metropolitan areas because it is very adaptable and has the ability to exist as large numbers of scattered, small population units as opposed to large populations in few locations. This adaptability may provide the time necessary to educate the public of the beneficial aspects of bats in metropolitan areas, and conduct research to provide suitable roost opportunities in selected areas where human/bat interactions can be reduced.

The distribution of *Tadarida* will undoubtedly change as new location records are discovered through investigations of infestations and monitoring of specimens submitted to the ADHRL. Additional records may also be derived through the use of mist-nets that seem more productive when deployed adjacent to or within urban areas. Close communication with local pest control companies may also afford biologists opportunities to discover new locations and assist in the proper timing of exclusion activities to the benefit of the colony. The investigations of building and bridge infestations offer the greatest opportunities for more complete, long-term studies of *Tadarida* natural history, behavior, and colony dynamics. In all situations, we recommend bats be wing-banded to help facilitate understanding of inter- and intra-colony movements, roost fidelity, and possible migration.

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Literature Cited

Baker, R. J. and C. M. Ward. 1967. Distribution of bats in southeastern Arkansas. J. Mamm. 48:130-132.

Belwood, J. J. 1992. *Tadarida brasiliensis cynocephala*. Pp. 357-368, *In* Rare and endangered biota of Florida: mammals (S.R. Humphrey, ed.) Univ. Press Florida, Gainesville, 1:1-392.

Dunivan, J. D., C. R. Tumlison, and V. R. McDaniel. 1982. Cave fauna of Arkansas: further records. Proc. Arkansas Acad. Sci. 36:87-88.

Glass, B. P. 1958. Returns of Mexican free-tailed bats banded in Oklahoma. J. Mammal. 39:435-437.

Greenhall, A. M. 1982. House bat management. U.S. Dept. Interior, Fish and Wildl. Serv. Washington D.C. Resource Publication 14, 33 pp.

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.

Heidt, G. A., D. A. Saugey, and S. R. Bradford-Luck. 1987. Reported bat rabies in Arkansas. Proc. Arkansas Acad. Sci. 41:105-107.

Henry, T. H., T. L. Best, and C. D. Hilton. 2000. Body size, reproductive biology, and sex ratio of a year-round colony of *Eptesicus fuscus fuscus* and *Tadarida brasiliensis cynocephala* in eastern Alabama. Occas. Papers of the N.C. Museum of Natural Sciences and the N.C. Biological Survey, 12:50-56.

Kiser, W. M. 2000. Distribution and status of LeConte's free-tailed bat (*Tadarida brasiliensis cynocephala*) in Alabama. Occas. Papers of the N.C. Museum of Natural Sciences and the N.C. Biological Survey. 12:67-73.

Krutzsch, P. K. 2000. Anatomy, physiology and cyclicity of the male reproductive tract. Pp. 91-156, *In* Reproductive biology of bats (E.G. Crichton and P.H. Krutzsch, eds.). Academic Press, San Diego, California.

LaVal, R. K. 1973. Observations on the biology of *Tadarida brasiliensis cynocephala* in southeastern Louisiana. Amer. Midl. Nat. 89:112-120.

McAllister, C. T., S. E. Trauth, and L. D. Gage. 1995. Vertebrate fauna of abandoned mines at Gold Mine Springs, Independence County, Arkansas. Proc. Arkansas Acad. Sci. 49:184-187.

McDaniel, V. R. and J. E. Gardner. 1977. Cave fauna of Arkansas: Vertebrate taxa. Proc. Arkansas Acad. Sci. 31:68-71.

Saugey, D. A., R. H. Baber, and V. R. McDaniel. 1978. An unusual accumulation of bat remains from an Ozark cave. Proc. Arkansas Acad. Sci. 32:92-93.

Saugey, D. A., D. R. Heath, and G. A. Heidt. 1989. The bats of the Ouachita Mountains. Proc. Arkansas Acad. Sci. 43:71-77.

Saugey, D. A., D. R. Heath, C. Efaw, and G. A. Heidt. 1983. First report of Brazilian free-tailed bat maternity colonies in Arkansas. Proc. Arkansas Acad. Sci. 37:98-99.

Saugey, D. A., G. A. Heidt, D. R. Heath, T. W. Steward, D. R. England, and V. R. McDaniel. 1988a. Distribution and status of the Brazilian free-tailed bat (*Tadarida brasiliensis cynocephala*) in Arkansas. Proc. Arkansas Acad. Sci. 42:79-80.

Saugey, D. A., D. G. Saugey, G. A. Heidt, and D. R. Heath. 1988b. The bats of Hot Springs National Park. Proc. Arkansas Acad. Sci. 42:81-83.

Sealander, J. A. 1956. A provisional checklist and key to the mammals of Arkansas (with annotations). Am. Midl. Nat. 56:257-296.

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

Sealander, J. A. and J. F. Price. 1964. Free-tailed bat in Arkansas. J. Mammal. 45:152.

Sherman, H. B. 1937. Breeding habits of the free-tailed bat. J. Mammal. 7:85-90.

Spenrath, C. A. and R. K. LaVal. 1974. An ecological study of a resident population of *Tadarida brasiliensis* in eastern Texas. Occas. Papers Texas Tech Univ. 21:1-14. 14 pp.

Twente, J. W. 1956. Ecological observations on a colony of *Tadarida mexicana*. J. Mamm. 37:42-47.

Wilson, D. E. and S. Ruff (eds). 1999. The Smithsonian book of North American Mammals. Smithsonian Institution Press, Washington, D.C., 750 pp.

Thermodynamic Properties of Neutron-Rich Matter

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Abstract

The mechanism of supernova explosion and properties of neutron stars are uniquely determined by the equation of state of neutron-rich matter. Using a phenomenological equation of state within a thermal model, we study thermodynamic properties of neutron-rich matter. In particular, we investigate chemical (diffusive) and mechanical (isothermal) instabilities of neutron-rich matter and their dependence on the nuclear equation of state. Both instabilities are found to be heavily dependent upon the isospin asymmetry, temperature, and density of neutron-rich matter. We show that the boundary of the chemical instability extends farther out into the density-isospin symmetry plane than that of the mechanical instability. Results of this study provide a useful guide to current experiments exploring properties of neutron-rich matter.

Introduction

A puzzling problem in astrophysics today involves the properties of neutron stars and the related mechanism of supernova explosions. Investigations into these phenomena cannot be accomplished without the knowledge of the equation of state of isospin asymmetric nuclear matter. Thus, one of the most interesting subjects in nuclear physics today is the study of the nuclear equation of state using nuclear reactions induced by neutron-rich nuclei or radioactive beams (Li and Schröder, 2001). In these reactions transient states of nuclear matter with sufficiently high isospin asymmetries and large thermal and compressional excitations can be created. Moreover, novel phenomena such as multifragmentation, which is characterized by the emission of several intermediate mass fragments, may happen in these reactions. Multifragmentation in isospin-symmetric nuclear matter is thought to occur due to mechanical instabilities such as the Coulomb, surface and volumetric instabilities. However, in isospin-asymmetric nuclear matter, new mechanisms, such as the chemical instability, might be responsible for the multifragmentation. In this work we perform a study on the thermodynamic properties of isospin-asymmetric nuclear matter. In particular, using phenomenological nuclear equations of state within a thermal model we investigate the boundaries of chemical and mechanical instabilities and their dependence on the isospin asymmetry, temperature, density and nuclear equation of state.

Thermodynamic Analysis of Isospin-Asymmetric Nuclear Matter.--Thermodynamic stability does not occur for all nuclear matter of density ρ, temperature T, and isospin asymmetry $\delta \equiv (\rho_n - \rho_p)/\rho$. The necessary conditions for stability in asymmetric nuclear matter are (Müller and Serot, 1995)

$$(\partial E/\partial T)_{\rho,\delta} > 0, \quad (1)$$
$$(\partial P/\partial \delta)_{T,\delta} \geq 0, \quad (2)$$
$$(\partial \mu_n/\partial \delta)_{P,T} \geq 0, \quad (3)$$

where E, P, and μ_n are the energy per nucleon, pressure, and neutron chemical potential, respectively. The first condition is required by thermodynamic stability, and is satisfied by any reasonable equation of state (EOS); the second protects against mechanical instability that arises from density fluctuations; the last protects against chemical instability, which can lead to the runaway isospin fractionation (Li, 1997; Li, 2000). To understand the thermodynamic properties of nuclear matter, we must have a good knowledge of the nuclear EOS. At present, nuclear many-body theories predict vastly different isospin dependence of the nuclear EOS depending on both the calculation techniques and the bare two-body and/or three-body interactions employed, see e.g., (Brown, 2000; Horowitz 2001). Various theoretical studies have shown that the energy per nucleon $e(\rho,\delta)$ in nuclear matter of density ρ and isospin asymmetry parameter δ can be approximated very well by a parabolic function (Bombaci and Lombardo, 1991)

$$e(\rho,\delta) = e(\rho,0) + S(\rho)\bullet\delta^2. \quad (4)$$

In the above $e(\rho,0)$ is the EOS of isospin-symmetric nuclear matter and $S(\rho)$ is the symmetry energy at density ρ. The form of the symmetry energy as a function of density is rather strongly model dependent. Very divergent predictions on the isospin dependence of the nuclear EOS by various many-body theories have led to vastly different forms for $S(\rho)$. We adopt here a parameterization used by Heiselberg and Hjorth-Jensen in their studies on neutron stars (Heiselberg and Hjorth-Jensen, 2000)

$$S(\rho) = S_0(\rho_0)\bullet u^\gamma, \quad (5)$$

where $u \equiv (\rho/\rho_0)$ is the reduced density and $S_0(\rho_0)$ is the symmetry energy at normal nuclear matter density ρ_0. The value of $S_0(\rho_0)$ is known to be in the range of about 27-36 MeV from analyzing atomic masses. By fitting the result of variational many-body calculations, Heiselberg and Hjorth-Jensen found that $S_0(\rho_0) = 32$ MeV and $\gamma = 0.6$. However, as shown by many other authors, previously (Bombaci and Lombardo, 1991) and more recently by Brown (Brown, 2000), using other approaches, the extracted value of γ varies widely, even its sign is undetermined. Therefore, in this work we allow γ to be a free parameter and study its influence on the thermal properties of asymmetric nuclear matter. Further, we use a constant value of 30 MeV for $S_0(\rho_0)$ in this work.

The symmetry energy per nucleon has a kinetic and a potential contribution (Li, Ko and Bauer, 1998)

$$S(\rho)=3/5 \bullet E^0{}_F\, u^{2/3}\,(2^{2/3}-1)+V_2 \qquad (6)$$

where $E^0{}_F$ is the Fermi energy at ρ_0, and V_2 is the potential contribution. The asymmetry potential energy density is then:

$$W_{asy}=V_2\rho\delta^2 \qquad (7)$$

From W_{asy}, we can obtain the single-particle potential energy $V^{n/p}{}_{asy}$, given by

$$V^{n/p}{}_{asy} \equiv (\partial W_{asy}/\partial \rho_{n/p}) \qquad (8)$$

and whose value is

$$V^{n/p}{}_{asy}=(S_0(\gamma-1)u^\gamma +4.2\, u^{2/3})\, \delta^2 \pm (S_0 u^\gamma-12.7u^{2/3})\delta \qquad (9)$$

where "+" and "-" are for neutrons and protons respectively. The chemical potential of asymmetric nuclear matter in equilibrium, μ_q, (q=n for neutrons, q=p for protons) is defined as:

$$\mu_q=V_0+V^{n/p}{}_{asy}+T[\ln(\lambda^3{}_T\, \rho_q/2)+\Sigma_n\, [(n+1)/n \bullet b_n(\lambda^3{}_T\, \rho_q/2)^n], \qquad (10)$$

where ρ_q is the density of nucleons, and $\lambda_T=(2\pi h^2/m_qT)$ is the thermal wavelength of a nucleon. The coefficients b_n are obtained from mathematical inversion of the Fermi distribution function (Jaqaman 1989). The single-particle mean field potential energy V_0, is defined as:

$$V_0=au+bu^\sigma \qquad (11)$$

with a, b, and σ being dependent upon the bulk compressibility of nuclear matter, K, taken in this discussion to take an accepted value 200 MeV, i.e.,

$$a = [-29.81-46.90(K+44.73)/(K-166.32)]\ (MeV), \qquad (12)$$

$$b = [23.45(K+255.78)/(K-166.32)]\ (MeV), \qquad (13)$$

$$\sigma =(K+44.73)/211.05 \qquad (14)$$

From the chemical potentials defined in (10), we can obtain the global pressure for the system from the Gibbs-Duhem relation

$$(\partial P/\partial \rho) = \rho/2\ [(1+\delta)(\partial \mu_n/\partial \rho) + (1-\delta)(\partial \mu_p/\partial \rho)]. \qquad (15)$$

which gives the separable result

$$P = P_0+P_{asy}+P_{kin} \qquad (16)$$

where P_0 is the isospin independent mean field contribution of the nuclear interaction, i.e.,

$$P_0= 1/2\ a\rho_0 u^2 + b\sigma\rho\ /(\sigma + 1)\ u^{\sigma+1}, \qquad (17)$$

P_{kin} is the kinetic contribution

$$P_{kin}=T\rho\{1+ 1/2\ \Sigma_n b_n\ (\lambda^3{}_T\, \rho/4)^n\ [(1+\delta)^{n+1}+(1-\delta)^{n+1}], \qquad (18)$$

and P_{asy} is the contribution from the isospin dependent portion of the nuclear interaction and is given by

$$P_{asy} = (S_0\ \gamma\rho_0 u^{\gamma+1}-8.5\rho_0 u^{5/3})\delta^2. \qquad (19)$$

With the above thermodynamic relations we can establish boundaries of both mechanical and chemical stability regions in the (ρ,T,δ) configuration space. The mechanical stability is readily evident from Eqn. (15), while the chemical instability must be derived from the Maxwellian relation (Li and Ko, 1997)

$$(\partial\mu_n/\partial\delta)_{T,P}=(\partial\mu_n/\partial\delta)_{T,\rho}-(\partial\mu_n/\partial\rho)_{T,\delta}\bullet(\partial P/\partial\rho)^{-1}{}_{T,\delta}\bullet\ (\partial P/\partial\delta)_{T,\rho}. \qquad (20)$$

Results and Discussions

We now turn to the results of our analysis. We first concentrate on the study of mechanical instability and on its dependence on the isospin asymmetry of the system. In Fig. 1, we study the pressure as a function of density, temperature, isospin asymmetry δ and the γ parameter. This allows us to explore the effects of temperature T, and density parameter γ, on not only the pressure itself, but also how these factors influence the mechanical instability. The latter happens in the region where the slope of the pressure with respect to density is negative. It is easy to correspond the increase in temperature with a decreasing probability of observing a mechanical instability. First of all, the effect of the γ parameter on the total pressure is rather small. This is because of the dominant role of the kinetic pressure. Secondly, it is seen that the pressure increases with the increasing isospin asymmetry δ and with increasing temperature. As a result the mechanical instability region shrinks when either the temperature or the isospin-asymmetry increases. Above a critical temperature T_c determined by

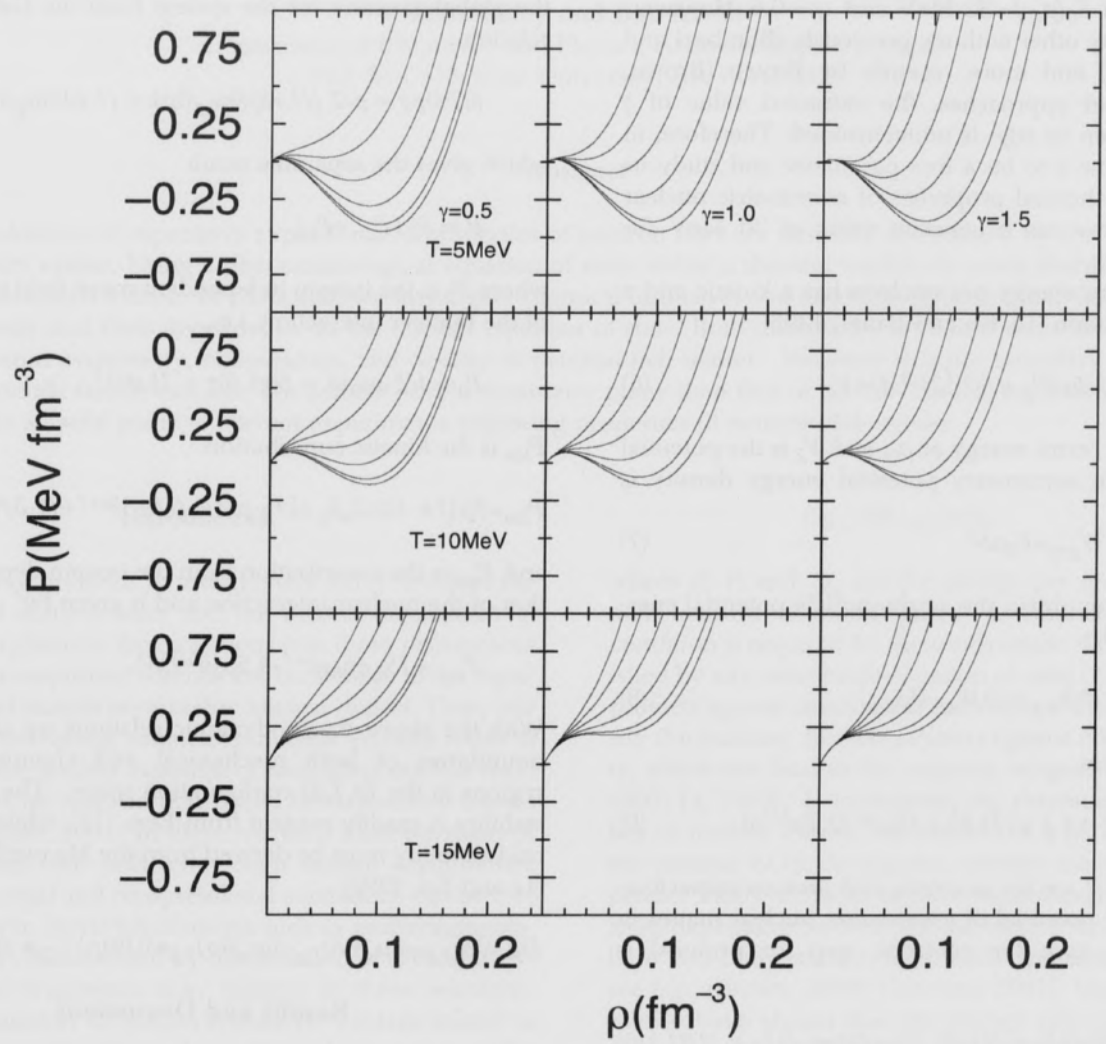

Fig. 1. System pressure, P, as a function of density, ρ, for values of isospin asymmetry of δ=0.0,0.2,0.4,0.6,0.8 and 1.0 (from bottom to top), respectively.

the condition

$$(\partial P/\partial\rho)_{T,\delta} = (\partial^2 P/\partial\rho^2)_{T,\delta} = 0, \qquad (21)$$

the pressure increases monotonically with density, and the mechanical instability disappears. More quantitatively, we show in Fig. 2, the critical temperature and density as a function of the isospin asymmetry parameter δ with the γ parameter of 0.5. It is interesting to see that both the critical temperature and density decrease with the increasing isospin asymmetry. Thus one expects to see a shrinking mechanical instability region for increasingly more neutron-rich systems.

Figure 3 shows the chemical potential of nuclear matter, $\mu(T, P,\delta)$, for both neutrons and protons with a parameter γ=0.5 at a typical temperature of 5 MeV. Each isobar on the graph is a result of a different constant pressure. First, we note that for corresponding pressures, the isobars for neutrons and protons begin from the same chemical potential at δ=0. This is what one expects at the limit of symmetric nuclear matter. It is seen that the chemical potential increases with δ for neutrons and decreases for protons. This is because the potential V_{asy} in the expression of the chemical potential, Eqn. (10), is repulsive for neutrons and attractive for protons. The most interesting feature in these plots is that there exists an envelope of pressures inside of which chemical instability occurs, i.e.,

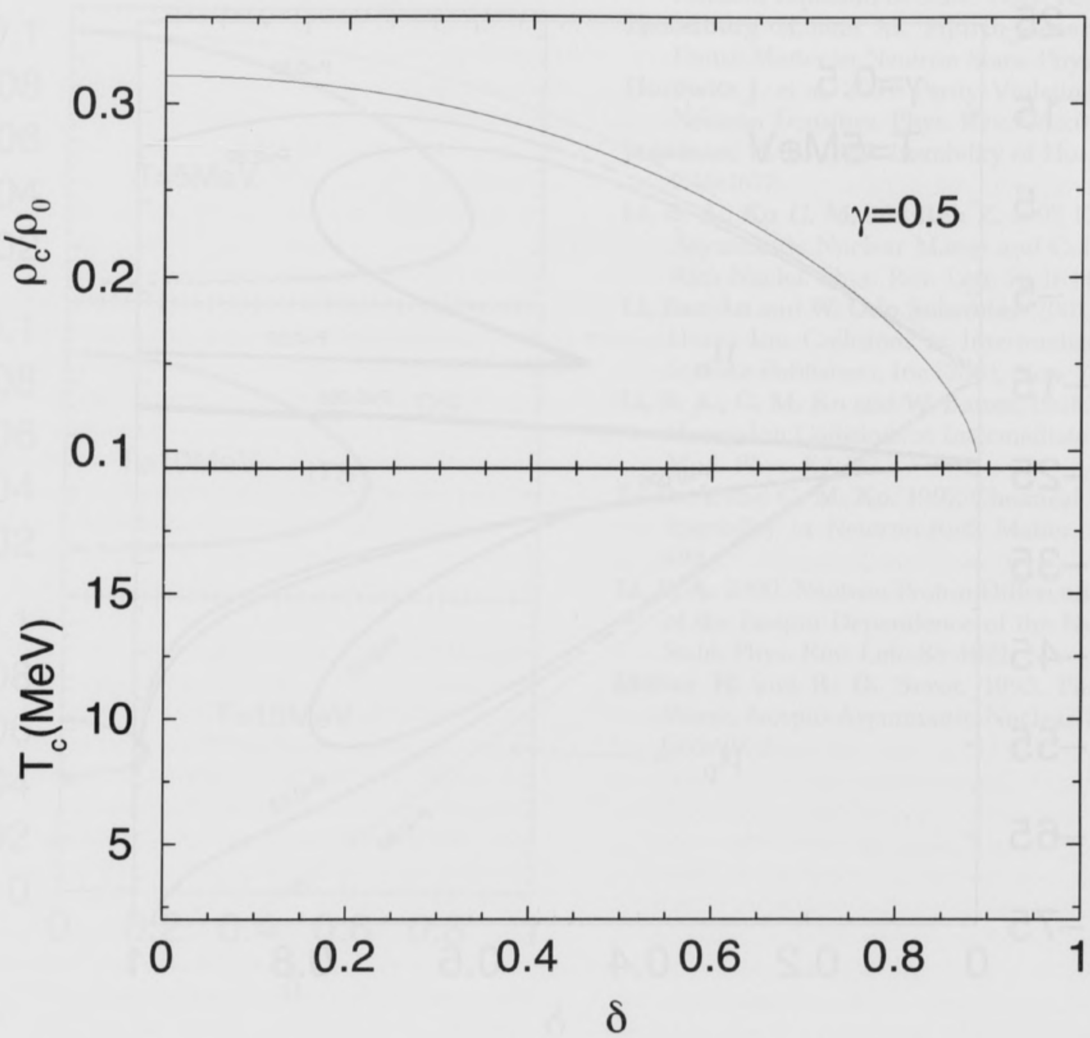

Fig. 2. Critical density (upper window) and critical temperature (lower window) isobars that enclose regions of mechanical instability for density parameter γ=0.5.

$$(\partial\mu_n/\partial\delta) \leq 0. \quad (22)$$

Inside this region, the system is unstable against isospin fluctuations. For instance, if several neutrons have migrated into a region of chemical instability due to some statistical or dynamical fluctuations in a reaction process, the isospin asymmetry parameter δ will increase and energy of the region will decrease. To minimize the total energy of the system, it is favorable to have more neutrons to move to the region thus leading to the further increase of the isospin fluctuation. By comparing results at the three different temperatures it is seen that the chemical instability region shrinks, i.e., for increasing temperature, chemical instability occurs for much less isospin-asymmetric matter. This shows that it is possible to observe phenomena due to the chemical instability even in reactions using stable nuclei, which can attain isospin asymmetry up to about 0.4.

After studying separately the mechanical and chemical instabilities, we are now ready to compare their relative boundaries in the configuration space of (T,ρ,δ). Shown in Fig. 4 are the boundaries of both chemical and mechanical instabilities in the (δ,ρ) plane for three temperatures, with the diffusive spinodal, which indicates the boundary for chemical instability, extending further out into the plane and enveloping the region of mechanical instability; the two regions of instability do not overlap. As the temperature increases, in accordance with Fig. 1, the mechanical instability region becomes less prominent over a more narrow

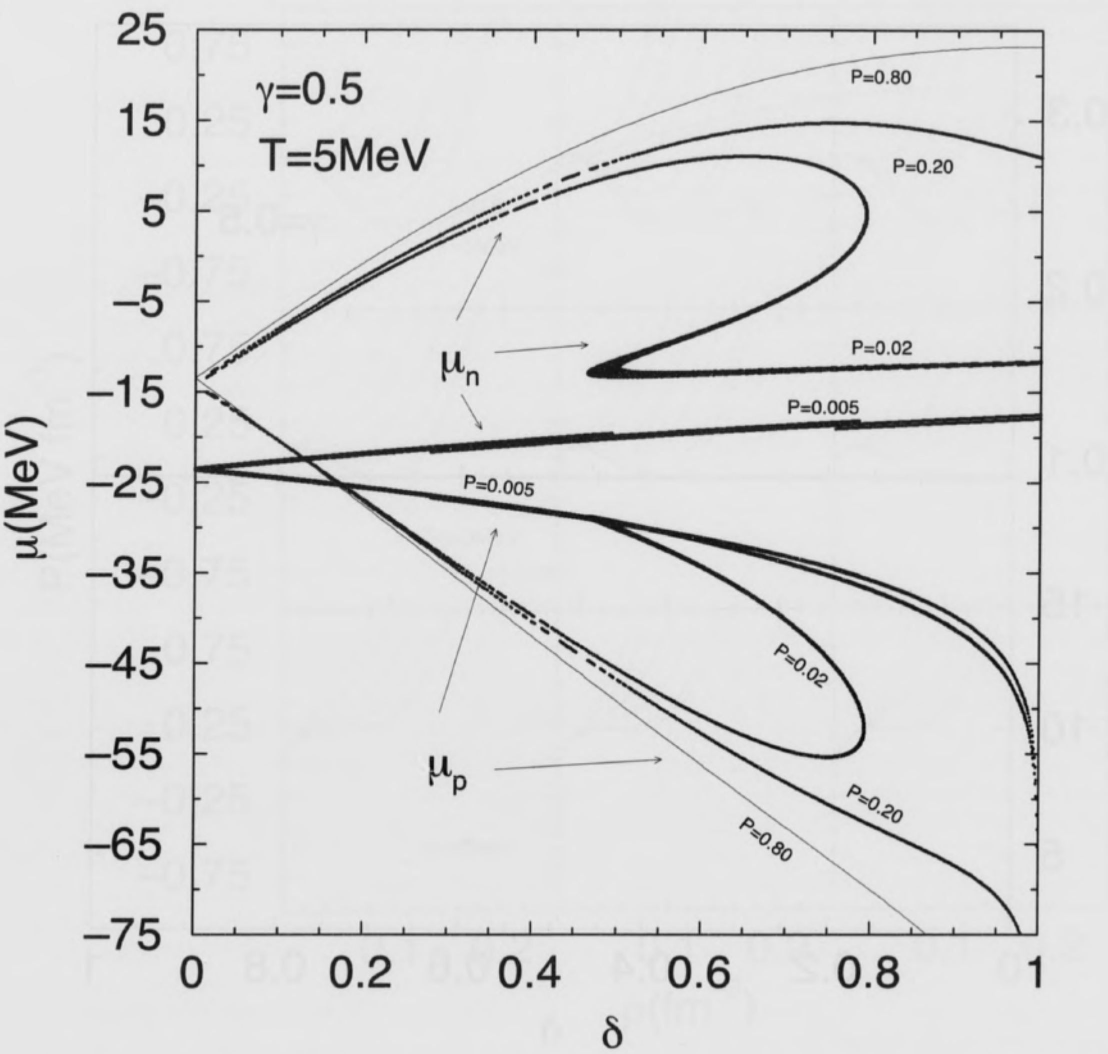

Fig. 3. Chemical potential, μ, for neutrons and protons as a function of isospin asymmetry δ, at temperature, T=*5* MeV and density parameter, γ=*0.5*. The isobars occur at constant pressures of value *P=0.005,0.02,0.20* and *0.80* MeV/fm^3, respectively, for neutrons and protons.

range of densities, and chemical instability will occur for a more isospin-symmetric liquid. Furthermore, there exists a maximum isospin asymmetry for each of the instabilities at constant temperature: as the density of the system decreases the diffusive and isothermal spinodals begin from a zero isospin asymmetry, extend out to a maximum value, and then decrease back down to zero.

Summary

Utilizing a phenomenological nuclear equation of state within a thermal model, we have explored the isospin dependence of the chemical and mechanical instabilities in nuclear matter. The diffusive spinodal is found to extend further out into the *(δ,ρ)* plane than the isothermal spinodal. It is shown that the isospin dependence of the nuclear equation of state plays a key role in determining the properties of nuclear matter. It is also shown that current experiments can readily create conditions where the mechanical and chemical instabilities can happen. Results of this study provide a useful guide to experiments exploring properties of neutron-rich matter.

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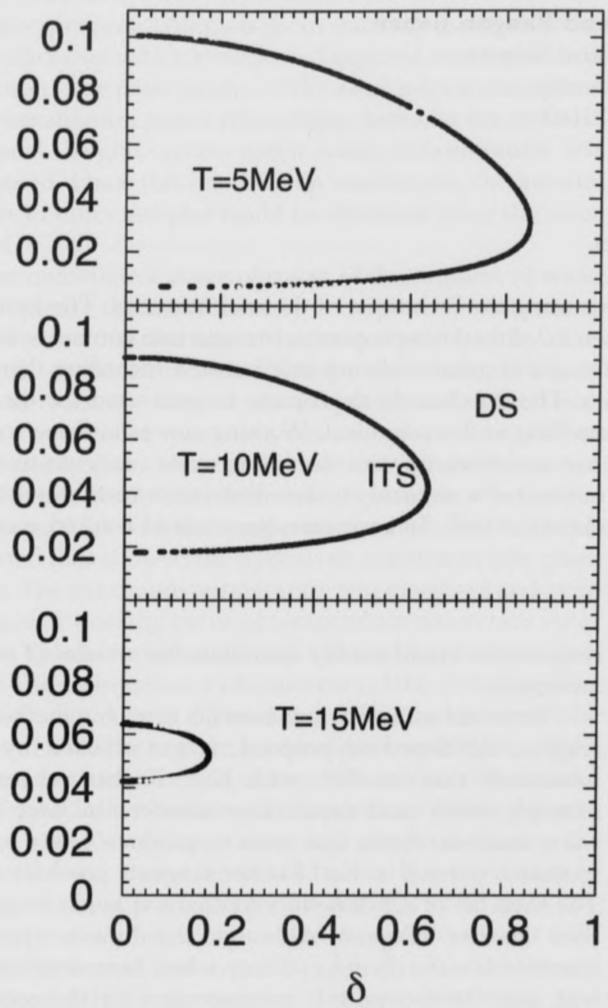

Fig. 4. Boundaries for the chemical and mechanical instabilities in the δ,ρ-plane at temperature, T=*5,10* and *15* MeV for the top, middle and bottom panels respectively and density parameter, γ=*0.5*.

lating and enlightening discussions. This work was supported in part by the National Science Foundation Grant No. 0088934 and Arkansas Science and Technology Authority Grant No. 00-B-14.

Literature Cited

Bombaci I. and **U. Lombardo.** 1991. Equation of State of Asymmetric Matter. Phys. Rev. C44:1892.

Brown, B. A. 2000. Neutron Radii in Nuclei and the Neutron Equation of State. Phys. Rev. Lett. 85:5296.

Heiselberg H. and **M. Hjorth-Jensen.** 2000. Phases of Dense Matter in Neutron Stars. Phys. Rep. 328:237.

Horowitz J. et al. 2001. Parity Violating Measurements of Neutron Densities. Phys. Rev. C63:025501.

Jaqaman, H. R. 1989. Instability of Hot Nuclei. Phys. Rev. C40:1677.

Li, B. A., Ko C. M. and **Ren Z.** 1997. Equation of State of Asymmetric Nuclear Matter and Collisions of Neutron-Rich Nuclei. Phys. Rev. Lett. 78:1644.

Li, Bao-An and **W. Udo Schröder.** 2001. Isospin Physics in Heavy-Ion Collisions at Intermediate Energies, Nova Science Publishers, Inc (2001, New York).

Li, B. A., C. M. Ko and **W. Bauer.** 1998. Isospin Physics in Heavy-Ion Collisions at Intermediate Energies. Int. Jou. Mod. Phys. E7:147.

Li, B. A. and **C. M. Ko.** 1997. Chemical versus Mechanical Instability in Neutron-Rich Matter. Nuc. Phys. A618: 498.

Li, B. A. 2000. Neutron-Proton Differential Flow as a Probe of the Isospin Dependence of the Nuclear Equation of State. Phys. Rev. Lett. 85:4221.

Müller H. and **B. D. Serot.** 1995. Phase Transitions in Warm, Isospin-Asymmetric Nuclear Matter. Phys. Rev. C52:2072.

Moisture Determination by Thermal Titrimetry Using the Enthalpy of Reaction of 2,2-Dimethoxypropane with Water

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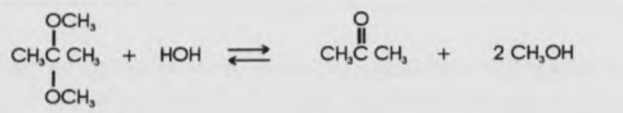
Abstract

Assays for water content can be readily and simply carried out using the technique of thermal titrations. The method is based on measuring the endothermic heat of reaction exhibited when 2,2-dimethoxypropane is brought into contact with water in the presence of an acid catalyst. The apparatus is simple, requiring a constant delivery rate buret, a recording thermistor thermometer, and a stirred, thermally insulated reaction container. The 2,2-dimethoxypropane reagent used for the water assays is environmentally friendly ("green"). It is stable, pleasant smelling and economical. Working curves in three solvents, acetonitrile, tetrahydrofuran and 1,4-dioxane, show excellent precision and linearity with increasing water concentrations to at least 0.07 M. Four different kinds of samples were subjected to this method of water assay to demonstrate its versatility: ethanol, nickel (II) nitrate hexahydrate, concentrated sulfuric acid, and two kinds of fuels. In each case, the method worked accurately and reproducibly with a minimum of time required.

Introduction

The Karl Fischer Method for the quantitative determination of the amount of water in a sample is considered to be the standard method of analysis. This is due to its wide range of applicability compared with numerous other methods available. Substances that react with Karl Fischer reagents, of course, preclude its use. Several excellent discussions of this method and its limitations have been published (Kolthoff and Elving, 1961). We describe a method for moisture determination that also appears to be widely applicable, particularly in some of those cases where the Karl Fischer method fails. Our method involves measuring the heat produced when 2,2-dimethoxypropane reacts with water as described by Equation 1.

Extensive use has been made of 2,2-dimethoxypropane



(1)

to dehydrate various samples containing water. The dehydration is easily carried out by pouring an excess of the ketal over the substance to be dried and warming gently. The reaction is driven to completion by removing the low boiling products, acetone and methanol. While in the process of drying various reagents with 2,2-dimethoxypropane, we noted that its reaction with water was accompanied by a considerable absorption of heat. It is a strongly endothermic reaction. We felt that by applying the method of thermal titrations, using 2,2-dimethoxypropane as the analytical reagent, one could readily quantitate the amount of water in a sample.

There are some obvious benefits to such a method. The reagent, 2,2-dimethoxypropane, is not affected by many substances that interfere with Karl Fischer reagent. For example, ferric and cupric ions interfere in Karl Fischer water analysis. Acids that react to produce esters with the methanol present in Karl Fischer reagents preclude its use. The shelf life of 2,2-dimethoxypropane is much longer than Karl Fischer reagent. Although 2,2-dimethoxypropane reacts with water, it does so only when heated or catalyzed with acid. Moreover, it is not necessary for the concentrations of 2,2-dimethoxypropane to be known in order to determine the amount of water present. The enthalpy of reaction can be used instead. The Karl Fischer reagent is a moisture-sensitive mixture of materials that contains, among other things, the toxic substances sulfur dioxide and pyridine. The 2,2-dimethoxypropane, on the other hand, is a pleasant smelling, harmless, relatively stable liquid that is easily and inexpensively obtainable in pure form.

Earlier investigators proposed methods that used 2,2-dimethoxypropane to accurately determine the amount of water in a sample. For example, Critchfield and Bishop measured the amount of acetone produced after reacting a moisture-containing sample with 2,2-dimethoxypropane (Critchfield and Bishop, 1961). The amount of acetone was determined spectroscopically by measuring its absorbance at 5.87 micrometers. When utilizing their method, one must take into account any carbonyl compounds that also absorb at this wavelength. Other workers have used 2,2-dimethoxypropane to determine the amount of water in a sample with the aid of a gas chromatograph (Badinad et al., 1965; Martin and Knevel, 1965). Martin and Knevel equilibrated different known amounts of water with 2,2-dimethoxypropane. Aliquots from each of these solutions were withdrawn with a syringe and injected into a gas chromatograph. The peak heights of the ketal were measured on the chromatogram and a relationship between the ratios of these peak heights to the initial water concentration was determined. Once this relationship was known, the amount of water in other samples could be obtained using the same method.

The quantitative determination of the amount of water in a sample by thermal titrimetry is not new. Greathouse et al. determined the amount of water in acetic acid by reaction with acetic anhydride (Greathouse et al., 1956). A known amount of excess acetic anhydride was titrated with small increments of water in a dewar flask until no further temperature rise was observed on a thermometer. Alternatively, acetic anhydride and the sample were mixed in a Dewar flask and the temperature noted. Then catalyst was added that allowed the hydrolysis reaction to take place quickly. The maximum temperature was observed and compared with a working curve of temperature rise versus water content. This latter technique was a precursor of what is now termed Direct Injection Enthalpimetry, DIE (Wasilewski et al., 1964). Spink and Spink used DIE to determine the amount of water in organic liquids (Spink and Spink, 1968). Their method involved injecting 80% wt/wt sulfuric acid into a dewar flask containing the sample and noting the temperature rise. A working curve was prepared relating the amount of water to the temperature rise. It is interesting to note that the heat produced by the addition of water to sulfuric acid was used by Somiya to determine the water content of sulfuric acid (Somiya, 1927). Finally, Wasilewski and Miller used DIE to do moisture analysis (Wasilewski and Miller, 1966). They used the heat produced when water is added to Karl Fischer reagent. First, they added a known excess of Karl Fischer reagent to the sample and noted the temperature. Next, they added an excess of water. The remaining Karl Fisher reagent reacted with the water producing −16.1 kcal per mole of water reacted.

The analytical method of thermal titrations is not widely recognized as a useful method for many types of determinations. Two monographs give an in-depth explanation of the method along with several examples (Barthel, 1975; Bark and Bark, 1969). In addition a theoretical derivation of thermal titration thermograms obtained can be found in Wilson (Wilson, 1968).

The intent of this paper is to describe a method to determine the amount of water in samples by thermal titrations using 2,2-dimethoxypropane as the analytical reagent. As will be shown, this method is very quick, simple, precise, and relatively accurate as far as instrumental methods are concerned. It is also environmentally friendly.

Materials and Methods

Two thermal titration systems were used for these analyses. The system used for obtaining calorimetry data and some of the water calibration measurements have been described in detail (Wilson, 1968). The remaining measurements were made using a FACTS Titration System, composed of a Sanda Dual Titration Station, F.A.C.T.S. Ce2010 Data Processing Module, National Instruments Lab-PC 1200 Control Board and PC computer (Sadtler, 1999). This latter instrument was used to make the majority of measurements. The instrumentation in both cases is similar in that what is required is an accurate constant rate delivery buret, a stable, sensitive thermistor thermometer, a stirred titration vessel that is thermally insulated, and a means of recording the resulting thermogram. The FACTS system is particularly useful because of the sophisticated data handling that produces a thermogram on which the temperature versus milliliters of titrant is plotted along with the first and second derivatives of temperature versus milliliters. The derivative plots greatly enhance the ability to measure the endpoint of the thermogram accurately without having to resort to graphical extrapolations.

In order to determine the amount of water in a sample by thermal titration with 2,2-dimethoxypropane, it is necessary to have a solvent capable of dissolving both the sample to be analyzed and the 2,2-dimethoxypropane. Ideally, one would like to have a solvent with low vapor pressure, no unpleasant odor, a low cost, and one that would dissolve a wide variety of inorganic and organic materials. Acetone and methanol are unsuitable because they are the products of the reaction between water and 2,2-dimethoxypropane. Moreover, alcohols, ketones, acid anhydrides, and acid chlorides, as well as amines cannot be used since they may react with the 2,2-dimethoxypropane (Killian et al; Baum and Hennion, 1938; Kreevoy and Taft, 1955; Hock, 1934). Consideration of the preceding criteria narrowed the choice of suitable solvents to three. These are acetonitrile, tetrahydrofuran, and 1,4-dioxane.

Acetonitrile, the most polar of the three, dissolves many inorganic salts, and hydrated salts readily. When used as a solvent, acetonitrile many times will become colored as the reaction proceeds. This is due to its polymerization. As the results show, this does not appear to pose a problem. It occurs after the titration has been completed in most cases. The other two solvents show no such effect.

Results

Table 1 provides a summary of our ability to establish a working curve for the determination of the amount of water in acetonitrile. In these analyses, water was added to ACS Reagent Grade acetonitrile over a range of 0.025 M to 0.078

Table 1. Thermal Titration of Water with 2,2-Dimethoxypropane

mMole H_2O Added	mMole H_2O Found
Acetonitrile Solvent	
5.98	6.41
11.96	12.60
17.95	18.92
23.92	25.31
mMole H_2O = 0.9490 mMole 2,2-DMP – 0.0514	
Tetrahydrofuran Solvent	
0.00	1.73
5.83	7.05
11.66	12.49
17.49	18.18
mMole H_2O = 1.0638 mMole 2,2-DMP – 1.7469	
1,4-Dioxane Solvent	
0.00	3.87
5.76	9.64
11.52	15.58
17.28	21.21
mMole H_2O = 0.9935 mMole 2,2-DMP – 3.8530	

M. Titrations were then performed on each solution with 2,2-dimethoxypropane, using methane sulfonic acid catalyst. Table 1 also contains the results obtained when tetrahydrofuran and 1,4-dioxane were used as the solvents for the water analysis.

Table 2 gives the results of the analysis of the amounts of water in various solvents and fuels:

Ethanol measurements.--25.00 mL of freshly opened pure alcohol plus 0.50 mL methanesulfonic acid catalyst were placed into the titration vessel and titrated with 2,2-dimethoxypropane. As a comparison, 25.00 mL of the same pure ethanol was taken from a laboratory wash bottle that had been exposed to the air for some time. Again, 0.50 mL of methanesulfonic acid catalysts was added. No additional solvent was needed because all components were mutually soluble.

Gasoline and Aviation Fuel.--Gasoline and aviation fuel are not soluble with the methanesulfonic acid catalyst. All are soluble in tetrahydrofuran. Because these solvents generally contain only small amounts of water, the 2,2-dimethoxypropane was first diluted 1:5 with tetrahydrofuran for the water analysis. This helped to improve the precision of the experiment. First a blank had to be obtained to find the amount of water in the tetrahydrofuran solvent. Five replicate titrations were performed on 50.00 mL ACS Reagent Grade tetrahydrofuran to which 0.50 mL methanesulfonic acid catalyst had been added. The titrations were made using the diluted 2,2-dimethoxypropane described

Table 2. Analytical Results of Thermal Titrations Using 2,2-Dimethoxypropane (DMP)

Sample	No. Replications	mL DMP	Grams H_2O Found	%H_2O
"New" Ethanol	5	4.3±0.2	0.62±0.03	2.5±0.1
"Old" Ethanol	5	5.2±0.3	0.76±0.04	3.0±0.2
Acetronitrile	5	1.52±0.02	0.223±0.003	0.45±0.01
Tetrhydrofuran	5	1.05±0.06	0.153±0.009	0.31±0.02
87 Octane, Exxon, Sat'd	5	0.46±0.09	0.07±0.01	0.13±0.03
"Old" C152 Aviation Fuel	5	0.192±0.009	0.028±0.001	0.056±0.002
H_2SO_4, Conc.	3	1.4875±0.0	0.21785±0.0	0.43570±0.0
"New" $Ni(NO_3)_2 \cdot 6H_2O$	4	2.13±0.03	0.311±0.005	39.4±0.6
"Old" $Ni(NO_3)_2 \cdot 6H_2O$	4	2.42±0.07	0.35±0.01	45±1

All results expressed in % vol/vol except for nickel samples which are in % wt/wt

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earlier. This established the blank to be subtracted from all the analyses involving the two fuels. Each of the fuels was analyzed for water by measuring 50.00 mL gasoline or aviation fuel, 50.00 mL tetrahydrofuran, and 0.50 mL methanesulfonic acid catalyst. Five replicate titrations were performed on the gasoline and on the aviation fuel. The gasoline was Exxon 87 octane that had been equilibrated with water to saturate the sample. The aviation fuel was an old sample of C152 fuel taken from an aircraft, and it was already saturated with water.

Sulfuric Acid.--One of the most remarkable and useful applications of this analytical method is that sulfuric acid can be easily and quickly assayed for water content. Since the sulfuric acid provides the hydrogen ion catalyst needed in the reaction, the titrations were carried out directly on 50.00 mL samples of fresh, ACS Reagent Grade concentrated sulfuric acid. Because the results were so precise, only three replicate determinations were required.

Inorganic Salts.--The assay for water in inorganic salts is quite useful. The water of hydration of these salts can be measured. Also, those salts that have adsorbed various amounts of water from exposure to humid air can be analysed. Because of this, many reagent bottles with water logged samples can be salvaged because the concentrations of the salts can be established. Acetonitrile was found to be the best solvent for water assays of inorganic salt samples. Five replicate titrations of 50.00 mL of acetonitrile plus 0.50 mL methanesulfonic acid were carried out to determine the amount of water in the solvent. The salt samples were massed, 3.95 g, into a 250.00 mL volumetric using acetonitrile solvent. Then 50.00 mL aliquots of the solution were titrated after adding 0.50 mL methanesulfonic acid catalyst to each. Four replications were performed on the two salt samples studied.

Discussion

As Table 1 shows, the amount of water determined by thermal titrimetry was close to the amount of water added to the sample. The reason more water was detected is that the solvents themselves were found to contain a small amount of water. This fact is evidenced in Table 2 for the titrations of neat acetonitrile (0.44% v/v H_2O) and tetrahydrofuran (0.31% v/v H_2O). The data in Table 1 were plotted to establish a working curve for each solvent. Linear least squares fitting of the data gave the values shown in Table 1 for each solvent. It must be emphasized that the solvents must be titrated each day to find the water content for that time and batch of solvent. The water assays for each of the solvents in Table 1 also reveal that the working curves for all three solvents are very precise and linear to approximately 0.07 M water concentration.

The four water assays chosen illustrate some of the wide applicability and usefulness of the method of thermal titrations using 2,2-dimethoxypropane. The first assays, summarized in Table 2, compare the amount of water found in a freshly opened bottle of pure ethanol with a sample of ethanol taken from a laboratory wash bottle that had been exposed to the air for a period of time. As expected the aged ethanol sample had absorbed some water from the air in the laboratory.

An interesting application of this method is its use to determine water of hydration of hydrated salts. A sample of nickel (II) nitrate hexahydrate from a freshly opened bottle of ACS reagent grade material was analyzed for water content. The theoretical weight percent water in this compound is 37.16% wt./wt. This compares well with the analysis, which showed 39.3% wt./wt. The larger value indicates that the sample contained a small amount of excess moisture. Another nickel (II) nitrate hexahydrate sample was taken from a reagent bottle that had been on the shelf for several years and had absorbed so much water that it was syrupy. This sample had absorbed an additional 7.84% wt./wt. water.

Astonishingly, concentrated sulfuric acid can be easily assayed for water content. A bottle of freshly opened ACS Reagent Grade sulfuric acid contained a trace of water as shown in Table 2 In this assay, the amount of heat produced during titration per mole of 2,2-dimethoxypropane added was large enough to increase the signal to noise ratio to the point where there was no scatter in the replicate measurements.

Finally, the amount of water was assayed in two samples of fuel. The original sample of gasoline had less water than the detection limits for this method. In order to test the method, the gasoline was first saturated with water. Therefore, the value for the amount of water given in Table 2 in the Exxon gasoline represents the saturation solubility of water in gasoline. In the case of the aviation fuel, a sample was removed from the sump in the tanks of a small, private aircraft. Again, the water content was quite low.

Conclusions

Assay of samples for water content is easily accomplished by the method of thermal titrations using 2,2-dimethoxypropane as the analytical reagent. It takes less than five minutes to carry out a single titration. This method should be a strong candidate for automation. The components of the system are robust and not contaminated, and the single analytical reagent needed is environmentally friendly. The method can be applied to virtually any sample provided it can be brought into a solution that allows for mutual miscibility of the sample, acid catalyst, and 2,2-dimethoxypropane.

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Literature Cited

Badinad, A. C. Quincy, and R. J. Guilluy. 1965. J. Pharm. Belg. 20:397 ff.

Bark, L. S. and S. M. Bark. 1969. Thermometric Titrimetry Pergamon Press, Oxford.

Barthel, J. 1975. Thermometric Titrations John Wiley & Sons, New York.

Baum, A. A. and G. F. Hennion. 1938. J. Am. Chem. Soc. 60:568 ff.

Critchfield, F. E. and E. T. Bishop. 1961. Anal. Chem. 33:1034 ff.

Greathouse, L. M. H. J. Janssen, and C. M. Haydel. 1956. Anal. Chem. 28:357 ff.

Hoch, J. 1934. Comt. rend. 199:1428 ff.

Killian, D. B. G. F. Hennion, and J. A. Nieuwland. 1935. J. Am. Chem. Soc. 57:544 ff.

Kolthoff, I. M. and P. J. Elving. 1961. Treatise on Analytical Chemistry, p. 69-206, Vol. Part II., Vol. 1. Interscience, New York.

Kreevoy, M. M. and J. Taft, R. W. 1955. J. Am. Chem. Soc. 77:5590 ff.

Martin, J. H. and A. M. Knevel. 1965. J. Pharm. Sci. 54:1464 ff.

Sadtler, T. 1999. SANDA F.A.C.T.S Ce2000 Operational Manual. SANDA Corporation, 4005 Gypsy Lane, Philadelphia.

Somiya, T. 1927. J. Soc. Chem. Ind. (Japan) 30:106 ff.

Spink, M. Y. and C. H. Spink. 1968. Anal. Chem. 40:617 ff.

Wasilewski, J. C. and D. C. Miller. 1966. Anal. Chem. 38:1750 ff.

Wasilewski, J. C. P.T.-S. Pei, and J. Jordan. 1964. Anal. Chem. 36:2131 ff.

Wilson, E. W., Jr. 1968. Thermometric Titration of Water with 2,2-Dimethoxypropane. Dissertation, University of Alabama, Tuscaloosa.

A Multi-Phase Transport Study of Relativistic Nuclear Collisions

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Abstract

A multi-phase transport model (AMPT) is developed for the study of hot and dense matter produced in relativistic nuclear collisions. This model includes both initial partonic and final hadronic scattering. Using the AMPT model, we study the momentum distributions of charged particles such as protons, antiprotons, pions, and kaons in central heavy ion collisions at Super Proton Synchrotron (SPS) and Relativistic Heavy Ion Collider (RHIC) energies. The results are consistent with experimental data at these energies. They indicate a significant nuclear shadowing but a relative weak jet quenching in the initial dense matter. Antiproton to proton ratio at mid-rapidity increases appreciably with energy, demonstrating the approach to a nearly baryon-anti-baryon symmetric matter in high energy collisions. Kaon to pion ratio is almost constant within the energy range studied here, providing strong evidence for strangeness equilibration in these reactions.

Introduction

Quarks and gluons are the most fundamental strongly interacting building blocks of matter. In normal matter they are confined in bigger building blocks, hadrons. Hence they are sometimes referred to as partons (parts of hadrons). Beyond some critical conditions of extremely high temperature/density, hadrons melt, and these quarks and gluons can roam freely inside the high temperature/density region, which is called the Quark-Gluon Plasma (QGP). Quark-Gluon Plasma is believed to have existed in the early Universe a few microseconds after its creation in the Big Bang. It also exists in the highly compressed cores of neutron stars (Müller, 1995). The knowledge of the Quark-Gluon Plasma is crucial for the understanding of the Universe and many other fundamental questions about nature.

In the laboratory, relativistic nuclear collisions are used to create conditions close to those in the early Universe and to study the formation and properties of Quark-Gluon Plasma. Currently, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) is the world's largest and most powerful machine dedicated to the study of Quark-Gluon Plasma. RHIC consists of a pair of circular accelerators that accelerate two beams of gold nuclei in opposite directions to 99.995% of the speed of light. Collisions between these two beams happen in one of the four experiment halls around the ring. After the violent head-on collision of two nuclei, a hot and dense region (possibly Quark-Gluon Plasma) is created. This hot and dense region then expands, cools, and finally decays into thousands of small debris particles. These debris particles go into the experiment instruments. Patterns in the debris can be used to study the Quark-Gluon Plasma formation and properties.

Methods

A Multi-Phase Transport Model.--As all experimentally observed quarks and gluons are bound in bigger hadrons, the transient QGP phase with freely moving quarks and gluons can only be studied through their manifestation in the final hadronic distributions. Also, the Quark-Gluon Plasma produced in nuclear collisions differs from the ideal Quark-Gluon Plasma in that it only exists for a finite lifetime and in a finite spatial region. This makes the task of deciphering the information contained in the final hadronic spectra especially challenging.

One important theoretical approach is the computer based transport model approach. In this approach, initial conditions are assumed based on the extrapolation of known physics, and information about particle-particle interactions is taken from experimental data or from theoretical calculations. The model follows the space-time evolution of the system, automatically taking into account the effect of finite QGP space-time dimensions in realistic collisions. After the calculation, the model particle spectra are compared with experimental data. The differences are resolved by adjusting model assumptions and/or parameters. These better constrained assumptions and parameter values can be further understood as results of fundamental physics principles behind nuclear interactions. In this way, experimental data can be used to extract information about the particle production mechanism in the collisions.

We recently developed such a model which is called A Multi-Phase Transport model (AMPT) (Zhang et al., 2000a; Zhang et al., 2000b; Lin et al., 2001). In addition to following the space-time evolution of the system, this model explicitly takes into account the different phases that are produced in relativistic nuclear collisions. In particular, the initial conditions are obtained from the Heavy Ion Jet INteraction Generator (HIJING) (Wang and Gyulassy, 1991) by using a Woods-Saxon radial shape for the colliding nuclei. In a nucleus of A nucleons, the number of partons is smaller than A times the number of partons in a nucleon. This is called the nuclear shadowing effect. In the multiphase model, it is modeled via the gluon-recombination mechanism of Mueller-Qiu (Mueller and Qiu, 1986). After the colliding nuclei pass through each other, the Gyulassy-Wang parton coherent parton production model (Gyulassy and Wang, 1994) is applied for the generation of the initial space-time information of the produced partons. These partons rescatter elastically according to the Zhang's Parton Cascade (ZPC) (Zhang, 1998). As the system evolves in time, the density of quarks and gluons becomes low, and further interactions between quarks and gluons become minimal. The quarks and gluons are then grouped into hadrons according to the Lund model (Andersson et al., 1983). The ensuing space-time evolution of the hadron system is described by A Relativistic Transport (ART) model (Li and Ko, 1995).

Results and Discussion

Particle Production in Relativistic Nuclear Collisions.-- We used the model to study heavy ion collisions at SPS energies and found that it gave smaller numbers of net baryons and kaons at midrapidity than those observed in experiments. To increase the net baryon at midrapidity, we introduced both the popcorn mechanism of baryon-antibaryon production in the Lund string fragmentation and baryon-antibaryon production from and annihilation to mesons in the ART model. The kaon number was increased by adding in the ART model the production and destruction of K^* resonances and by adjusting the two parameters in the splitting function used in the Lund string fragmentation. Results from the improved AMPT model for central Pb+Pb collisions at 158 AGeV from the SPS, corresponding to impact parameters of $b \leq 3$ fm, are shown in Fig. 1 for the rapidity distributions and in Fig. 2 for the transverse momentum spectra of charged particles including pions, kaons, protons, and antiprotons. We see that the theoretical results shown by solid curves agree reasonably with the experimental data (Bearden et al., 1997; Appelshäuser et al., 1999; Siklèr et al., 1999). On the other hand, the HIJING model with default parameters, shown by dashed curves in Fig. 2, underpredicts the inverse slopes of the transverse momentum spectra for kaons and protons in these collisions. Final state hadronic scatterings are thus important in describing the transverse momentum spectra.

With parameters in the AMPT model constrained by experimental data from heavy ion collisions at SPS energies, we then studied heavy ion collisions at RHIC energies. We first show in Fig. 3 by the solid curve the pseudorapidity distribution of total charged particles in central ($b \leq 3$ fm) Au+Au collisions at 130AGeV. The theoretical result is consistent with the data from the PHOBOS collaboration (Back et al., 2000) shown in the figure by the full circle. We note that the total charged particle multiplicity increases appreciably without final hadronic scatterings but is hardly affected by partonic scatterings. The latter is partly due to the absence of inelastic scattering in the ZPC model. To model the effect of parton energy loss due to inelastic scatterings, we introduce the jet quenching as in default HIJING. In Fig. 3 we show by dashed curves the results from AMPT model with a jet quenching of $dE/dx=1$ GeV/fm. Also shown in Fig. 3 are the results obtained by neglecting nuclear shadowing on parton production in the AMPT model. In both cases, the total charged particle multiplicity is larger than that from the default AMPT model. The PHOBOS data is thus consistent with a significant nuclear shadowing effect but a rather weak jet quenching. Our predictions for the multiplicities of pions, kaons, protons and antiprotons are also shown by solid curves in Fig. 3. It is seen that the $\bar{p}/p$ ratio is significantly increased in comparison with that in central Pb+Pb collisions at SPS.

We have also studied the transverse momentum spectra of pions, kaons, and protons in central Au+Au collisions at 130 AGeV. We find that all three particles, especially protons, have larger transverse momenta at RHIC than at SPS. As expected, jet quenching suppresses moderately the yields of these particles at high transverse momenta.

The colliding energy dependence of the particle multiplicities and particle ratios at central rapidity is studied in Fig. 4. In particular, we add in results for central Au+Au collisions at $\sqrt{s} = 200$ AGeV, the highest energy at RHIC. The proton yield is seen to have a minimum at energies between SPS and the highest RHIC energy, while antiproton yield increases almost linearly with the natural logarithm of the center of mass energy squared, ln(s). As a result, the $\bar{p}/p$ ratio increases rapidly from about 0.1 at SPS to about 0.8 at highest RHIC energy, indicating the formation of nearly baryon-anti-baryon symmetric matter at high energies. Meson yield increases faster than ln(s). The K^-/K^+ ratio increases gradually from 0.7 at SPS to about 0.9 at AGeV. The K^+/π^+ ratio is almost constant within this energy range, suggesting the approximate chemical equilibrium for strangeness production.

The dependence on nuclear shadowing and jet quenching also increases with energy. At $\sqrt{s} = 130$ AGeV, shadowing causes an increase of 20% in charged particle production at central rapidity while at $\sqrt{s} = 130$ AGeV, it causes an increase of 30%. Jet quenching increases the particle production by 10% at $\sqrt{s} = 130$ AGeV and by 20% at $\sqrt{s} = 130$ AGeV.

Conclusions

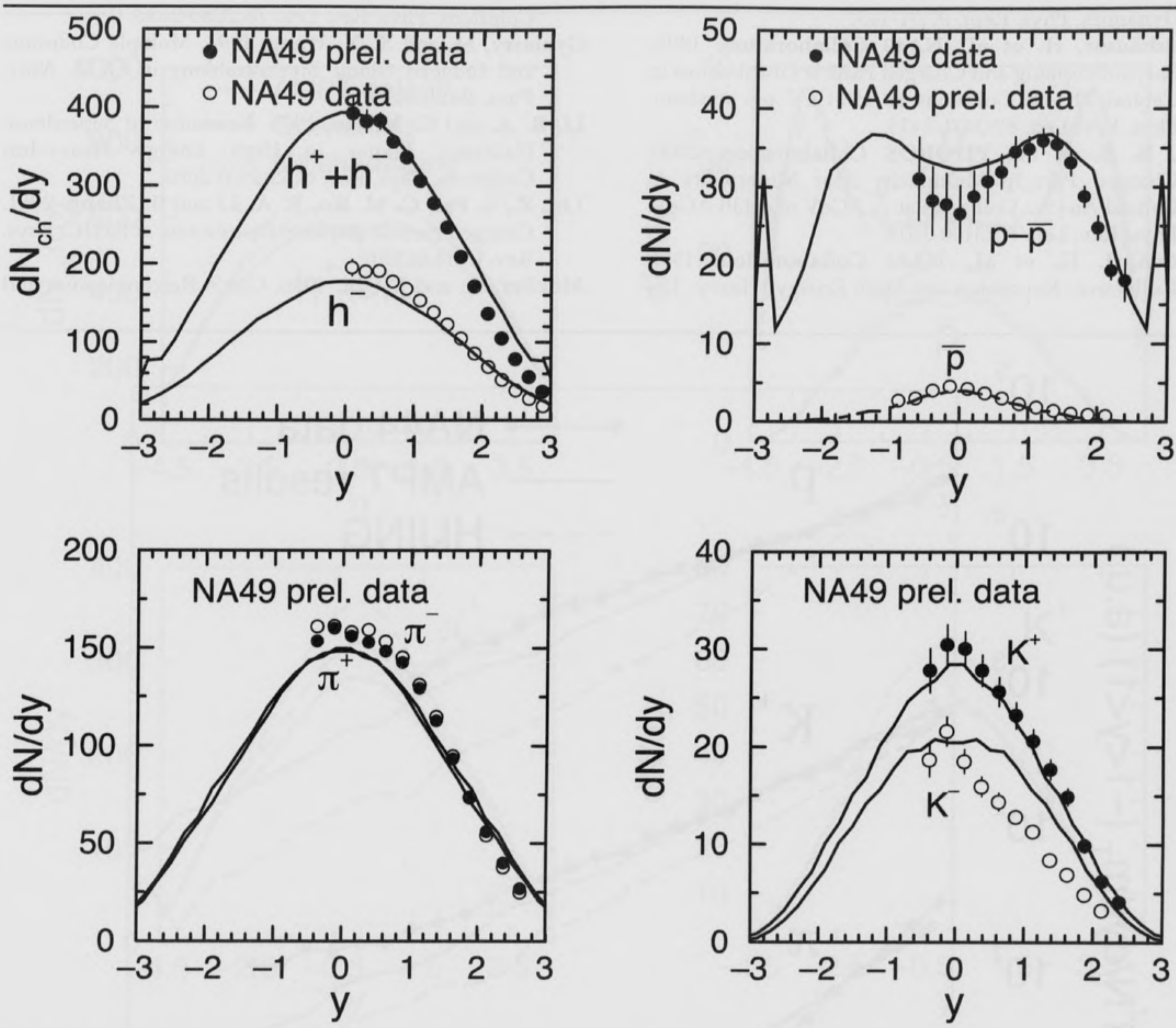

Fig. 1. Rapidity distributions at SPS.

To summarize, a multi-phase transport model has been developed for heavy ion collisions at RHIC energies. Comparisons of the theoretical results with the PHOBOS data on total charged multiplicity indicate that there is a significant nuclear shadowing but a weak jet quenching in the initial stage of collisions. The predicted transverse momentum spectra of particles are found to have larger inverse slopes at RHIC than at SPS. Antiproton to proton ratio at mid-rapidity increases appreciably with energy, demonstrating the approach to a nearly baryon-anti-baryon symmetric matter in high energy collisions. Kaon to pion ratio is almost constant within the energy range studied here, providing strong evidence for strangeness equilibration in these reactions.

ACKNOWLEDGMENTS.—This research was supported by the National Science Foundation Grants PHY-9870038 and PHY-0088934, Welch Foundation Grant A-1358, Texas Advanced Research Program Grant FY-99-010366-0081, and Arkansas Science and Technology Grant 00-B-14.

Literature Cited

Andersson, B., G. Gustafson, G. Ingelman and **T. Sjöstrand.** 1983. Parton Fragmentation and String

Dynamics. Phys. Rept. 97:31-145.
Appelshäuser, H. et al., NA49 Collaboration. 1999. Baryon Stopping and Charged Particle Distributions in Central Pb+Pb Collisions at 158-GeV per nucleon. Phys. Rev. Lett. 82:2471-2475.
Back, B. B. et al., PHOBOS Collaboration. 2000. Charged Particle Multiplicity near Midrapidity in Central Au+Au Collisions at $\sqrt{s}$ AGeV and 130-AGeV. Phys. Rev. Lett. 85:3100-3104.
Bearden, I. G. et al., NA44 Collaboration. 1997. Collective Expansion in High-Energy Heavy Ion Collisions. Phys. Rev. Lett. 78:2080-2083.
Gyulassy, M. and **X. N. Wang.** 1994. Multiple Collisions and Induced Gluon Bremsstrahlung in QCD. Nucl. Phys. B420:583-614.
Li, B. A. and **C. M. Ko.** 1995. Formation of Superdense Hadronic Matter in High Energy Heavy-Ion Collisions. Phys. Rev. C 52:2037-2063.
Lin, Z., S. Pal, C. M. Ko, B. A. Li and **B. Zhang.** 2001. Charged Particle Rapidity Distribution at RHIC. Phys. Rev. C 64:011902.
Mueller, A. and **J. Qiu.** 1986. Gluon Recombination and

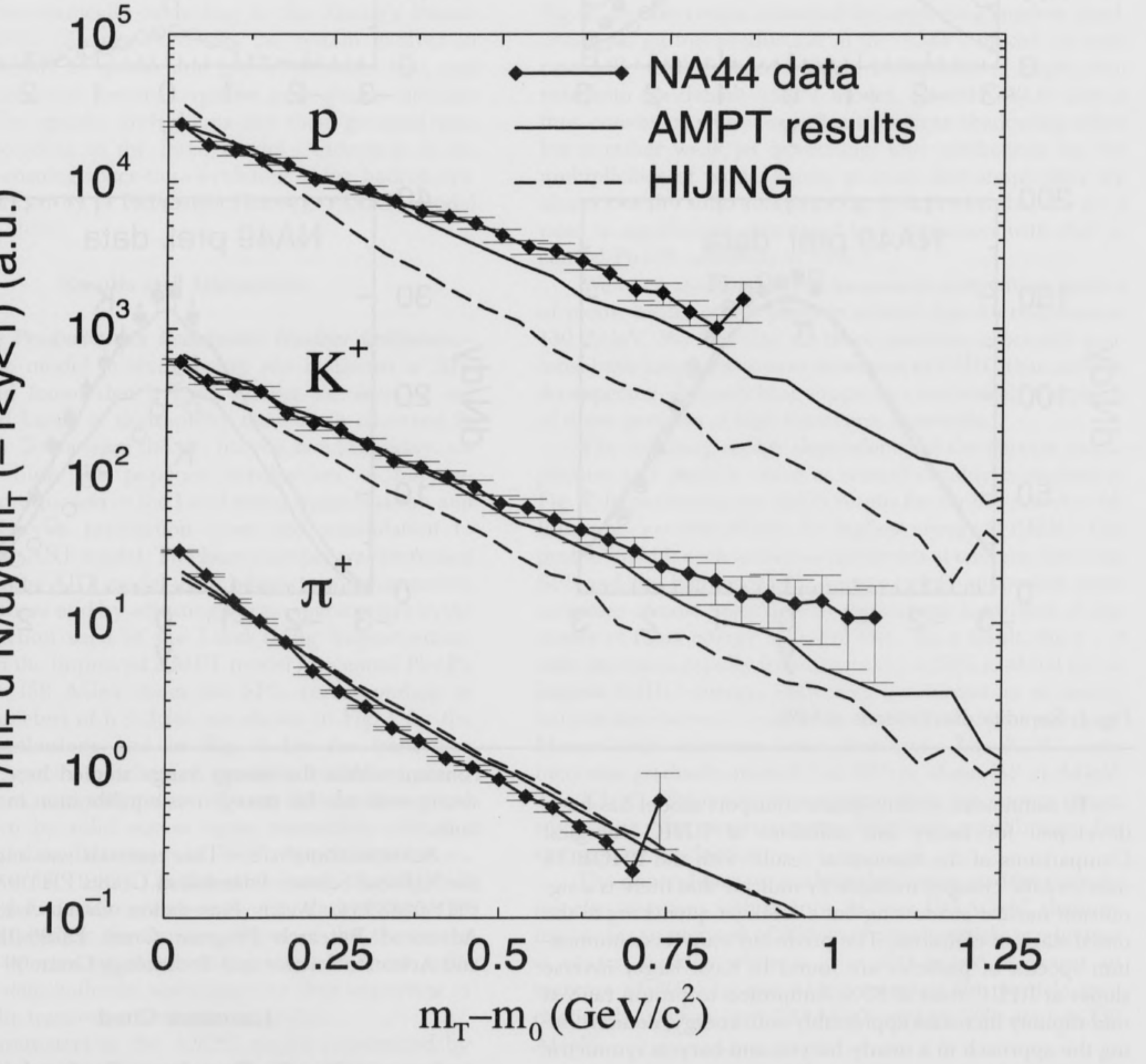

Fig. 2. Transverse momentum spectra at SPS.

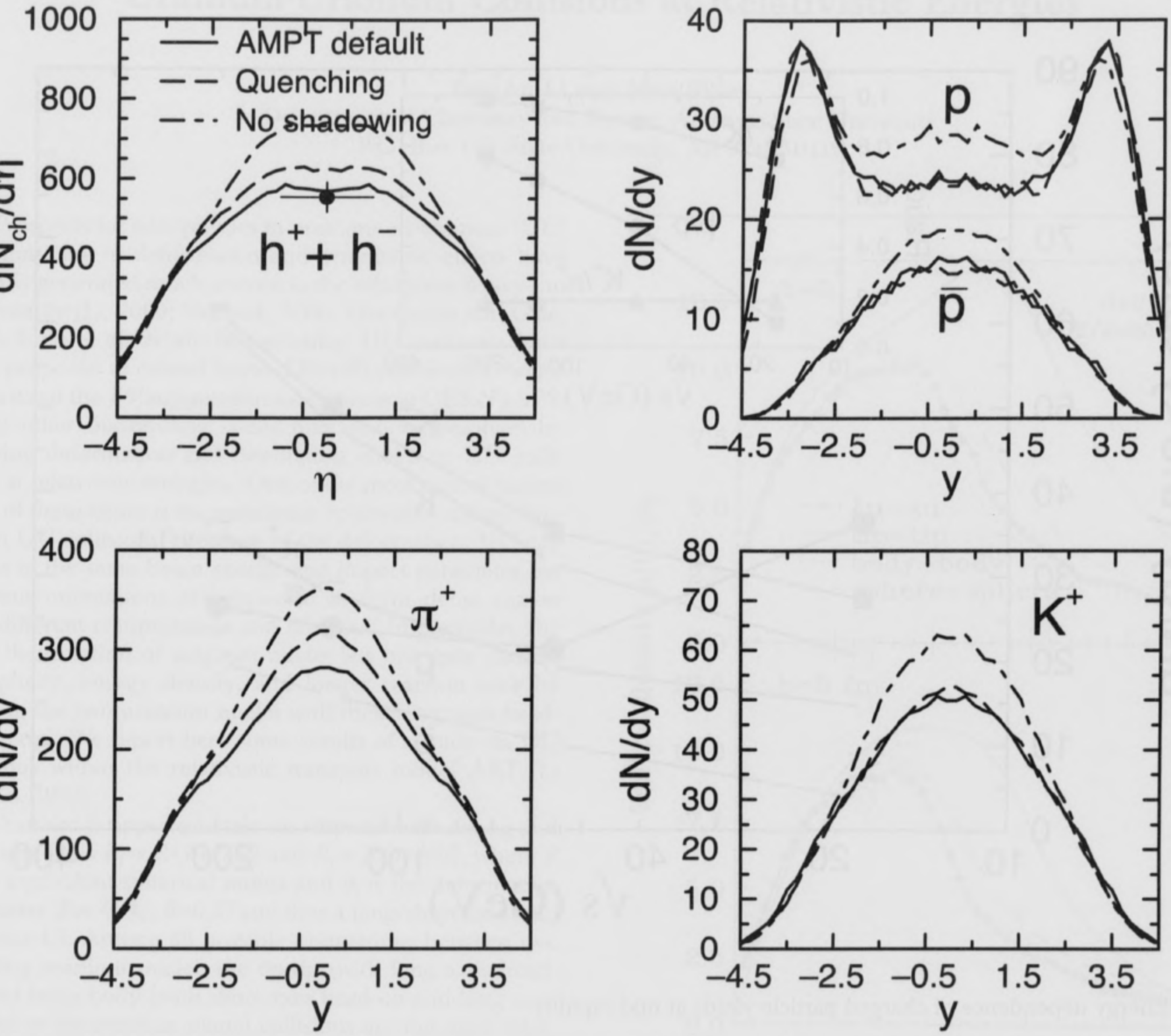

Fig. 3. Rapidity distributions at RHIC.

Shadowing at Small Values of x. Nucl. Phys. B268:427-452.

Müller, B. 1995. Physics and Signatures of the Quark-Gluon Plasma. Rep. Prog. Phys. 58:611-636.

Siklèr, F. et al., NA49 Collaboration. 1999. Hadron Production in Nuclear Collisions from the NA-49 Experiment at 158-GeV/A. Nucl. Phys. A661:45c-54c.

Wang, X. N. and **M. Gyulassy.** 1991. HIJING: A Monte Carlo Model for Multiple Jet Production in pp, pA, and AA Collisions. Phys. Rev. D 44:3501-3516.

Zhang, B. 1998. ZPC 1.0.1: a Parton Cascade for Ultrarelativistic Heavy Ion Collisions. Comput. Phys. Commun. 109:193-206.

Zhang, B., C. M. Ko, B. A. Li and **Z. Lin.** 2000a. Multiphase Transport Model for Relativistic Nuclear Collisions. Phys. Rev. C 61:067901.

Zhang, B., C. M. Ko, B. A. Li, Z. Lin and **B. H. Sa.** 2000b. J/ψ Suppression in Ultrarelativistic Nuclear Collisions. Phys. Rev. C 62:054905.

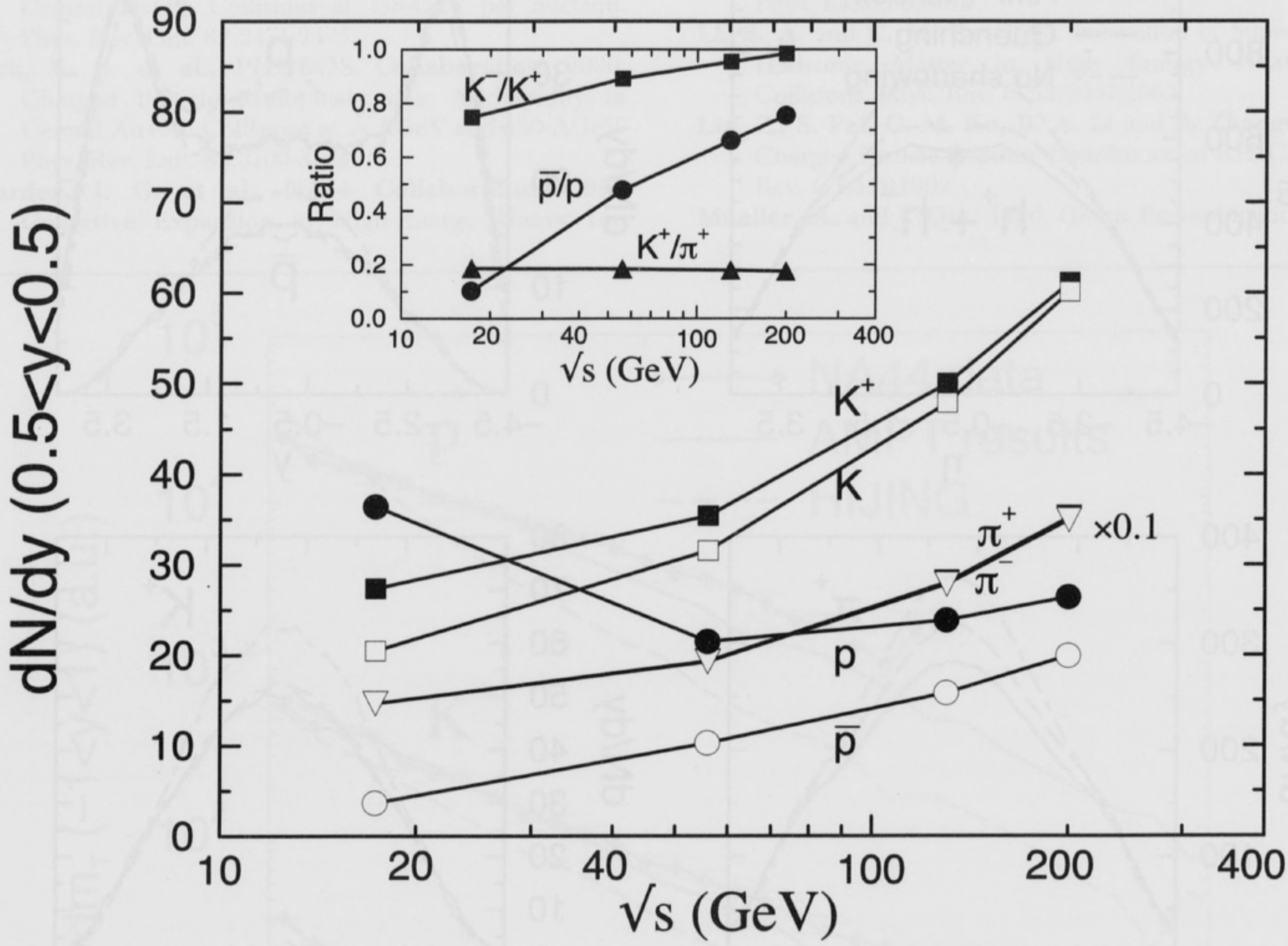

Fig. 4. Energy dependence of charged particle yields at mid-rapidity.

GENERAL NOTES

Uranium-Uranium Collisions at Relativistic Energies

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Prospects for new physics in uranium-on-uranium (UU) collisions due to deformation and orientation effects have recently generated much interest in the relativistic heavy-ion community (Li, 2000; Shuryak, 2000; Das Gupta and Gale, 2000; Kolb et al. 2000). In particular, UU collisions have been proposed to extend beyond Pb+Pb collisions to better understand the J/Ψ suppression mechanism at CERN's SPS. Many other outstanding issues may also be resolved by studying deformation and orientation effects in UU collisions at relativistic energies. One of the most critical factors to all of these issues is the maximum achievable energy density in UU collisions. Because of the deformation, UU collisions at the same beam energy and impact parameter but different orientations are expected to form dense matter with different compressions and lifetimes. In particular, the large deformation of uranium nuclei lets one gain particle multiplicity, energy density, and longer reaction time by aligning the two uranium nuclei with their long axes head-on (tip-tip). We report here some results of a study on UU collisions within the relativistic transport model ART (Li and Ko, 1995).

Uranium is approximately an ellipsoid with a long and short semi-axis $R_l = R\cdot(1+2/3\delta)$ and $R_s = R\cdot(1-1/3\delta)$, where R is the equivalent spherical radius and δ, is the deformation parameter. For ^{238}U, $\delta=0.27$ and thus a long/short axis ratio of about 1.3. Among all possible orientations between two colliding uranium nuclei, the tip-tip (with long axes head-on) and body-body (with short axes head-on and long axes parallel in the reaction plane) collisions are the most interesting ones. Shown in Fig. 1 are the evolution of central baryon densities in the UU collisions at a beam energy of 20 GeV/nucleon and an impact parameter of 0 and 6 fm, respectively. While the body-body UU collisions lead to density compressions comparable to those reached in the Au-Au and spherical UU collisions, 30% more compression is obtained in the tip-tip UU collisions at both impact parameters. The high-density phase (i.e., with $\rho/\rho_0 \geq 5$) in the tip-tip collisions lasts about 3-5 fm/c longer than the body-body collisions. The higher compression and longer passage time render the tip-tip UU collisions the most probable candidates to form the Quark-Gluon-Plasma (QGP).

The elliptic flow reflects the anisotropy in the particle transverse momentum (p_t) distribution at midrapidity, i.e.,

$$v_2 = \langle (p^2_x - p^2_y)/p^2_t \rangle, \quad (1)$$

where $p_x(p_y)$ is the transverse momentum in (perpendicular to) the reaction plane, and the average is taken over all particles in all events. The v_2 results from a competition between the "squeeze-out" perpendicular to the reaction plane and the "in-plane flow". Shown in Fig. 2 is the nucleon elliptic flow as a function of impact parameter in UU collisions with different orientations at beam energy of 10

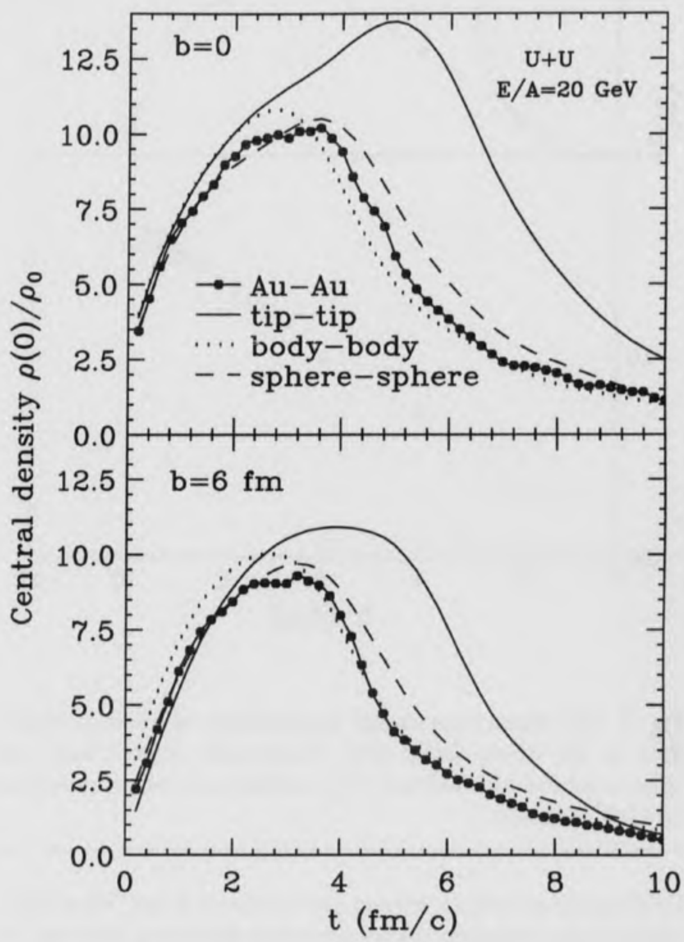

Fig. 1. The evolution of central baryon density in Au-Au (filled circles), tip-tip (solid line), body-body (dotted line) and sphere-sphere (dashed line) UU collisions at a beam energy of 20 GeV/nucleon and an impact parameter of 0 (upper panel) and 6 fm (lower panel), respectively.

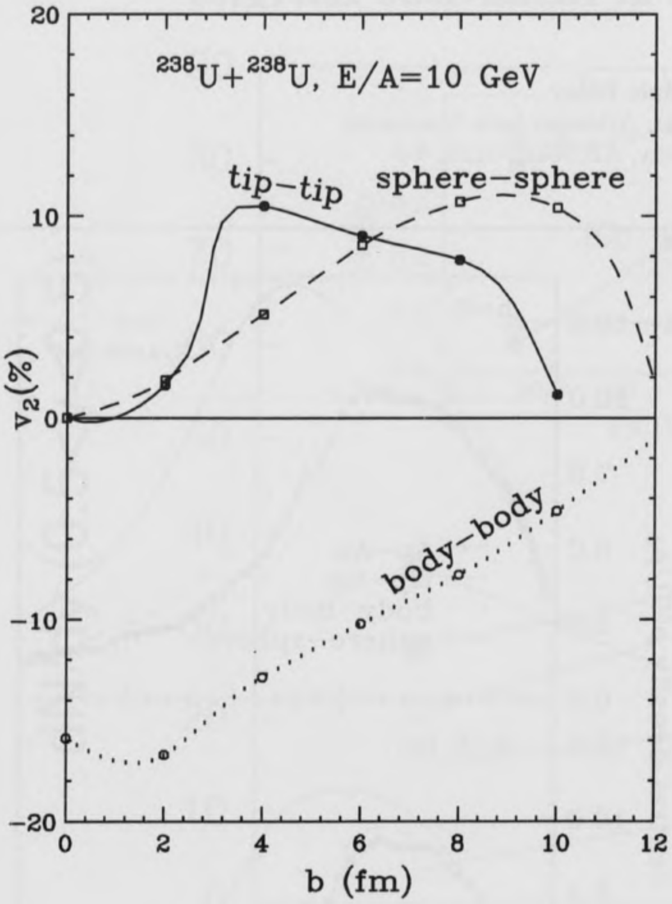

Fig. 2. The impact parameter dependence of nucleon elliptic flow in the tip-tip (solid line), body-body (dotted line) and sphere-sphere (dashed line) UU collisions at beam energy of 10 GeV/nucleon.

GeV/nucleon and an impact parameter of 6 fm. We initialized the two uranium nuclei such that their long axes are in the reaction plane in both tip-tip and body-body collisions. It is seen that both the tip-tip and sphere-sphere collisions lead to a strong "in-plane flow" (positive v_2) whereas the body-body reactions result in a large "squeeze-out" (negative v_2). Only in the body-body UU collisions, is the strength of elliptic flow the highest in the most central collisions where the shadowing effect in the reaction plane the strongest. Whereas in tip-tip and sphere-sphere UU collisions the elliptic flow vanishes in the most central collisions due to symmetry. Similar results are found for pions too.

It is also of considerable interest to study deformation and orientation effects on particle production. Shown in Fig. 3 are the multiplicities of pions and positive kaons as a function of impact parameter. The maximum impact parameter for the tip-tip and body-body UU collisions is $2R_s$ and $2R_b$ respectively. As one expects the central (with $b \leq 5$ fm) tip-tip UU collisions produce more particles due to the higher compression and the longer passage time of the reaction. While at larger impact parameters, the smaller overlap volume in the tip-tip collisions leads to less particle production than the body-body and sphere-sphere reactions. Also as one expects from the reaction geometry, the multiplicities in the body-body collisions approach those in the sphere-sphere collisions as the impact parameter reaches zero. In the most central collisions, the tip-tip UU collisions produce about 15% (40%) more pions (positive kaons) than the body-body and sphere-sphere UU collisions. These deformation and orientation effects on particle production are consistent

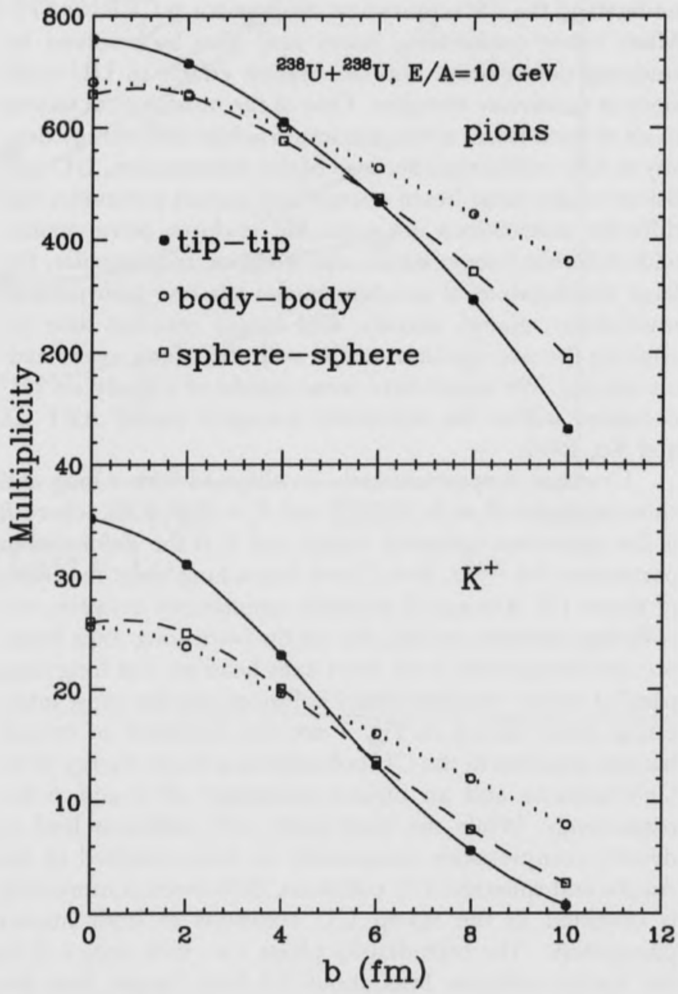

Fig. 3. The impact parameter dependence of pion (upper panel) and positive kaon (lower panel) production in the tip-tip (solid line), body-body (dotted line) and sphere-sphere (dashed line) UU collisions at a beam energy of 10 GeV/nucleon.

with those on density compression shown in Fig. 1. Compared to pions, kaons are more sensitive to the density compression since most of them are produced from second chance particle (resonance)-particle (resonance) scatterings at the energies studied here.

By using A Relativistic Transport model we have studied the deformation/orientation effects on the compression, elliptic flow, and particle production in uranium on uranium (UU) collisions at relativistic energies. The compression in the tip-tip UU collisions is about 30% higher and lasts approximately 50% longer than in the body-body or spherical UU collisions.

Moreover, we found that the nucleon elliptic flow in the body-body UU collisions has some unique features. The tip-tip UU collisions are thus more probable to create the QGP at the AGS/BNL and SPS/CERN energies. At RHIC/BNL and LHC/CERN energies, however, the "squeeze-out" of particles in the central body-body collisions is more useful for studying properties of the QGP.

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Literature Cited

Das Gupta S. and **C. Gale.** 2000. On the Choice of Colliding Beams to Study Deformation Effects in Relativistic Heavy-Ion Collisions Phys. Rev. C62: 031901.

Kolb, P.F., J. Solfrank and **U. Heinz.** 2000. Anisotropic Transverse Flow and the Quark-Hadron Phase Transition. Phys. Rev. C62: 054909.

Li, B.A. 2000. Uranium-Uranium collisions at Relativistic Energies, Phys. Rev. C61: 021903.

Li, B.A. and **C. M. Ko.** 1995. Formation of Superdense Matter in High Energy Heavy-Ion Collisions. Phys. Rev. C52: 2037.

Shuryak, E.V. 2000. High Energy Collisions of Strongly Deformed Nuclei: an Old Idea with a New Twist. Phys. Rev. C61: 034905.

Results of a Bat Survey in the Western Ozark National Forest

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Sixteen species of bats are known to occur in Arkansas (Sealander and Heidt, 1990). Most information on distribution of these species is based on scattered site records and cave surveys (Sealander and Young, 1955; Baker and Ward, 1967; Gardner and McDaniel, 1978). Studies on geographic distribution, status, and ecology of endangered bats in Arkansas have been conducted since 1978 (Wilhide et al., 1998). Although bats are commonly studied in caves, investigations of free-ranging bats in the summer also have been studied. In Arkansas such studies have been undertaken primarily in the Sylamore Ranger District of the eastern Ozark National Forest (Wilhide et al., 1998) and various ranger districts of the Ouachita National Forest (Saugey et al., 1989). However, few studies of that type have been conducted in the western Ozarks. Surveys of this northwestern region of Arkansas are needed to determine distribution and abundance of bats. The Ozarks appear to be an important area for biodiversity of bats, and the many caves found throughout the region provide locations for hibernacula, mating colonies, and maternity colonies (Harvey, 1986, 1994).

The study was conducted at two sites in northwestern Arkansas. One site was Whitzen Hollow, which is a small watershed located in the Lee Creek Unit of the Ozark National Forest near the Arkansas-Oklahoma border. Preliminary work in this area by J. D. Wilhide in spring 1999 verified the presence of five species of common bats, and a survey of small caves in the area documented that a small number of Ozark big-eared bats (*Corynorhinus townsendii ingens*) and eastern pipistrelles (*Pipistrellus subflavus*) were using the sites as roosts (J. Briggler and J. Prather, pers. comm.).

The other site was the Wedington Unit of the Ozark National Forest, which is a large forested tract in the northwestern corner of the Boston Mountain Ranger District. It is separated from the main national forest. This unit consists of Lake Wedington, as well as several ponds and streams, all of which should provide ideal habitat for bats. There has been no work done to ascertain the presence of bat species that inhabit this area.

Bats were captured using mist nets (Kunz, 1988; Tuttle, 1976). Netting was conducted 29 April through 19 October 2000. A total of 59 net nights (one net-night equals one mist net opened into the capture position for a netting session) was generated on 45 different dates, with one or two net-nights per date. Nets were put up before sundown and were taken down at midnight. Twenty-two sites were netted including six streams and 16 ponds. Each site was netted twice, once during early summer (April – July) and once in late summer (August – October). Nets (3 x 6 or 3 x 9 m) were placed across ponds or stream crossings prior to dusk and checked at 10-min. intervals. Actual netting periods varied from 4 to 6 hours depending on the time of sundown. Bats were removed from nets and identified, and sex, reproductive status, length of forearm, and mass were recorded. Bats were banded with a numbered plastic band and released at the site of capture. Ambient temperature was recorded every hour.

During 45 nights of netting, a total of 142 bats was captured, representing eight species in six genera of the family Vespertilionidae. Only one bat, a male *Myotis septentrionalis*, was recaptured. Species caught were: big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), little brown bat (*Myotis lucifugus*), northern long-eared bat (*Myotis septentrionalis*), evening bat (*Nycticeius humeralis*), and the eastern pipistrelle (*Pipistrellus subflavus*). About twice as many bats were captured in Whitzen Hollow as compared to the Wedington Unit (Table 1). Sex ratios for the Wedington Unit were almost equal, whereas almost twice as many males as females were captured at Whitzen Hollow. Whitzen Hollow was a compact area with relatively few water resources, whereas the Wedington Unit was expansive and included many ponds and streams as well as the Illinois River and Lake Wedington. The smaller size of Whitzen Hollow permitted a more adequate sampling of the area. There are many caves there providing a great roosting habitat for bats. Since the Wedington Unit covered a larger area, it was more difficult to sample. Furthermore, most of the ponds there were too large and deep for netting, and because much of the land is privately owned or leased for cattle, many of the ponds and streams were not available for sampling. These differences in sites could explain the dramatic differences in the number of bats netted. Even though it was lacking in numbers of bats, the Wedington Unit supported a greater number of species than Whitzen Hollow (Table 1). Of the species captured, the big brown bat was the only species not found in the Wedington Unit. Three species, the hoary bat, the silver-haired bat, and the little brown bat, were lacking in the Whitzen Hollow sample. The most com-

Table 1. Bats captured in the Wedington Unit and Whitzen Hollow study areas.

Species	Wedington Unit			Whitzen Hollow		
	Male	Female	Total	Male	Female	Total
Eastern Pipistrelle	8	5	13	10	0	10
Evening Bat	5	3	8	18	8	26
Eastern Red Bat	7	4	11	11	10	21
Big Brown Bat	0	0	0	5	1	6
Northern Long-eared Bat	1	6	7	14	15	29
Little Brown Bat	3	5	8	0	0	0
Hoary Bat	1	0	1	0	0	0
Silver-haired Bat	0	1	1	0	0	0
Grand Total	25	24	49	58	34	92

Table 2. Seasonal trends in species distribution between sites.

Species	April - July		August - October	
	Whitzen	Wedington	Whitzen	Wedington
Eastern Pipistrelle	8	4	2	9
Evening Bat	19	4	7	4
Eastern Red Bat	19	6	3	3
Big Brown Bat	5	0	1	0
Northern Long-eared Bat	6	5	23	2
Little Brown Bat	0	2	0	6
Hoary Bat	0	1	0	0
Silver-haired Bat	1	0	0	0
Grand Total	57	23	36	24

mon species found in the Wedington Unit were, in order of abundance, the eastern pipistrelle, the eastern red bat, the evening bat, and the little brown bat (Table 1). The most common species found in Whitzen Hollow were the northern long-eared bat, the evening bat, and the eastern red bat.

The Shannon Diversity Index, (H'), (Cox, 1996) was used to measure heterogeneity at both study areas analyzing differences based on time of year. Results showed that the Wedington Unit had a greater diversity of species in both the early (H' = 1.03) and late (H' = 0.75) parts of the season as compared to Whitzen Hollow, with the greatest diversity being earlier in the year. This trend was not the same for species diversity in Whitzen Hollow with the greater diversity there being later in the season (H' = 0.58), rather than earlier (H' = 0.51). This phenomenon might be explained by noting that two species (the hoary bat and the silver-haired bat) were caught only early in the season (Table 2), which would influence the diversity calculations. Overall, the Wedington Unit had more than twice the number of species (H' = 1.06) compared to Whitzen Hollow (H' =

Table 3. Seasonal trends and habitat use by bats in the western Ozarks.

	April - July					August - October				
Species	Pond	Stream	Male	Female	Total	Pond	Stream	Male	Female	Total
Eastern Pipistrelle Bat	4	8	11	1	12	4	7	7	4	11
Evening Bat	19	4	15	8	23	9	2	8	3	11
Eastern Red Bat	17	8	12	13	25	5	2	6	1	7
Big Brown Bat	5	0	5	0	5	1	0	0	1	1
Northern Long-eared Bat	10	1	3	8	11	24	1	12	13	25
Little Brown Bat	1	1	1	1	2	0	6	2	4	6
Hoary Bat	1	0	1	0	1	0	0	0	0	0
Silver-haired Bat	1	0	0	1	1	0	0	0	0	0
Grand total	58	22	48	32	80	43	18	35	26	61

0.43). This contrasts with the population finding (Table 1) which reflects higher numbers of bats in Whitzen Hollow suggesting a large population with few species whereas the Wedington Unit appears to support a small population of many species. Evenness, (J′), too, was calculated (Pielou, 1969) yielding almost equal values for overall evenness in both the Wedington Unit ($J' = 0.38$) and Whitzen Hollow ($J' = 0.36$). However, there were differences between sites as well as seasonal differences within sites. The Wedington Unit had higher evenness values for both the early ($J' = 0.54$) and late ($J' = 0.53$) seasons than did Whitzen Hollow. While the evenness values for the Wedington Unit were almost equal for both seasons, the values for Whitzen Hollow varied between season with the greatest value later ($J' = 0.32$) as compared to earlier ($J' = 0.27$). Other important seasonal differences are sex ratio and habitat differences between seasons. More males than females were caught at both sites. Pond habitat had higher use during both seasons than streams due to more netting at ponds than streams. It is interesting to note, however, that certain species such as the eastern pipistrelle and little brown bat were captured over streams, whereas evening bats, eastern red bats, northern long-eared bats, and big brown bats all were captured over ponds (Table 3). Seasonal trends between sites show that Whitzen Hollow had more activity than the Wedington Unit early in the season, but activity was much closer to the same in both sites in the latter part of the year (Table 2).

To summarize, this study is the first extensive bat survey conducted in the western part of the Ozark National Forest. Therefore, it represents a pioneer baseline study since the Arkansas literature on bats is lacking on published studies of this kind for comparison. It is important to conduct such a survey to document the species of bats present in an area. This study shows that a variety of bats inhabit the Wedington Unit and Whitzen Hollow areas.

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Literature Cited

Baker, R. J. and **C. M. Ward.** 1967. Distribution of bats in southeastern Arkansas. J. Mammalogy 48:130-132.

Cox, G. W. 1996. Laboratory Manual of General Ecology. 7th Ed. Chicago: Wm. C. Brown Publishers.

Gardner, J. E. and **B. R. McDaniel.** 1978. Distribution of bats in the delta region of northeastern Arkansas. Proc. Arkansas Acad. Sci. 32:46-48.

Harvey, M. J. 1986. Arkansas bats: a valuable resource. Arkansas Game and Fish Commission, Little Rock. 48 pp.

Harvey, M. J. 1994. Status of endangered Gray Bat hibernating populations in Arkansas. Proc. Arkansas Acad. Sci. 48:250-251.

Kunz, T. H. 1988. Ecological and behavioral methods for the study of bats. Smithson. Institut. Press, Washington D.C.

Pielou, E. C. 1969. An introduction to mathematical ecology. Wiley-Interscience, New York.

Saugey, D. A., D. R. Heath, and **G. A. Heidt.** 1989. The bats of the Ouachita Mountains. Proc. Arkansas Acad. Sci. 43:71-77.

Sealander, J. A. and **G. A. Heidt.** 1990. Arkansas Mammals: Their Natural History, Classification, and Distribution. Univ. Arkansas Press, Fayetteville, Arkansas.

Sealander, J. A. and **H. Young.** 1955. Preliminary observations on the cave bats of Arkansas. Proc. Arkansas Acad. Sci. 7:21-31.

Tuttle, M. D. 1976. Collecting techniques. Pp. 71-86. *In* Baker, R. J., J. K. Jones, Jr., and D. C. Carter (eds.).

Biology of bats of the New World family Phyllostomatidae. Part I. Spec. Publ. Mus., Texas Tech Univ. No. 10. 218 pp.

Wilhide, J. D., M. J. Harvey, V. R. McDaniel, and V. E. Hoffman. 1998. Highland pond utilization by bats in the Ozark National Forest, Arkansas. Proc. Arkansas Acad. Sci. 52:110-112.

Non-Commercial Software for the Analysis and Interpretation of High Resolution Molecular Spectra

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Infrared spectroscopy is a powerful method of analysis with a rich chemical history. Indeed, the application of this technique to identify functional groups in complex organic molecules by their characteristic infrared absorption band features is well known (Silverstein etal., 1981). Moreover, if the absorption intensities can be accurately measured, a quantitative analysis for the material absorbing the radiation can be performed (Bernath, 1995; Miller, 2000). For the most part, low resolution commercial FTIR instruments are well suited for this type of analytical measurement. However, in the gas phase, using an infrared spectrometer with sufficient resolution, spectroscopists can not only obtain accurate vibrational frequencies for the molecular systems under investigation, they can also quantitatively measure the rotational energy spacing within a vibrational state. The measurement and subsequent analysis of such data provides a wealth of fundamental information about the chemical and physical bonding interactions in the molecule. Details concerning molecular structure, the strength of chemical bonds, and the shape of molecular potential energy surfaces can all be extracted from the high resolution spectra (Nesbitt, 1988). Although there are a number of methods which have been developed to extract this detailed molecular information (Hollas, 1996), assignment of the individual spectral features (to include rotational quantum number assignments) is necessarily required. Assigning spectral features for a previously unknown or unreported molecular spectrum can be a tedious, time consuming task, particularly if the species under investigation is a symmetric top possessing perpendicular vibrational bands or an asymmetric top molecule (Herzberg, 1950; Hollas, 1998). One commonly used method for assigning the individual transitions in a complex spectrum involves calculating a stick spectrum (to include relative intensities), overlaying the stick spectrum on the observed spectrum, and translating the calculated spectrum until a set of likely features in the observed spectrum can be identified. As the stick spectrum is initially generated using molecular constants obtained from *ab initio* predictions or extrapolated from ground vibrational state values, an iterative process in which the input constants are varied slightly for each iteration is often required to obtain a consistent set of assignments. Over the past year, we have developed the necessary Visual Basic code to allow this proven systematic procedure for assigning complex rotationally resolved spectra to be implemented in a spreadsheet type environment. Here we describe the software and provide one example of its utility.

In Fig. 1 we show the rotationally resolved vibrational

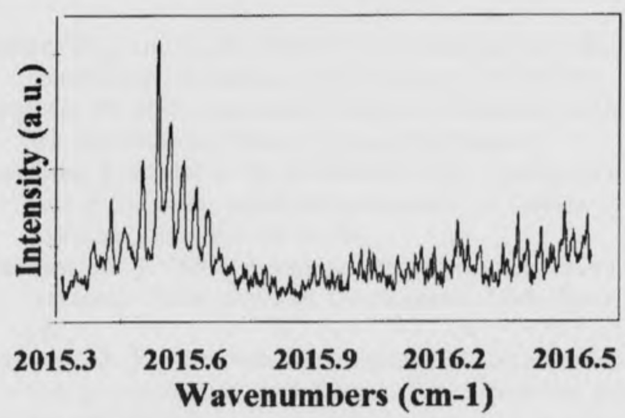

Fig. 1. Rotationally resolved infrared spectrum for the ν_{10} band of jet cooled iron pentacarbonyl.

spectrum for the jet cooled iron pentacarbonyl molecule. This particular spectrum corresponds to the ν_{10} perpendicular vibrational band of iron pentacarbonyl (Ford, 2001). Perpendicular bands of symmetric tops typically possess a number of sub-bands, due to rotation about the symmetry axis of the molecule, which are offset slightly from one another (Herzberg, 1950; Hollas 1998). A calculated stick spectrum for several different sub-bands of the iron pentacarbonyl ν_{10} band is shown in Fig. 2 (Ford, 2001). Based on the data in these figures, assignment of the individual spectral features in this spectra could potentially be a formidable task.

Chem Spec II, the software program we developed to

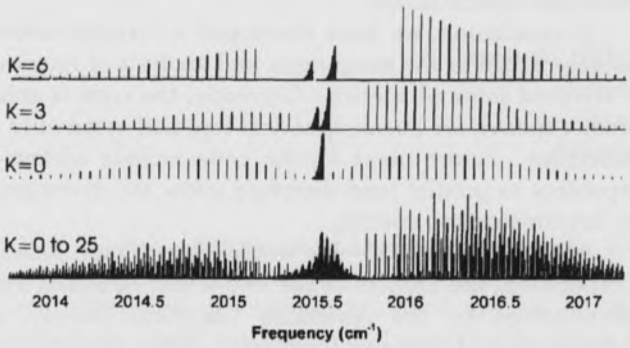

Fig. 2. Predicted stick spectrum for several sub-bands or K-states and the complete ν_{10} band of iron pentacarbonyl. Note, the individual sub-bands are slightly offset from one another.

aid in the analysis and interpretation of such complex molecular spectra, is quite user friendly. In fact, we have attempted to make it emulate spreadsheet programs such as Excel or Quattro Pro as much as possible. In Fig. 3 the graphical user interface (GUI) for Chem Spec II is shown. Note the similarity between the GUI in Fig. 3 and an Excel

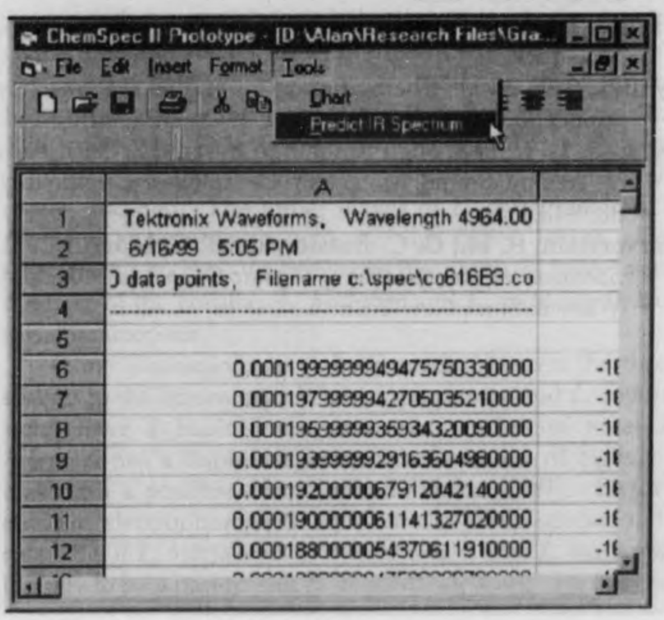

Fig. 3. The graphical user interface for Chem Spec II.

spreadsheet. To access the infrared spectral prediction portion of the program, one needs simply to select the PREDICT IR SPECTRUM option under the TOOLS pull-down menu. Upon selection of the PREDICT IR SPECTRUM option, a dialog box appears which contains the Predict IR Spectrum Wizard (see Fig. 4). Within the Wizard dialog box, the spectroscopist must set all parameters rele-

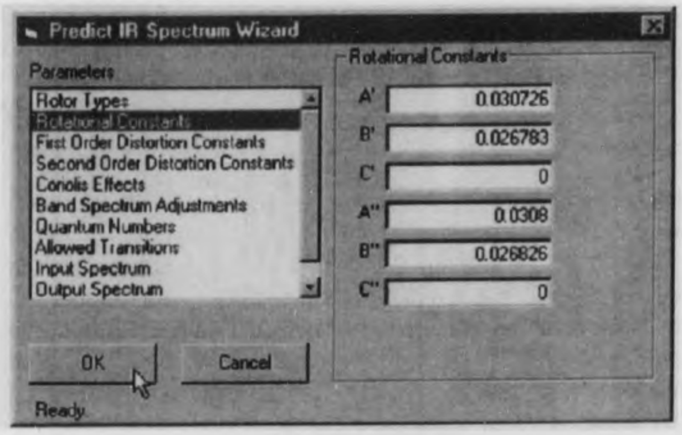

Fig. 4. The Predict IR Spectrum Wizard. Here the rotational constants for the ground and excited states of a prolate symmetric top are being entered.

vant to the problem under consideration including the Rotor Type for the molecule (e.g., symmetric top), entering values for the Rotational Constants, indicating the Allowed Transitions, and inputing the Quantum Numbers for the transitions to be plotted. This last feature is particularly useful if the operator is interested in examining a single sub-band. Chem Spec II also has the capability to include other effects that are often observed in rotationally resolved spectra such as coriolis coupling and centrifugal distortion. Once the necessary parameters have been input, the predicted spectrum must be output to the spreadsheet by selecting an appropriate output range. The output range is determined in a manner similar to that in Excel or Quattro Pro (see Fig. 5). The predicted spectrum can then be displayed and/or over-layed on the observed spectrum. Figure

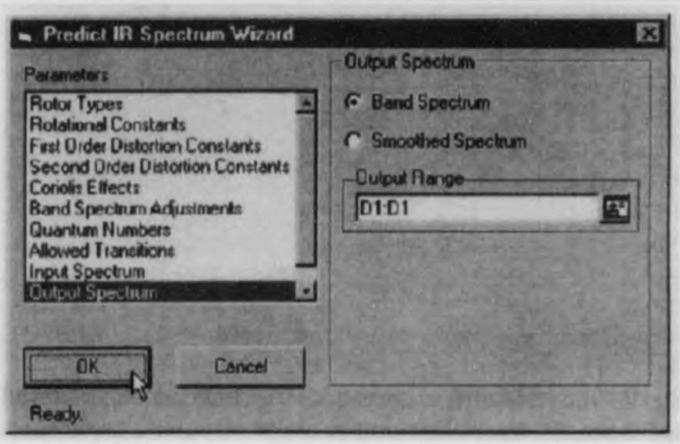

Fig. 5. Selecting the output range for the calculated stick spectrum in the Chem Spec II spreadsheet.

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6 provides an example of such a plot. If a likely set of spectral features cannot be identified, changes in rotational constants can be input and a new stick spectrum can be calculated and plotted through the prediction wizard with a few mouse clicks. Once a likely progression is identified, the actual quantum number assignment is obtained by clicking on each stick in the calculated spectrum. Selection of any feature in the stick spectrum causes a dialog box to appear which contains the rotational quantum number information as shown in Fig. 7. Using this software package, we have assigned the entire ν_{10} perpendicular band of jet cooled iron pentacarbonyl. A detailed analysis of these assignments will appear in a manuscript being prepared for the Journal of Molecular Spectroscopy.

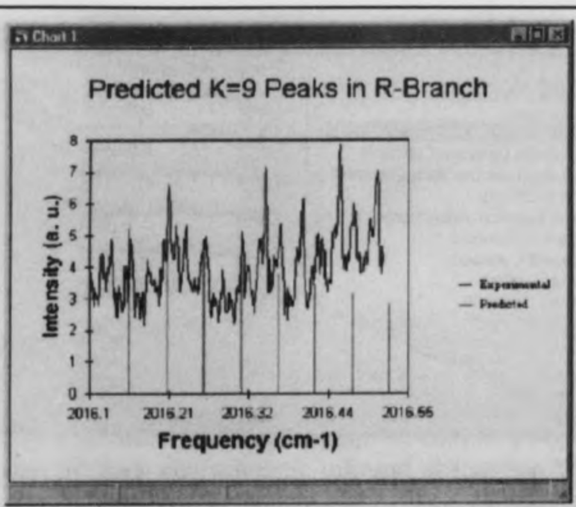

Fig. 6. Plot of the calculated stick spectrum overlayed on the observed infrared spectrum.

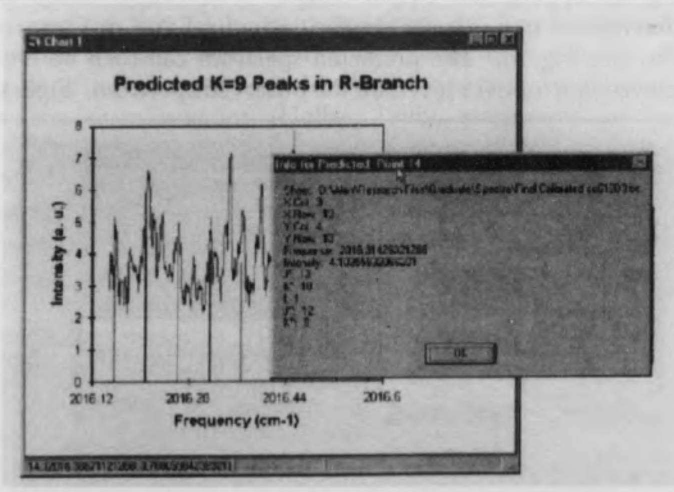

Fig. 7. Once a likely progression is identified in the observed spectrum, the quantum number assignment for a given spectral feature is obtained by clicking on the appropriate stick.

In conclusion, we have developed a versatile software package to aid in the assignment and analysis of rotationally resolved infrared spectra. Currently, the code is able to predict spectra for linear, spherical top, and symmetric top molecules. Future plans for the code include adding the capability to predict (and therefore allow the investigation of) asymmetric top spectra.

ACKNOWLEDGMENTS.—We would like to thank Research Corporation, the Donors of the Petroleum Research Fund, administered by the American Chemical Society, and Arkansas State University for support of this project.

Literature Cited

Bernath, P. F. 1995. Spectra of Atoms and Molecules. Oxford.

Ford, A. R. 2001. Rotationally Resolved Infrared Spectroscopy and DFT Study of Jet Cooled Iron Pentacarbonyl. Masters Thesis.

Herzberg, G. 1950. Molecular Spectra and Molecular Structure II: Infrared and Raman Spectra. D. Van Nostrand Company, New Jersey.

Hollas, J. M. 1998. High Resolution Spectroscopy. J. Wiley & Sons, New York.

Hollas, J. M. 1996. Modern Spectroscopy. J. Wiley & Sons, New York.

Miller, C. E. 2000. Chemometrics for on-line spectroscopy applications-theory and practice. J. Chemometrics, 14,1.

Nesbitt, D. J. 1988. High Resolution Infrared Spectroscopy of Weakly Bound Molecular Complexes. Chem. Rev. 88, 843.

Silverstein, R. M., G. C. Bassler, and **T. C. Morrill.** 1981. *Spectrometric Identification of Organic Compounds.* 4th Ed. J. Wiley & Sons, New York.

Diversity of *Lamium* (Lamiaceae) in Arkansas, Including Occurrences of *Lamium hybridum* and Flower Color Forms

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Two species of *Lamium*, *Lamium purpureum* L. and *Lamium amplexicaule* L., are common throughout Arkansas (Smith, 1988). We are reporting a third species, *Lamium hybridum* Vill., which has been found at several locations in the state.

The epithet suggests a hybrid origin of this taxon, and various authors have regarded it as originating from *L. purpureum* and either *L. amplexicaule* or some other species (Fernald, 1970; Gleason, 1952; Tutin et al., 1972). Little and Warburg (1953) found the balance of evidence against this hypothesis and pointed out that when *L. hybridum* seeds germinated none of the progeny show characteristics intermediate between those of *L. purpureum* and *L. amplexicaule.* Jones and Jones (1965) reported that artificial crosses between *L. purpureum* and *L. amplexicaule* were unsuccessful. They also constructed a hybrid index in an area where both *L. purpureum* and *L. amplexicaule* had been growing together for several years and found that no individuals showing characteristics of a hybrid were present.

In the field, *L. hybridum* can easily be distinguished from *L. purpureum* and *L. amplexicaule* by leaf characteristics. The leaves of *L. hybridum* are somewhat similar to those of *L. purpureum*, but the blades are distinctly notched, not merely toothed. The upper leaves of *L. purpureum* and *L. hybridum* have petioles, whereas the upper leaves of *L. amplexicaule* do not. *L. purpureum* has a ring of hairs inside the base of the corolla. *L. hybridum* and *L. amplexicaule* lack this characteristic.

Other distinctions have been made between the three species in the laboratory. While *L. purpureum* and *L. amplexicaule* have a haploid chromosome number of nine, *L. hybridum* has a haploid chromosome number of eighteen, making it a possible allopolyploid (Taylor, 1991). Taylor's enzyme electrophoretic analysis of the three species indicates that if *L. hybridum* is of hybrid origin then *L. purpureum* is likely to be a parent, but *L. amplexicaule* is not. He has also compared the anthocyanins that occur in the three species. The anthocyanins of *L. hybridum* were found to be more closely related to that of *L. purpureum* (Taylor, 1991).

Our cursory investigation of the pigments in the three species supports a closer relationship between the pigments found in *L. purpureum* and *L. hybridum* than those found in *L. amplexicaule.* Pigments were extracted from plants of the three species using hot water. The extracts were then scanned in a Cary 50 ultraviolet spectrophotometer. The resulting absorption curves for the three species showed a closer relationship between the pigments of *L. purpureum* and *L. amplexicaule* than those of *L. hybridum.*

Populations of *L. hybridum* have been found in five counties in Arkansas. Voucher specimens from each of these counties were deposited in the Henderson State University Herbarium (HEND). *D. L. McDaniel 290* was collected in Midway in Hot Spring County. *D. W. Smith 107* was collected in Hempstead County. *Haley 027* was collected in Garland County north of Hot Springs on Highway Five and was associated with both *L. purpureum* and *L. amplexicaule. Marsh 9604* was also collected in Garland County and was associated with *L. amplexicaule. Marsh 9468* was collected at the Lower Dam Recreation Area at Lake DeGray in Clark County, and *Marsh 9490* was collected at the Highway 7 Ouachita River Access also in Clark County. *Marsh 9612* was collected in Nevada County. In all locations, except the one site in Nevada County, *L. hybridum* was associated with at least one other species of *Lamium.*

Lamium hybridum seems to be the same taxon that some sources designate *L. purpureum* var. *incisum* (Willd.) Pers., and Kartesz (1994) adopts this usage with the notation "auct. non Vill." attached to the synonymized binomial. Our review of the literature and field studies lead us to disagree with this interpretation, and we conclude that *L. hybridum* is a well-defined species. It is distinguished from *L. purpureum* by chromosome number as well as morphological characters, and it occurs in populations that are extensive and distinctive. It frequently occurs sympatrically with *L. purpureum* with no intermediates between the two taxa. *L. hybridum* is probably widespread but often overlooked because of its superficial resemblance to *L. purpureum.*

Variation in the flower color of *L. amplexicaule* and *L. purpureum* was also observed during field investigations. Dwight Moore (1941) reported the white-flowered form of *L. amplexicaule* in Arkansas and designated it as *Lamium amplexicaule* forma *albiflorum.* This form reportedly not only had white flowers but lacked the red pigment throughout the stem and leaves (Moore, 1941). Smith (1988) states that the white-flowered form is scattered throughout Arkansas. We have found this form only in two locations in Malvern, in Hot Spring County. *Marsh 9492* was collected at Centennial Park, where *L. amplexicaule* forma *albiflorum* occurs as a substantial population. The other site, consisting of only a few plants, is in Malvern in a city park off Highway 270. *L. amplexicaule* forma *albiflorum*, *L. amplexicaule*, *L. hybridum*, and *L. purpureum* were all observed at this location.

Lamium purpureum occurs in three different color forms. Besides the normal dark purple coloration of the top leaves and flowers, a form also exists that has pale pink flowers and less purple coloration in the stem and leaves. We will informally refer to this as the pastel form. The pastel form, as well as the white-flowered form, occurs in distinct patches among the normal purple form. The white-flowered form of *L. purpureum* has been previously reported in Washington County (Smith, 1988). We are reporting several more locations for this form. T. Fulmer found two sites for the white-flowered form in Clark County. One site is at the Lower Dam Recreation Area at Lake DeGray. The other site in Clark County is on the northern end of the Ouachita Baptist University campus. The authors found the white-flowered form of *L. purpureum* in Little Rock at the corner of Cedar Hill and Brookwood in Pulaski County. At this location all three color forms were present. *Haley 025*, a voucher specimen of the pastel form, and *Haley 026*, a voucher specimen of the white-flowered form, were collected at this location. The white-flowered form also lacks the purple pigment in the stem and leaves. The stem and leaves have a yellowish color.

Literature Cited

Fernald, M. L. 1970. Gray's manual of botany, eighth edition. D. Van Nostrand Company. xiv + 1632 pp.

Gleason, H. A. 1952. The new Britton and Brown illustrated flora of the northeastern United States and adjacent Canada. Vol. 3 New York Botanical Garden. iii + 589 pp.

Jones, S. B., Jr., and **C. A. Jones.** 1965. Status of *Lamium hybridum* Vill. (Labiatae). Amer. Midl. Nat. 74:503-505.

Kartesz, J.T. 1994. A synonymized checklist of the vascular flora of the United States, Canada, and Greenland, 2nd ed. Vol. 1–Checklist. Timber Press, Portland, Oregon. xi + 622 pp.

Little, J. E. and **E. F. Warburg.** 1953. *Lamium hybridum* Vill. Watsonia. 2:361-368.

Moore, D. M. 1941. White-flowered forms of some Arkansas wild flowers. Proc. Arkansas Acad. Sci. 1:25-27.

Smith, E. B. 1988. An atlas and annotated list of the vascular plants of Arkansas, second edition. Published by the author. iv + 489 pp.

Taylor, R. J. 1991. The origin of *Lamium hybridum*, a case study in the search for the parents of hybrid species. Northwest Sci. 65:116-124.

Tutin, T. G., V. H. Heywood, N. A. Burgess, D. H. Valentine, S. M. Walters, and **D. A. Webb** (eds). 1972. Flora Europaea. Vol. 3 Cambridge Univ. Press. xxix + 370 pp.

A Status Report on Harperella, *Ptilimnium nodosum* (Rose) Mathias, in Arkansas

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Introduction

A survey of the federally endangered *Ptilimnium nodosum* (Apiaceae) was conducted in Arkansas during August 2000. During the course of the research, 12 populations of the species in the state were visited to estimate population size. *Ptilimnium nodosum* is unique in both morphology and habitat requirements. The unique morphological characteristics that differentiate the plant from all others in this family are its hollow, septate, quill-like leaves (Easterly, 1957). *Ptilimnium nodosum* is distributed across the eastern and southern flanks of the Appalachian Mountains in six southeastern states in the U. S.: Alabama, Georgia, Maryland, North Carolina, South Carolina, and West Virginia (Bartgis, 1997).

After review by the U. S. Fish and Wildlife Service, the plant was listed as a federally endangered species in 1988 (U. S. Fish and Wildlife Service, 1988). Two years later, the plant was discovered in Arkansas (Bates, 1993). Since that time, multiple occurrences have documented extending the range of the species in Arkansas to four counties (Montgomery, Garland, Scott, Yell) in the Ouachita and Fourche LaFave watersheds. This study will establish a highly repeatable and accurate method by which populations of *P. nodosum* may be monitored. Accurate population estimates are essential to the formulation of sound management policies and to address the impact of various forestry or recreational activities in the area.

Methods

Twelve populations of *Ptilimnium nodosum* were surveyed to determine population size. Two procedures were used. On sites comprised of a small number of individuals, i.e., less than about 250 plants, a complete census of the populations was made.

For larger occurrences, a sampling procedure was used to estimate population size. The technique involved two basic steps, an estimate of the area of occurrence and a 10 % sample based on a stratified random design. The area of occurrence was determined by using the off-set method (Christians and Agnew, 2000). This method is appropriate for measuring irregularly shaped but discrete areas.

The first step in utilizing the off-set method is determining the longest axis of the occurrence. A line is established to bisect the occurrence into roughly equal halves. Next, the total length of the occurrence is determined and offset lines are established at right angles to the long axis of the occurrence. Offset lines divide the long axis of the occurrence into equal segments. The long axis and offset lines served as a grid for stratified random sampling of the area.

The area of the occurrence was calculated by adding the measurements of all offset lines and multiplying the sum of these by the interval used to mark offsets along the main axis. This provided an estimate of the occurrence in square meters.

To determine sample size, the total area of the occurrence was multiplied by 10 %. This provides the total area necessary for a 10% sample of the population. The sample plot size was established at 0.5 m^2.

Plots were systematically placed throughout the occurrence so that each subdivision had an equal number of plots. Plots were randomly assigned within each subunit. This resulted in a uniform number of plots per subdivision while maintaining a random plot layout. The number of individual *Ptilimnium nodosum* plants was recorded in each plot. Plot counts were totaled and multiplied by 10 to yield a total population estimate.

Results

The 2000 survey resulted in a total population estimate of 31,517 individuals at 12 locations in the Ouachita Mountains. Table 1 summarizes the results of this survey and also provides population estimates generated from two previous surveys. It is important to note the methods employed to estimate population size in previous years differ from the current survey. Therefore, past estimates are not directly comparable to the current study.

Discussion

The 2000 survey generated population estimates greater than any previous survey. Specifically, the difference between the last survey of 1999 and the survey of 2000 was in excess of 21,000 plants. Since different methods were employed on previous studies, it is impossible to know if these differences represent increases in population size or simply reflect differences due to sampling methodology. It should be noted that the plants' small size and high density make population estimates problematic when non-systemat-

Table 1: Population sizes from previous studies compared to current study.
Note: populations that were not previously surveyed are denoted with an na.

Location	1996	1999	2000
Fiddlers Creek, Site 1	250	500	2832
Fiddlers Creek, Site 2	na	225	632
West Fiddlers Creek, Site 3	na	250	2001
Irons Fork, Site 4	2500	na	5834
Irons Fork, Site 5	2000	500	11691
Irons Fork, Site 6	500	500	2700
Irons Fork, Site 7	na	50	110
Irons Fork, Site 8	500	500	312
Irons Fork, Site 9	10,000	na	3177
Irons Fork, Site 10	75	na	55
Ouachita, North Fork, Site 11	50	na	52
Rainy Creek	na	1000	2476

ic methods are used. We can conclude from these data that past population estimates were low. It seems improbable that the populations would have undergone such a dramatic increase in one season. The problems of comparing past survey data should further underscore the importance of establishing standardized sampling methods. This is essential to provide meaningful data sets for longitudinal studies of this species. Although no sampling technique is perfect, population trends can be effectively and repeatedly estimated by the methods employed in this study.

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Literature Cited

Bartgis, R. L. 1997. The distribution of the endangered plant *Ptilimnium nodosum* (Rose) Mathias (*Apiaceae*) in the Potomac River drainage. Castanea. 62:55-59.

Bates, V. 1993. An endangered species status report: *Ptilimnium nodosum* (Rose) Mathias in Arkansas. Report submitted to the Arkansas Natural Heritage Commission. 80 pp.

Christians, N. and **M. L. Agnew.** 2000. The mathematics of turf grass maintenance. 3rd Ed. Sleeping Bear Press. Atlanta, Georgia. 176 pp.

Easterly, N. 1957. A morphological study of *Ptilimnium.* Brittonia. 9:136-145.

Hinterthuer, B. 1999. Survey of *Ptilimnium nodosum.* Report submitted to the Arkansas Natural Heritage Commission, Little Rock, Arkansas. 20 pp.

Hudson, E. 1996. Survey of *Ptilimnium nodosum.* Report submitted to the Arkansas Natural Heritage Commission, Little Rock, Arkansas. 26 pp.

U. S. Fish and Wildlife Service. 1988. Endangered and threatened wildlife and plants; Determination of *Ptilimnium nodosum* to be an endangered species. Federal Register. 50:37978-37982.

Food Habits of the Ouachita Dusky Salamander, *Desmognathus brimleyorum* (Caudata: Plethodontidae), in Arkansas

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Desmognathus is part of the family Plethodontidae of lungless salamanders. It is a large, multi-specific genus endemic to the eastern and southcentral United States and Canada. Members are characterized by a rigid lower jaw and a body that is usually more robust than slender. As adults they are often found in or very near permanent streams and fish-less ponds (Behler and King, 1992). The genus is represented in Arkansas by two species: *D. fuscus*, the most widespread member in North America, and *D. brimleyorum*, found only in the streams of southwestern Arkansas and southeastern Oklahoma (Conant and Collins, 1991). The food habits of several species of *Desmognathus* have been studied (Barbour and Lancaster, 1946; Hairston, 1949; Donovan and Folkerts, 1972; Sites, 1978; Keen, 1979; Jones, 1981; Kleeberger, 1982; Davic, 1991; Camp, 1997). However, nothing to our knowledge is known about the diet of *D. brimleyorum*.

Fifty-two adult Ouachita dusky salamanders (*D. brimleyorum*) were collected by hand from small streams on Rich Mountain in Polk County, Arkansas, in the spring and summer of 1980. Specimens were placed in plastic bags on ice following capture and processed within 24 hr in the laboratory at Arkansas State University (ASU). Salamanders were killed in a dilute chloretone solution and fixed in 10% formalin for 48 hr prior to examination. Stomachs were removed and stored in individual vials containing 70% ethanol. Food items were removed, counted, and identified using a binocular dissecting microscope and dichotomous keys provided by Merritt and Cummins (1984) and Borror et al. (1989). A food item consisted of a whole specimen or parts representing a whole specimen.

Desmognathus brimleyorum feeds predominately on arthropods (Table 1). Although *D. brimleyorum* is strongly aquatic as an adult (Conant and Collins, 1991), most of the food items (89%) were terrestrial in origin. The most commonly encountered food items were adult terrestrial beetles (Coleoptera), ants (Formicidae), and adult flies (Diptera). A similar study of adult *D. fuscus* from Tennessee revealed that species' diet to be as much as 85% terrestrial (Sites, 1978). Barbour and Lancaster (1946) and Bennett and Bellis (1972) reported similar findings from their food habits studies of *D. fuscus*. Davic (1991) reported a significant ontogenetic shift in the diet of the closely related blackbelly salamander, *D. quadramaculatus*, in North Carolina. The data indicated an abrupt shift from aquatic to aerial prey associated with meta-

Table 1. Stomach Contents of *Desmognathus brimleyorum*
A=Adult, L=Larva, T=Terrestrial, Aq.=Aquatic

Taxa	% Occurrence in Stomachs N=52	Total Number of Individuals
Coleoptera (A)(T)	17.30	14
Coleoptera (L) (T=6, Aq.=2)	5.76	8
Hymenoptera		
Formicidae	17.30	9
Diptera (A)	15.38	11
Chironomidae (L)	1.92	1
Orthoptera		
Gryllacrididae	9.60	5
Isopoda	7.69	4
Lepidoptera (A)	3.84	3
Ephemeroptera (L)	3.84	2
Oligochaeta	3.84	3
Dermaptera	1.92	1
Trichoptera (A)	1.92	1
Acari	1.92	1
Turbellaria	1.92	1
Ictaluridae		
Noturus sp.	1.92	1
Plethodontidae		
Desmognathus sp.	1.92	1
Nematoda (Parasitic)	28.84	38

morphosis. It suggests that the aquatic items in the diet of *D. brimleyorum* may be consumed by younger aged adults which are less likely to leave the stream to forage. Further study is needed to better understand this potential behavior in *D. brimleyorum.* Future research should also focus on food preference, seasonal variation, and interspecific competition.

In addition, nematodes were present in 15 of the 52 (28.84%) stomachs examined. A total of 38 individuals were found. McAllister et al. (1995) did an extensive study of the parasites of *D. brimleyorum* and found four species of parasitic nematodes in the stomach or intestine of 41 specimens examined.

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Literature Cited

Barbour, R. W. and **L. Y. Lancaster.** 1946. Food habits of *Desmognathus fuscus* in Kentucky. Copeia, 1946: 48-49.

Behler, J. and **F. W. King.** 1992. The Audubon Society field guide to North American reptiles and amphibians. Knopf Publ., New York, 356 pp.

Bennett, B. M. and **E. D. Bellis.** 1972. Comparative food habits of *Desmognathus f. fuscus* and *Desmognathus o. ochrophaeus* along a Pennsylvania stream. Proc. Pennsylvania Acad. Sci. 46:57-58.

Borror, D. J., C. A. Triplehorn, and **N. F. Johnson.** 1989. An introduction to the study of insects. Saunders College Publ., Philadelphia, 875 pp.

Camp, C. D. 1997. The status of the black-bellied salamander (*Desmognathus quadramaculatus*) as a predator of heterospecific salamanders in Appalachian streams. J. Herpetol. 31:616-619.

Conant, R. and **J. T. Collins.** 1991. A field guide to reptiles and amphibians of eastern and central North America. Houghton Mifflin Co., Boston, 3rd ed., 450 pp.

Davic, R. V. 1991. Ontogenetic shift in the diet of *Desmognathus quadramaculatus.* J. Herpetol. 25:108-111.

Donovan, L. A. and **G. W. Folkerts.** 1972. Foods of the seepage salamander, *Desmognathus aeneus.* Herpetologica 28:35-37.

Hairston, N. G., Sr. 1949. The local distribution and ecology of the plethodontid salamanders of the southern Appalachians. Ecol. Monog., 19:49-73.

Jones, R. L. 1981. Distribution and ecology of the seepage salamander *Desmognathus aeneus* Brown and Bishop (Amphibia: Plethodontidae), in Tennessee. Brimleyana 7:95-100.

Keen, W. H. 1979. Feeding and activity patterns in the salamander *Desmognathus ochrophaeus* (Urodela: Plethodontidae). J. Herpetol. 13:461-467.

Kleeberger, S. R. 1982. An empirical analysis of competition in the salamanders *Desmognathus monticola* and *D. quadramaculatus.* Unpublished Ph.D. Diss., Kent State University, Kent, Ohio. 157 pp.

Merritt, R. W. and **K. W. Cummins.** 1984. An introduction to the aquatic insects of North America 2nd Ed. Kendall-Hunt Publ. Co., Dubuque, IA. 441 pp.

McAllister, C. T., C. R. Bursey, S. J. Upton, S. E. Trauth, and **D. B. Conn.** 1995. Parasites of *Desmognathus brimleyorum* (Caudata: Plethodontidae) from the Ouachita Mountains of Arkansas and Oklahoma. J. Helminthol. Soc. Wash. 62:150-156.

Sites, J. W., Jr. 1978. The foraging strategy of the dusky salamander, *Desmognathus fuscus,* (Amphibia, Urodela, Plethodontidae): an empirical approach to predation theory. J. Herpetol. 12:373-383.

A Redescription of *Eimeria macyi* (Apicomplexa: Eimeriidae) from the Eastern Pipistrelle, *Pipistrellus subflavus* (Mammalia: Chiroptera), from Arkansas

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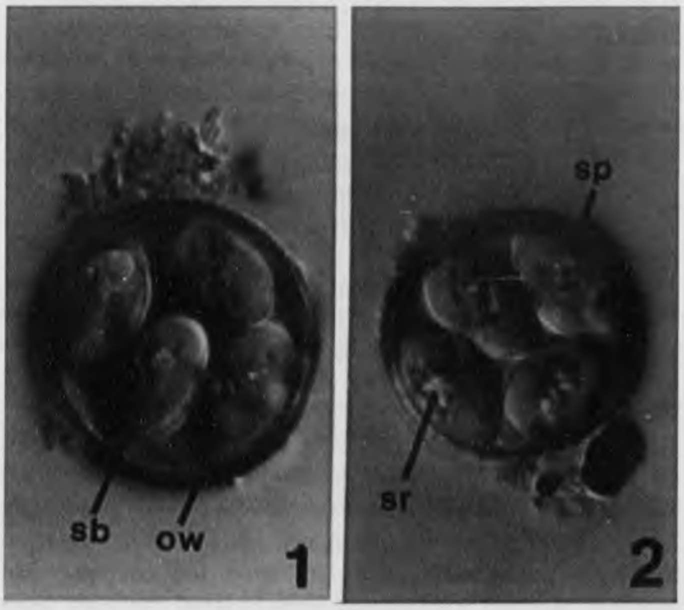
In the class Mammalia, the bats (order Chiroptera) are second only to rodents (order Rodentia) in the number of recognized taxa: 920 vs. 2,016 species (Feldhamer et al., 1999). Unlike rodents, however, which have been reported to harbor more than 400 eimerian parasites (Scott and Duszynski, 1997), only about 30 species of bat eimerians have been described (Duszynski, 2001), and few have been reported since their original descriptions. It has been speculated that this low diversity of coccidia in bats was due to the lack of surveying bats for parasites (Ubelaker et al., 1977); however, even with increased interest in the coccidian parasites of bats over the last two decades, most bat species still remain to be examined (Duszynski, 2001 for summary). Except for the report by Yang-Xian and Fu-Qiang (1983) who noted a prevalence of 70% for a Chinese bat (*Myotis ricketti*), overall prevalence of *Eimeria* spp. in 86 species of chiropterans of the world was reported by Duszynski (2001) to be quite low (number infected/number examined, 234/2114 = 11%). When compared to similar surveys on large sample sizes of rodents by Stout and Duszynski (1983), who reported a prevalence of 29%, prevalence of infection in bats ranges from less than 1% to about 10% on average (Marinkelle,1968; Scott and Duszynski, 1997; Duszynski, 2001). With this dichotomy in mind, there is obviously a need to further investigate the ecology of coccidia of bats.

Wheat (1975) provided a description of *Eimeria macyi* from 2 of 3 eastern pipistrelles (*Pipistrellus subflavus*) from Clarke County, Alabama; sporulation of oocysts took place within one week at 23°C. A line drawing of the parasite was included in the description, but no photomicrographs were published. Herein, we provide, the first photomicrographs of *E. macyi* and document additional information on the species, including the second report of the parasite since its original description >25 years ago.

Five adult eastern pipistrelles were collected by hand from Twin Mines, Polk County, Arkansas (34° 27' 35" N, 94° 11' 41" W) on 1 September 2000. They were returned to the laboratory, overdosed with an intraperitoneal injection of sodium pentobarbital (Nembutal ®), and intestinal contents and feces were placed in vials containing 2.5% aqueous (w/v) potassium dichromate solution ($K_2Cr_2O_7$). Samples were screened for coccidia and positive samples containing unsporulated oocysts were allowed to sporulate exogenously at room temperature (ca. 23°C) for one week in Petri dishes containing a thin layer of $K_2Cr_2O_7$. Fully sporulated oocysts were concentrated by flotation in modified Sheather's sugar solution (specific gravity = 1.30) or examined as wet mounts and photographed with Nomarski interference-contrast (DIC) optics. Measurements were made on 20 parasites using a calibrated ocular micrometer and are reported in micrometers (μm) with the mean length and width followed by the ranges in parentheses. Oocysts were 60 days old when measured and photographed. Photosyntypes (see Bandoni and Duszynski, 1988) of sporulated oocysts have been deposited in the Harold W. Manter Laboratory of Parasitology, University of Nebraska, Lincoln as HWML 16566.

Two of five (20%) individuals of *P. subflavus* (Arkansas State University Museum of Zoology, ASUMZ 26060-26061) were passing an eimerian that closely matched Wheat's (1975) description of *E. macyi* (Figs. 1-2). Subspherical oocysts measured 22.2 x 20.5 (19.2-24.8 x 18.4-24.0), with a rough-pitted bilayered oocyst wall ca. 1.6 thick (outer wall 1.0, inner wall 0.6), and a shape index of 1.1 (1.0-1.2). A micropyle and oocyst residuum are absent, but polar granules (mostly two to several fragments) are present. The sporocysts are ovoid, 12.4 x 8.3 (11.2-13.8 x 7.2-9.6), with a shape index of 1.5 (1.3-1.7). Stieda and substieda bodies and clusters of 100 or more sporocyst residua are present. The sporozoites are elongate and reflex within the sporocyst, 16.4 x 3.4 *in situ*, and contain both anterior and posterior refractile bodies.

Our isolate of *E. macyi* possessed oocyst and sporocyst (mean) measurements that were slightly larger than those provided by Wheat (1975). Oocysts of Wheat's original isolate measured 19.0 x 17.6 (16-21 x 15-19), and sporocysts



Figs.1-2. Oocysts of *Eimeria macyi* from *Pipistrellus subflavus* in Arkansas. x 1,800. Abbreviations: bilayered oocyst wall (ow); sporocyst (sp), Stieda body (sb); sporocyst residuum (sr).

measured 11 x 7 (10-12 x 6-8). Sporozoites were not measured by Wheat (1975). The differences between the isolates may be the result of several factors: (1) patent period sampling times which have been documented to affect mean measurement results (Duszynski, 1971), (2) calibration of the microscopes, and/or (3) wet mount measurements vs. Wheat's (1975) measurements on oocysts and sporocysts in concentrated sucrose solution. However, other morphological comparisons (both quantitative and qualitative) between the two isolates were identical, and there is little doubt that our isolate represents *E. macyi.*

There appears to be 9 species of *Eimeria* from North American bats (Table 1), all in hosts from the family Vespertilionidae. With the exception of *E. macyi* reported from *P. subflavus* in Alabama (Wheat, 1975) and now Arkansas (present study, new geographic record), *E. jacksonensis* from the evening bat (*Nycticeius humeralis*) in South Carolina (Duszynski et al., 1999), and *E. californicensis* from the California myotis (*Myotis californicus*) in California (Duszynski et al., 1999), the majority of eimerians have been reported from bats collected in New Mexico. This reflects the fact that the principal investigator of these hosts (Duszynski) resides in New Mexico.

In conclusion, of the 16 species of bats found in Arkansas (Sealander and Heidt, 1990), only *P. subflavus* is known to have been surveyed for coccidia. We plan to survey additional species of Arkansas bats for coccidians and determine whether they share the low prevalence of *Eimeria* spp. observed in other chiropterans.

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Literature Cited

Bandoni, S., and D. W. Duszynski. 1988. A plea for improved presentation of type material for coccidian. J. Parasitol. 74:519-523.

Duszynski, D. W. 1971. Increase in size of *Eimeria separata* oocysts during patency. J. Parasitol. 57: 948-952.

Duszynski, D. W. 2001. Coccidia (Apicomplexa: Eimeriidae) of the mammalian order Chiroptera. Spec. Publ. Mus. Southwest. Biol. No. 5. Univ. New Mexico Press, Albuquerque, NM. 43 pp.(In press).

Duszynski, D. W., D. W. Reduker, and B. B. Parker. 1988. *Eimeria* from bats of the world. II. A new species in *Tadarida femorosacca* from Sonora, Mexico. J. Parasitol. 74:317-321.

Duszynski, D. W., D. T. Scott, J. Aragon, A. Leach, and T. Perry. 1999. Six new *Eimeria* species from vespertilionid bats of North America. J. Parasitol. 85:496-503.

Feldhamer, G. A., L. C. Drickamer, S. H. Vessey, and J. F. Merritt. 1999. Mammalogy: Adaptation, diversity, and ecology. McGraw-Hill, Boston, 563 pp.

Marinkelle, C. J. 1968. *Eimeria eumopos* n. sp. from a Colombian bat *Eumops trumbulli.* J. Protozool. 15:57-58.

Scott, D. T., and D. W. Duszynski. 1997. *Eimeria* from bats of the world: Two new species from *Myotis* spp. (Chiroptera: Vespertilionidae). J. Parasitol. 83:495-501.

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

Stout, C. A., and D. W. Duszynski. 1983. Coccidia from kangaroo rats (*Dipodomys* spp.) in the western United States, Baja California, and northern Mexico with descriptions of *Eimeria merriami* sp. n. and *Isospora* sp. J. Parasitol. 69:209-214.

Ubelaker, J. E., R. D. Specian, and D. W. Duszynski. 1977. Endoparasites. Pp. 7-56, *In* Biology of bats of the New World family Phyllostomatidae, Part II (R. J. Baker, J. K. Jones, and D. C. Carter, eds). Spec. Publ., Mus. Texas Tech Univ., Lubbock, TX.

Wheat, B. E. 1975. *Eimeria macyi* sp. n. (Protozoa: Eimeriidae) from the eastern pipistrelle, *Pipistrellus subflavus,* from Alabama. J. Parasitol. 61:920-922.

Yang-Xian, Z., and C. Fu-Qiang. 1983. A new species of the genus *Eimeria* (Sporozoa: Eimeriidae) from *Myotis ricketti* Thomas. Acta Zootaxon. Sin. 1-3.

Table 1. Summary of the valid and named *Eimeria* species from North American bats.*

Bat species	Locality	*Eimeria* spp.	Reference(s)
Antrozous pallidus	NM	*antrozoi*	Scott and Duszynski, 1997; Duszynski et al., 1988, 1999
Myotis californicus	CA, NM	*californicensis, humboldtensis*	Duszynski et al, 1999
Myotis ciliolabrum	NM	*pilarensis, rioarribaensis*	Scott and Duszynski, 1997 Duszynski et al., 1999
Myotis evotis	NM	*evoti*	Scott and Duszynski, 1997; Duszynski et al., 1999
Myotis lucifugus	NM	*catronensis*	Scott and Duszynski, 1997; Duszynski et al., 1999
Myotis yumanensis	NM	*catronensis, pilarensis*	Scott and Duszynski, 1997 Duszynski et al., 1999
Nycticeius humeralis	SC	*jacksonensis*	Duszynski et al., 1999
Pipistrellus subflavus	AL, AR	*macyi*	Wheat, 1975; present study

*At least seven North American bat taxa from California and New Mexico have been reported to be infected with unsporulated or a few partially sporulated oocysts of 12 *Eimeria* spp. (see Scott and Duszynski, 1997; Duszynski et al., 1988, 1999; Duszynski, 2001). These have not been included in our table and await further study.

A Ouachita Mountain Population of *Diphasiastrum digitatum* (Dillenius ex. A. Braun) Holub Reported in Montgomery County on the Ouachita National Forest

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Diphasiastrum digitatum or southern running-pine as a North American endemic is the most abundant species of *Diphasiastrum* on the continent. This species of club moss is known to occur in coniferous or mixed forests, with varying degrees of disturbance, and at elevations up to 1500 meters. Cranfill (Ferns & fern allies of Kentucky, Kentucky Nature Preserves Commission Scientific and Technical Series No.1, 1980) states that it can be found in a wide variety of situations from wet acidic seeps to dry oak-pine or oak-hickory woods. The sporophytes require only a sandy or gravelly, slightly acidic substrate on which to grow, but Cranfill believes the gametophytes are dependant upon some amount of disturbance. The horizontal stems creep in the leaf litter on the soil surface and root at intervals. The plants are readily recognized by the fan-shaped branch complements.

The main range of *D. digitatum* is Newfoundland south to Georgia and west to Minnesota and Alabama (Wagner & Beitel, Flora of North America Vol. 2, p. 30-31, 1993). Disjunctive populations have been reported in northern Arkansas in Baxter, Benton, and Stone counties in the Ozark Mountains (Peck & Taylor, Proc. Ark. Acad. Sci., 49:130-137, 1995). The population discovered in the Ouachita Mountains represents a range extension of approximately 220 km or about 140 miles southward.

The new population, found during a survey of last winter's ice storm damage, occurs on a revegetated road bank in the southern portion of Montgomery County, Arkansas in Section 35, Township 4 South, Range 27 West. We have made the following observations at this site. There are seven patches of club moss in this population and patches range in size from approximately 40 square meters to 20 square centimeters. The cones of the last season are still present indicating fertility on the two largest patches, and these seem to be expanding by up to one meter of new growth of horizontal stems. The site is on a 35% slope on a road bank constructed approximately 20 years ago that is now covered in pine, sweetgum and maple saplings, low-bush blueberry, greenbrier, Christmas fern, and other plants, with leaf litter approximately 10 cm deep. We did an extensive search on the surrounding area and found no other populations of *Diphasiastrum* present.

This population is on a north aspect toe slope of Paul Mountain at approximately 310 m in elevation. Soils on this area are shallow, gravelly, shaley loam overlain with 10 to 15 cm of decomposed organic matter and leaves. The densest patches are in better sunlight, but establishment seems to occur even in the semi-shade. Many roadsides, gravel pits, and other similarly disturbed habitats offer such exposure for this ancient survivor.

Vouchers for this reported population were collected by Theo Witsell of the Arkansas Natural Heritage Commission, collection number TW-O 1-002, and will be deposited in the herbarium of the University of Arkansas at Little Rock. We appreciate Theo Witsell and Jason Haley for digitizing, collecting, and processing some of this information and for their good company in the field.

Plasmid Analysis of Bacteria that Metabolize the Detergent Igepon

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When humans go on long-term space missions, they will need basic life support supplies. The Advanced Life Support (ALS) program of the National Aeronautics and Space Administration (NASA) is currently testing bioregenerative life support systems to facilitate long-term space missions, including the colonization of Mars. In order to reduce resupply requirements to a space habitat, efficient recovery and recycling of resources from wastes is critical. Water comprises the largest mass in the waste of human-occupied habitats. Recycling of water is desirable since the costs associated with launch to low-orbit have been projected to be as high as $22,000/kg (Moses et al., 1989). It is estimated that each person on these long-term missions will require 27 kg per day thus making resupply costly and possibly curtailing scientific and other critical payloads.

Wastewater from showering, laundry, dishwashing, and other activities associated with personal hygiene contain low concentrations of contaminants. Soaps and detergents are the major organic contaminants. This wastewater is commonly know as "graywater". Graywater makes up the largest single waste stream comprising approximately 80% of total wastes (Gerba et al., 1995). The recycling of graywater to obtain potable water and water for personal hygiene use is essential for space habitats that are difficult to resupply. The reuse of graywater on Earth is also becoming a desirable goal as water demands are rapidly reducing water sources due to overuse of groundwater supplies and pollution.

NASA is developing plant production facilities as part of the ALS program for the purpose of water recycling and food production. Water recycling in these protocols would involve root associated microbial degradation of organic material, including detergents in graywater, and plant transpiration and condensation to purify the water. Igepon, a linear alkyl methyl taurate detergent currently in use on the International Space Station and a common ingredient of soaps and detergents, is actively degraded by bacteria in hydroponic systems (Bubenheim et al., 1997). The taxonomy and genetics of bacteria that degrade igepon are currently being investigated.

Plasmids are extrachromosomal DNA elements that replicate independently of chromosomal DNA and are often involved in the metabolism of xenobiotic compounds, such as detergents. This study investigated the presence of plasmids in seventeen strains of bacteria that degrade igepon that were isolated from a variety of environments.

Bacterial strains that metabolize igepon were isolated by David Gilmore from environments surrounding Arkansas State University by growth on a medium containing igepon as the sole carbon source (Table 1). This medium contains per liter 10 ml of a 100x salt solution containing sodium sulfate 0.74 g/L, magnesium chloride 0.12 g/L, potassium phosphate (monobasic) 0.09 g/L, calcium chloride 0.64 g/L, sodium bicarbonate 2.75 g/L, potassium chloride 0.91 g/L, sodium chloride 4.22 g/L, and ammonium chloride 100 g/L as the nitrogen source. The composition of this medium is based on the expected concentrations of these compounds in graywater. Igepon was added from a 50x solution (5% w/v) for a final concentration of 0.2% w/v. All chemicals were obtained from Sigma Chemical company (St. Louis, MO) with the exception of igepon TC-42, which was generously supplied by K. Wignarajah (Moffett Field, CA).

To prepare this medium, 1.5 g of agar (Difco Detroit,

Table 1. Igepon Metabolizing Bacterial Strains

Strain	Biolog Identification	Source
ASU 1	Ralstonia species	soil
ASU 2	*Delftia acidovorans*	soil
ASU 3	ND	soil
ASU 4	ND	soil
ASU 5	*Pseudomonas putida*	soil
ASU 6	*Stenotrophomonas maltophila*	water
ASU 7	ND	water
ASU 8	*Ochrobactrum anthropi*	compost
ASU 9	*Pseudomonas putida*	compost
ASU 10	ND	compost
ASU 11	*Stenotrophomonas maltophila*	sewage sludge
ASU 12	ND	sewage sludge
ASU 13	*Pseudomonas nitroreducens*	sewage sludge
ASU 14	*Ralstonia eutropha*	sewage sludge
ASU 15	ND	lettuce roots
ASU 16	*Ralstonia eutropha*	lettuce roots
ASU 17	ND	lettuce roots

MI) was added to distilled water. Following sterilization, 1 ml of sterilized 100x salt solution and 2 ml of filter sterilized 50x igepon solution were added after the medium had cooled to approximately 60° C. The medium was dispersed in 5 ml volumes into sterile test tubes and solidified as slants. Igepon degrading bacteria were subcultured on this medium every three to four weeks by incubating at 28° C for three days.

Bacteria were inoculated from the igepon slants into trypticase soy broth (TSB) medium (Difco) and grown overnight at 28° C until stationary phase (typically 18 to 22 hours depending on the strain). Cell densities were adjusted using a spectrophotometer set at 600 nm for plasmid procedures using Qiagen (Valencia, CA) plasmid DNA isolation columns as suggested by the manufacturer. Initially a "miniprep" alkaline sodium dodecyl sulfate (SDS) procedure was used (Hruby et al., 1990). Another plasmid isolation method used was a cleared lysate procedure that employed the detergent Triton X-100 for lysis of cells (Scott et al., 1981). The final procedure employed the use of Qiagen miniprep plasmid DNA isolation columns. The protocol of the manufacturer was used in these procedures. For gel electrophoresis of plasmid DNA, 1/5 volume of loading dye containing bromophenol blue as tracking dye (Sambrook et al., 1989) was added to approximately 1 µg of DNA sample in a 10 mM Tris base 1 mM EDTA (ethylenediaminetetracetic acid) buffer, pH 8.0, and loaded on a 0.7% agarose (BioRad Hercules, CA) gel. Gels were electrophoresed following standard procedures in a Tris Acetate buffer at 5 volts per cm.(Sambrook et al., 1989). Gels were stained in a 2 µg/ml solution of ethidium bromide for 10 min, destained in distilled water, and examined on a UV transilluminator for the presence of plasmid DNA. Photographs of gels were made with a Polaroid camera using 667 black and white film and a Tiffen yellow UV filter (Fisher Scientific Plano, TX). Plasmid DNA standards consisted of pBlu 5.5 kb (Carolina Biological Supply Burlington, NC) and pMO1896 approximately 57 kb, which is a Tn*5* loaded derivative of the IncP10 plasmid R91-5 in *Pseudomonas aeruginosa* strain PAO 11 (Nordeen and Holloway, 1990; Chandler and Krishnapillai, 1977). All chemicals used in plasmid DNA isolation procedures were obtained from Sigma chemical company.

Initial attempts to isolate plasmids using the mini-prep alkaline SDS method failed to show the presence of plasmids in any of the seventeen igepon strains examined in this study. During this preliminary phase of the research, one strain obtained from lettuce roots (ASU17) failed to grow on the igepon cultivation medium and was not further characterized. The mini-prep alkaline SDS method is designed for high copy number, low molecular weight plasmids such as pBlu. The pBlu plasmid was routinely isolated in high yields (3-4 µg/ml of culture) utilizing this method. These results suggested that the igepon strains did not contain low molecular weight, high copy number plasmids. Some bacteria are difficult to lyse due to differences in cell wall or cell membrance structure, so a cleared lysis method that works well with bacteria that are difficult to lyse with SDS was tried (Scott et al., 1981). This method is routinely used to isolate both low molecular weight, high copy number plasmids, as well as high molecular weight, low copy number plasmids from *Pseudomonas* species such as *P. aeruginosa.* This method also failed to indicate the presence of plasmid DNA in the sixteen igepon metabolizing strains examined. The final plasmid isolation procedure involved the use of commercial plasmid DNA isolation columns from Qiagen. These columns are essentially anion exchange columns that can be used to successfully elute plasmid DNA under high salt conditions. Two of the sixteen igepon metabolizing strains, ASU12 and ASU15, showed the presence of high molecular weight plasmids using this procedure. As an internal control, pBlu in *E. coli* HB101 and pMO1896 in *P. aeruginosa* strain PAO11 were included in each isolation procedure to determine the effectiveness of isolating low molecular weight, high copy number and high molecular weight, low copy number plasmids, respectively. These plasmids were routinely isolated using this procedure, which lends credibility to the Qiagen DNA isolation procedure. The plasmids from strains ASU12 and ASU15 were clearly larger than pMO1896, although the precise molecular weight has not been characterized. It is estimated that these plasmids are between 60 and 100 Kb in size based on comparisons with the migration of pMO1896; however, they may be larger (Fig. 1). There are two plasmids in strain ASU12 because a doublet is clearly resolved during prolonged electrophoresis with both plasmids larger than pMO1896 (Fig. 1).

Although we can not rule out the presence of other plasmids in strains ASU12 or ASU15 or in the other fourteen igepon metabolizing strains examined, we find this possibility remote due to the failure to isolate plasmids using a variety of isolation procedures and the ability to routinely isolate both low molecular weight (pBlu) and high molecular weight (pMO1896) plasmids with the Qiagen plasmid DNA isolation columns. The exact size of these plasmids will be determined by restriction enzyme digestion; however, an increase in the yield of these plasmids is necessary for these procedures. The role of these large plasmids in the degradation of igepon has not been determined yet. To establish an igepon metabolizing phenotype, these plasmids will be excised from low melting temperature agarose gels and transformed in restriction deficient *E. coli* strains that fail to metabolize igepon. Growth of these strains on the igepon cultivation medium will indicate the possible presence of genes involved in igepon metabolism and will be the subject of subsequent investigations.

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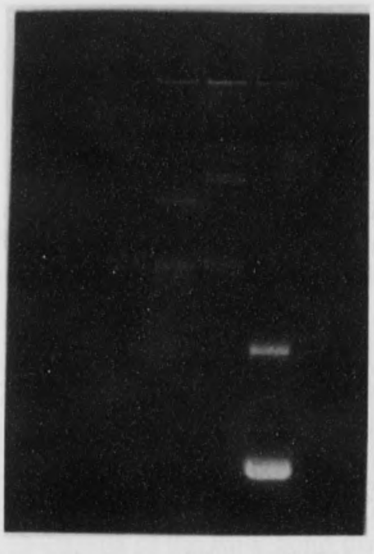

Fig. 1. Agarose gel electrophoresis of plasmid DNA isolated using Qiagen plasmid DNA isolation columns. Lane 1 ASU 15 Lane 2 pMO1896 (56.7 kb) Lane 3 ASU 12 Lane 4 pBlu (5.5 kb). Arrow to the left of Lane 1 indicates position of plasmid in strain ASU 15. Faint smeared bands in the middle of the gel are chromosomal DNA. Intense band at bottom of gel in Lane 4 is covalently closed circular form of pBlu, band above this is an open circular form of pBlu.

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Literature Cited

Bubenheim, D., K. Wignarajah., W. Berry, and **T. Wydeven.** 1997. Phytotoxic effects of gray water due to surfactants. J. Amer. Soc. Hort. Sci. 122:792-796.

Chandler, P. M. and **V. Krishnapillai.** 1977. Phenotypic properties of R factors of *Pseudomonas aeruginosa*: R factors transferable only in *Pseudomonas aeruginosa.* Genet. Res. 23:251-257.

Gerba, C. P., T. M. Straub, J. B. Rose, M. M. Karpiscak, K. E. Foster, and **R. G. Brittain.** 1995. Water quality study of graywater treatment systems. Wat. Res. Bull. 31:109-116.

Hruby, D. E., J. M. Brinkley, H. C. Kand, R. P. Haugland, S. L. Young, and **M. H. Melner.** 1990. Mini-Prep in Ten Minutes. BioTecniques 8:172-173.

Moses, W. M., T. D. Rogers, H. Chowdhury, and **R. Cusick.** 1989. Performance characterization of water recovery and water quality from chemical/organic waste products. Paper 891509, 19th Intl. Soc. Conf. Environ. Systems. Soc. Automotive Eng. Int., Warrendale, PA.

Nordeen, R. O. and **B. W. Holloway.** 1990. Chromosome mapping in *Pseudomonas syringae* pv. *syringae* strain PS224. Jo. Gen. Micro. 136:1231-1239.

Sambrook, J., E. F. Fritsch, and **T. Maniatis.** 1989. Molecular cloning. A laboratory manual, 2nd ed. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY.

Scott, K. F., B. G. Rolfe, and **J. Shine.** 1981. Biological nitrogen fixation: Primary structure of the *Klebsiella pneumoniae nifH* and *nifD* genes. J. Mol. Appl. Gen. 1:71-81.

Status of Pet Mountain Lions (*Puma concolor*) in Arkansas

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The practice of keeping mountain lions (*Puma concolor*) and other large and exotic animals as pets has been increasing in popularity in the United States, and prices for these animals have dropped in recent years (Green, Animal Underworld: Inside Americaís black market for rare and exotic species, Public Affairs, P. 95-97 and 120-121, 1997). Though the U.S. Department of Agriculture, Animal & Plant Health Inspection Service does require permits for the sale of wild animals, regulation of the care and living conditions of mountain lions kept as personal pets is the responsibility of state and local governments.

The Arkansas Game and Fish Commission (AGFC) has authority over all wildlife in Arkansas, including individuals living in captivity, and has regulated private ownership through provisions in the AGFC Code of Regulations. However, it is difficult to trace the regulatory history of mountain lions in Arkansas because of incomplete AGFC records. In 1937 the AGFC required permits for possession of wild birds and animals outside of an open hunting season, but this may not have been applied to pet mountain lions since apparently there was not a general closed season on nongame animals until 1967. However, 1957 AGFC regulations did not include mountain lions on a list of approved wildlife pets, and another section of the 1957 code prohibited possession of predatory animals. From 1980-1987 possession of mountain lions was prohibited though an exception was made for those having proof of legal ownership. This exception was eliminated in January 1987 but was restored in March 1990 with the caveat that ownership must be in accordance with U.S. Department of Agriculture regulations (AGFC regulations, 1937-2001).

Two different mail surveys were used to determine the status of pet mountain lions in Arkansas in 2000. The first, sent to 155 AGFC wildlife officers, requested that officers report the total number of dangerous wild animal pets, including mountain lions, present in their county and the known escapes and injuries caused by wildlife pets from 1997-2000. In counties where more than one wildlife officer was present, they were asked to consult with each other and submit only one report for the county. Wildlife officer survey data were supplemented with other AGFC records and newspaper accounts of escapes and human injuries caused by pet mountain lions from 1990-2000. The second survey, sent to all 308 incorporated Arkansas towns, asked whether or not the towns had any regulations relating to the keeping of animals and requested that each townís officials return copies of applicable ordinances.

Wildlife officers returned surveys for 66 counties (88%) and reported at least 101-151 pet mountain lions in 20 Arkansas counties, four of which had more than five pet mountain lions. The respondent from Benton County estimated there were 50-100 pet mountain lions in the county based on prior complaints and said that he knew of at least 10 pet mountain lions within 10 miles of his home. Escapes or intentional releases of pet mountain lions are not uncommon; there was at least one incident each year from 1997-1999, three in 2000, and two in the first three months of 2001. Three of the five incidents of human injury recorded from 1990-2000 occurred during an escape or subsequent recapture attempt. Poor caging that did not fully prevent contact between the animal and the public allowed the other two injuries to occur. Since there are no requirements for reporting escapes or injuries to the AGFC, it is likely that there are many more undocumented incidents than reported herein.

A total of 192 towns (62%) returned the town ordinance survey, 42 (22%) of which have wildlife pet ordinances. These ordinances vary in the severity of restriction and animals covered; 17 towns prohibit all wildlife pets, 15 only prohibit dangerous wildlife pets, four allow wildlife pets under permit, three prohibit most wildlife pets, one prohibits only dangerous reptiles, and one prohibits only lions. Nine towns also prohibit the keeping of exotic animals in addition to other wildlife pet restrictions while one town only specifically prohibits exotic animals. Most of these ordinances were enacted in recent years, increasing from at least six in 1989 to 42 in 2000.

Arkansas is not unique in facing issues relating to captive mountain lions; in 1993 there were an estimated 300-500 pet mountain lions in Florida, and in the late 1970s a New York official estimated that 5-10 mountain lions escape or are released by private owners in that state every year (McBride et al., Proc. Ann. Conf. Southeast Assoc. of Fish and Wildlife Agencies, 47:394-402, 1993; East, American Forests, 85:21, 54-59, 1979). This study demonstrates that pet mountain lion ownership is widespread in Arkansas and that citizen concern expressed by a 700% increase in town wildlife pet ordinances since 1990 is warranted due to the number of escapes and human injuries caused by these pets.

Synthesis of a Ruthenium-tetra(tht)dichloride Compound and the Molecular Structure of the Partially Oxidized Compound $RuCl_2(tht)_{2.2}(tht\text{-}O)_{1.8}$

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Attempts to prepare $CpRu(thietane)_3^+$ from $CpRu(PPh_3)_2^+$, in order to model potential ligand interactions in the metal carbonyl-catalyzed cyclooligomerization of thietane (Adams and Falloon, 1995), were unsuccessful. The di-thietane complex, $[CpRu(PPh_3)(thietane)_2]OTf$, can be prepared by direct ligand substitution from the di-tht complex, $[CpRu(PPh_3)(tht)_2]OTf$, tht = tetrahydrothiophene. The shortening of the Ru-P bond distance in the di-thietane complex as compared to the mono-thietane complex, $[CpRu(PPh_3)_2(thietane)]OTf$, may explain why a third thietane ligand can not be attached (Nave et al., 2001).

One method for the synthesis of tri- and tetra-thietane complexes may employ $RuCl_2(dmso)_4$ (Evans et al., 1973) as a starting material. Due to less ring strain, initial reactions were carried out with THT as a ligand. Herein, we report the synthesis of $RuCl_2(tht)_4$ and the crystal structure of the partially oxidized reaction product, $RuCl_2(tht)_{2.2}(tht\text{-}O)_{1.8}$.

Under N_2, 0.700 g (1.44 mmol) $RuCl_2(dmso)_4$ was dissolved in 5 mL THT. The reaction was refluxed overnight. Upon cooling, the precipitate was filtered, washed with acetone, and dried. Yield = 0.279 g, 36.8 %. ^1H NMR (δ, ppm, $CDCl_3$): 3.0, 2.1.

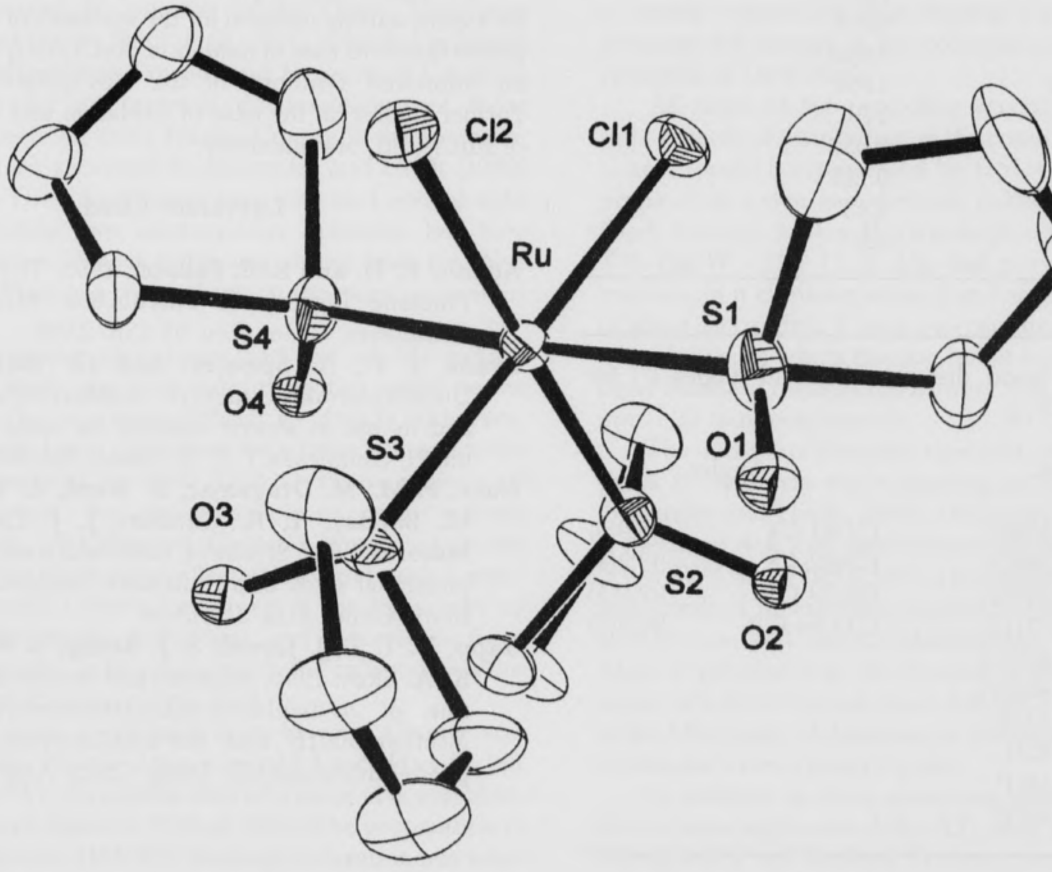

Fig. 1. Ortep (30% probabilities) of $RuCl_2(tht)_{2.2}(tht\text{-}O)_{1.8}$ showing S and O labeling scheme.

Table 1. Crystallographic data for $RuCl_2(tht)_{2.2}(tht\text{-}O)_{1.8}$.

Formula	$C_{16}H_{32}Cl_2O_{1.8}RuS_4$
Formula weight	553.49
Unit cell dimensions	
a (Å)	9.1486(8)
b (Å)	11.2865(10)
c (Å)	21.3525(18)
α(°)	90
β(°)	90.927(4)
γ(°)	90
V (Å^3)	2204.5(3)
D_{calc} (g cm^{-1})	1.774
Space group	$P2_1/c$
Z	4
F(000)	1208.0
λ(Å)	0.7107
μ (cm^{-1})	1.35
Scan technique	θ-2θ
Diffractometer	Mercury CCD
2θ range (°)	4-52
Absorption range	0.74-1.00
Total reflections	7307
Unique reflections	4268
R for merge	0.043
Data for refinement	4268
Parameters refined	249
R(F)	0.053
R_w(F)	0.135
GOF	1.43
Max. Δ/σ	0.0

Table 2. Selected bond distances (Å) and angles (°) for $RuCl_2(tht)_{2.2}(tht\text{-}O)_{1.8}$.

Bond distances		Angles	
Ru-S1	2.350(2)	C1-S1-C4	90.9(5)
Ru-S2	2.286(2)	C5-S2-C8	93.2(4)
Ru-S3	2.296(2)	C9-S3-C12	92.9(5)
Ru-S4	2.371(2)	C13-S4-C16	92.5(5)
Ru-Cl1	2.430(2)		
Ru-Cl2	2.422(2)		
S1-O1	1.33(2)		
S2-O2	1.42(1)		
S3-O3	1.36(1)		
S4-O4	1.40(2)		

The NMR spectrum of $RuCl_2(tht)_4$ shows two peaks of equal intensity at positions different than the peaks observed for the $RuCl_2(dmso)_4$ protons (3.5, 2.8 ppm) (Evans et al., 1973). Also, the IR spectrum of the $RuCl_2(tht)_4$ compound shows the disappearance of the S=O stretches (1055 cm^{-1}) seen in the $RuCl_2(dmso)_4$ compound. This evidence suggests the formulation of $RuCl_2(tht)_4$.

Attempts to obtain single crystals of $RuCl_2(tht)_4$ failed. However, single crystals were obtained from the filtrate upon evaporation in air. Crystal data are given in Table 1. Examination of the structure (Fig. 1) shows each of the tht ligands has been partially oxidized to the tht-oxide. The occupancy factors for the O atoms are 0.41, 0.65, 0.47, and 0.27 for O1-O4, respectively, giving an average of 0.45 for the oxidized tht ligands. At present, the source of the oxidation is not known. The IR data for the crystals isolated from the filtrate does show the expected S=O stretches (1064 cm^{-1}).

The Ru-S distances are 2.296(2), 2.286(2), 2.350(2), and 2.371(2) Å for S1-S4, respectively. The shorter Ru-S distances are trans to the Cl^- ligands. This effect is also observed in the two different crystallographic forms for *cis*-$RuCl_2(tht\text{-}O)_4$ (Yapp et al., 1990). Selected bond distances and angles are given in Table 2 for $RuCl_2(tht)_{2.2}(tht\text{-}O)_{1.8}$.

Though $RuCl_2(tht)_4$ formed easily, it does not appear to be a good starting material for the synthesis of thietane complexes due to its ease of oxidation. $RuCl_2(tht)_4$ may allow for an improved synthesis of the $RuCl_2(tht\text{-}O)_4$ complex. Further studies on the ease of oxidation and crystallization of $RuCl_2(tht)_4$ are underway.

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.

Evans, I. P., A. Spencer, and G. Wilkinson. 1973. Dichlorotetrakis(dimethyl sulphoxide)ruthenium(II) and its use as source material for some new ruthenium(II) complexes. J. C. S. Dalton 204-209.

Nave, P. M., M. Draganjac, B. Ward, A. W. Cordes, T. M. Barclay, T. R. Cundari, J. J. Carbó, and F. Maseras. 2001. Synthesis, molecular structure and computational study of a ruthenium bis(thietane) complex. Inorg. Chim. Acta. 316:13-18.

Yapp, D. T. T., J. Jaswal, S. J. Rettig, B. R. James, and K. A. Skov. 1990. Synthesis and structural characterization of *cis*-dichlorotetrakis(tetramethylenesulfoxide-*S*)ruthenium(II) and *mer*-trichlorotris(tetrahydrothiophene)ruthenium(III). Inorg. Chim. Acta 177:199-208

New Records of the Woodchuck (*Marmota monax*) from Southern Arkansas

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The groundhog or woodchuck (*Marmota monax*) is a heavy-bodied squirrel that digs burrows in which it nests. An exception among rodents, the enamel of the incisors is white, and the postorbital processes, a familial trait of the Sciuridae, are robust and project at almost right angles to the sagittal plane of the skull (Hall, 1981). The fur is thick and coarse and grizzled in appearance, except for the underparts, which tend to have a reddish tinge, and the feet and tail, which usually are black (Sealander and Heidt, 1990; Kwiecinski, 1998).

Distribution of the woodchuck in Arkansas is confined primarily to the Interior Highlands, with most specimen records originating in counties in the Ozark Mountains (Sealander and Heidt, 1990). Hall (1981) indicated marginal records for Arkansas in Lincoln and Hempstead Counties, however, he did not provide documentation of those records. A specimen from Pulaski County is the southernmost woodchuck recorded by Sealander and Heidt (1990) for Arkansas. Their distribution map indicated several sight records extending into southwestern Arkansas, but they noted that the woodchuck is "almost absent from the West Gulf Coastal Plain (except perhaps on the extreme western edge.)"

Considering the appearance and size of this rodent, sight records likely are more valid than they might be for other species that are more difficult to identify. However, specimens verifiable in collections have been lacking for the Ouachita Mountains or Gulf Coastal Plains regions of Arkansas. Herein, we report specimen records from Garland, Clark, and Howard Counties, preserved in the Henderson State University collection of vertebrates, a specimen from Desha County, preserved in the University of Arkansas at Monticello collections, and a specimen from Hot Spring County, to be preserved in the collections at the University of Arkansas at Little Rock.

An adult male woodchuck from Howard County was collected 4.0 km West of Athens and 0.2 km N Hwy 26 (S8 or S9 T5S R28W). No precise date of collection is available, but the specimen dates to 1993 or 1994. The preparation is a skin and skeleton, HSU197. Standard measurements were 655 mm (total length), 160 mm (length of tail), 86 mm (length of hind foot), and 32 mm (length of pinna).

On 14 June 1997 a road-kill woodchuck was collected 12.9 km NE of Hot Springs National Park on Hwy 5 (S27 T1S R18W) in Garland County. The preparation is skeleton only, HSU345. The specimen was an adult as evidenced by wear of the teeth and epiphyseal closure. State of decomposition precluded determination of sex. No measurements are available, but homologous bones were smaller than those of HSU197.

A road-kill specimen was collected at the Malvern exit from Interstate 30 (I-30), S9 T4S R17W, on 6 June 2001. The adult male specimen was found about 100 m N I-30 and about 400 m east of the Ouachita River. This woodchuck is a county record for Hot Spring County and is being prepared for storage in the collections at the University of Arkansas at Little Rock.

All three of the preceding specimens verify previous sight records of distribution in the counties. However, a new county record is represented by HSU418, a male specimen prepared as a skin and skeleton, collected 7 March 2001 in Clark County, 8.1 km W Arkadelphia on St. Hwy 26 (S32 T7S R20W - Fig. 1). A dog had pursued this individual, resulting in it climbing about 2 to 3 m into a hardwood tree of about 20 cm dbh. It later was captured by guiding it from a brush pile, in which the dog had it bayed, and into a wire cage. Standard measurements were 630 mm - 150 mm - 85 mm - 28 mm, respectively.

The most southeastern reported record of the woodchuck in Arkansas was a sighting in NW Phillips County (Sealander and Heidt, 1990). However, on 10 March 1996, a specimen was collected farther south, in Desha County (SW¼ SW¼ S29 T10S R1W). The specimen (skin and skull) had standard measurements of 615 mm, 134 mm, 84 mm, and 34 mm, and was an adult female. The individual was taken in proximity to the dry side of the Mississippi River levee, at a farm located about 4.0 km E Kelso. It is housed at the University of Arkansas at Monticello (UAM904) and represents a new county record.

In addition to these specimen records, we also document a new sight record (by RT) near the border between Montgomery and Garland Counties, in Garland County, at Camp Clearfork (S6 T3S R22W). This Ouachita Mountains National Forest camp is located about 5 km west of Crystal

Fig. 1. Distribution of the woodchuck (*Marmota monax*) in Arkansas (modified from Sealander and Heidt, 1990). Smaller solid circles represent specimen records and stars represent sight records as presented by Sealander and Heidt (1990). New records are indicated by larger solid circles; the new sight record is represented by a solid square.

Springs off US Hwy 270. The individual had a burrow in the root system of a persimmon tree (*Diospyros virginiana*), located in the mowed area near the man-made pond. It was seen on several occasions around 17 June 1995, before increased seasonal activity of humans at the camp apparently forced it to move.

The southwestern extreme of the distribution of the woodchuck may occur in Arkansas. Specimens from Red Oak in Latimer County (McCarley and Free, 1962) and from Hodgen in LeFlore County (Caire et al., 1989) are the southernmost records for Oklahoma. Both are from a latitude about equal to that of Waldron in Scott County, Arkansas, and about 85 km north (by latitude) of the Clark County, Arkansas, record. One report of the woodchuck is documented for Bossier Parish, Louisiana, based on a newspaper article and photograph of a specimen, which Lowery (1974) discounted as a valid record of natural occurrence. Davis and Schmidly (1994) indicated no records of the woodchuck in Texas. The Clark County specimen, therefore, appears to be the southwesternmost record for this mammal in the United States, and the Desha County record presently is the most southern for Arkansas.

ACKNOWLEDGMENTS.—Information about the Hot Spring County record was supplied by T. Finley, and about the Desha County record by R. W. Wiley.

Literature Cited

Caire, W., J. D. Tyler, B. P. Glass, and **M. A. Mares.** 1989. Mammals of Oklahoma. Univ. Oklahoma Press, Norman. 567 pp.

Davis, W. B., and **D. J. Schmidly.** 1994. The mammals of Texas. Texas Parks Wildlife Dept., Austin, 338 pp.

Hall, E. R. 1981. The mammals of North America, 2nd ed. John Wiley and Sons, New York, 1181 pp.

Kwiecinski, G. G. 1998. *Marmota monax.* Mammalian Species 591:1-8.

Lowery, G. H., Jr. 1974. The mammals of Louisiana and its adjacent waters. Louisiana State Univ. Press, Baton Rouge, 565 pp.

McCarley, H., and **P. Free.** 1962. A new record of the woodchuck from Oklahoma. J. Mammal. 43:272.

Sealander, J. A., and **G. A. Heidt.** 1990. Arkansas Mammals. Univ. Arkansas Press, Fayetteville, 308 pp.

Synthesis and Characterization of a Ruthenium-Thioxane Complex

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Sabo-Etienne, Chaudret, and coworkers (see Rondon et al., 1994) have investigated the reaction of Cp^*Ru^+ with a variety of sulfur ligands. The addition of 1,4-dithiane at room temperature yields the chelated species, [Cp^*Ru(1,4-dithiane)OTfl], whereas a similar reaction at 80°C yields the tris-1,4-dithiane complex. When 1,3-dithiane is reacted with Cp^*Ru^+, carbon-sulfur bond cleavage is noted, and two different products are formed. Furthermore, Sabo-Etienne gave no explanation why carbon-sulfur bond cleavage occurs in the reaction with 1,3- dithiane whereas chelation occurs in the reaction with 1,4-dithiane. The reaction of pentamethylene sulfide (pms) was also mentioned, but the results were inconclusive (Rondon et al., 1994).

The reaction of pms with $CpRu(PPh_3)_2^+$ yields the sulfur-bound complex with the pms ligand in the chair configuration. The reaction of 1,4-dithiane with $CpRu(PPh_3)_2^+$ results in the loss of a triphenylphosphine and gives a chelated species similar to the 1,4-dithiane complexes seen by Sabo-Etienne (Rondon et al., 1994). The reaction of 1,3-dithiane with $CpRu(PPh_3)_2^+$ gives a single sulfur-bound ligand with two triphenylphosphines still attached to the ruthenium atom (Green et al., 2001). The purpose of the following experiment is to explore the coordination chemistry of the mixed heteroatom ring 1,4-thioxane with $CpRu(PPh_3)_2Cl$, i.e., to determine whether the product coordinates the 1,4-thioxane ligand through the sulfur, the oxygen or if chelation occurs (analogous to the 1,4-dithiane complexes).

Reactions were carried out under a dry nitrogen atmosphere using Schlenk techniques. $CpRu(PPh_3)_2Cl$ was prepared as described in the literature (Bruce and Windsor, 1977). All other reagents were used as purchased without further purification. The ^1H NMR spectrum was obtained on a JEOL GSX 270 MHz NMR spectrometer. Powder patterns were obtained on a Rigaku D/MAX-B X-ray powder diffractometer. The visible spectrum was obtained on a HP8952A diode array spectrophotometer. Elemental analysis was performed at Galbraith Laboratories, Knoxville, TN, USA.

Synthesis of [$CpRu(PPh_3)_2$(1,4-thioxane)]BF_4, 1. Under N_2, 0.100 g (0.138 mmol) $CpRu(PPh_3)_2Cl$ was dissolved in 20 mL of CH_2Cl_2, and 0.027 g (0.138 mmol) $AgBF_4$ was added to the stirring solution. The mixture was reacted for fifteen minutes, then filtered through celite into a flask that contained 20 mL of CH_2Cl_2 and 0.1 mL (1.069 mmol) of 1,4-thioxane. The solution was concentrated to approximately 10 mL under a N_2 stream and then layered with hexanes. Yellow microcrystals were isolated by filtration and washed with hexanes. Yield = 0.068 g, 50.04%. Elemental analysis, calc. for [$CpRu(PPh_3)_2$(thioxane)]BF_4 •CH_2Cl_2: 56.45% C, 4.64% H, 3.28% S; found: 55.44% C, 5.24% H, 3.65% S. ^{1}HNMR (δ, ppm, in $CDCl_3$): 7.24 (m, 30H), 4.80 (s, 5H), 3.72 (s, 4H), 2.58 (s, 4H). Visible spectrum (nm, in $CHCl_3$): 360 (ϵ = 2384 $M^{-1}cm^{-1}$).

The elemental analysis of the yellow crystals supports single atom 1,4-thioxane coordination. Upon examination of the NMR spectrum (Fig. 1), the peaks between 6.96 and 7.37 ppm represent the hydrogens of the triphenylphosphine ligands. The peak at 4.80 ppm corresponds to the cyclopentadienyl hydrogens. The peaks at 3.72 and 2.58 ppm represent the hydrogens next to the oxygen and sulfur, respectively. As with previous sulfur-containing compounds of $CpRu(PPh_3)_2^+$, coordination does not cause a large shift in ligand protons (Park et al., 1994; Green et al., 2001). This lack of a large shift also indicates that no C-S bond cleavage has occurred as was reported for 1,3-dithiane. The NMR spectrum of the yellow crystals suggests 1,4-thioxane coordination, but single crystals are needed to determine the mode of coordination, using X-ray diffraction techniques.

Due to the inability to obtain single crystals of 1, powder patterns of a series of triflate ($CF_3SO_3^-$) salts were undertaken. Powder patterns were taken on the following five compounds: [$CpRu(PPh_3)_2$(1,3-dithiane)]CF_3SO_3, [$CpRu(PPh_3)$(1,4-dithiane)]CF_3SO_3, [$CpRu(PPh_3)_2$(1,3,5-trithiane)]CF_3SO_3, [$CpRu(PPh_3)_2$(pms)]CF_3SO_3, and the triflate salt of [$CpRu(PPh_3)_2$(thioxane)]$^+$, for comparison. The powder pattern for the yellow crystals is not x-ray isomorphous to those compounds previously characterized. The results are inconclusive at this point.

Problems in crystal growth may be due to the reaction of the dechlorinating agent ($AgBF_4$ or $AgCF_3SO_3$) and the 1,4-thioxane. Two polymeric forms have been isolated from the reaction of AgO_3SCF_3 with 1,4-thioxane (Buchholz et al., 1996). The polymers contain either terminal or bridging thioxane ligands. Multiple attempts to recrystallize [$CpRu(PPh_3)_2$(thioxane)]BF_4 gave very thin plates. A marginal unit cell was obtained and the cell volume was consistent with the proposed formulation.

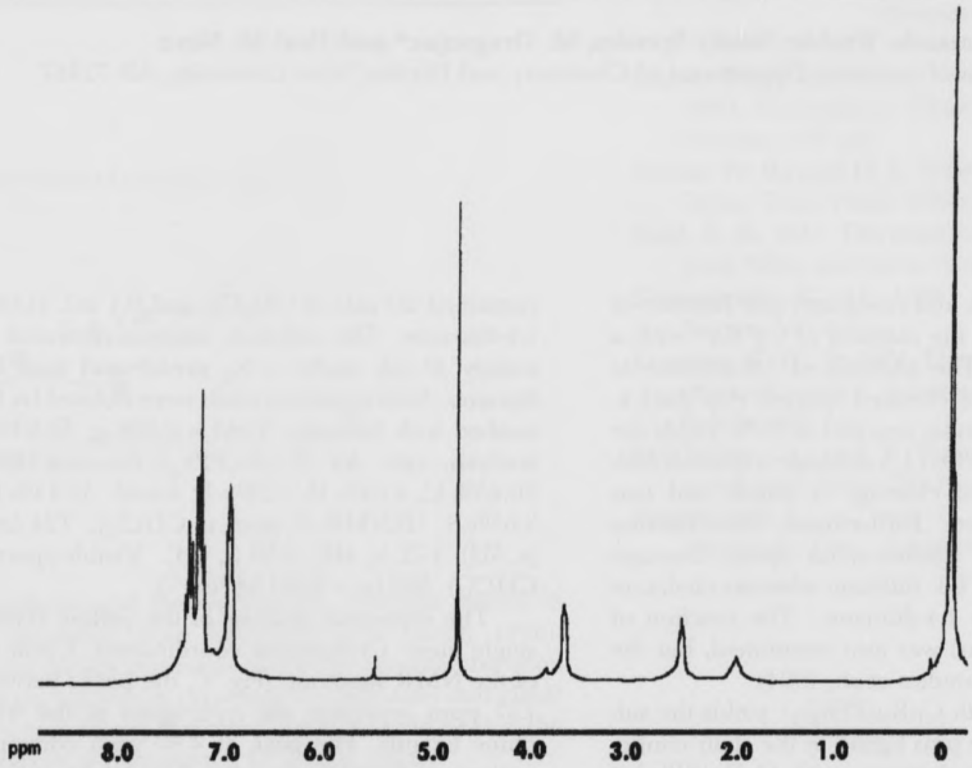

Fig. 1. NMR spectrum of $[CpRu(PPh_3)_2(thioxane)]BF_4$.

Sulfur coordination of the 1,4-thioxane ligand to a metal center has been shown for platinum (Burgarcic, et al., 1993), palladium (Moullet et al., 1997), and tungsten (Boorman et al., 1998). Reaction of $K_2[PtCl_4]$ with 1,4-thioxane at room temperature yields the *cis*-$[PtCl_2(1,4\text{-thioxane})_2]$ complex, but reaction of $PtCl_2$ with 1,4-thioxane at 70°C gives the *trans*- $[PtCl_2(1,4\text{-thioxane})_2]$ complex (Burgarcic et al., 1993). The tetrakis(1,4-thioxane)palladium(II) complex has been synthesized by the reaction of $[Pd(CH_3CN)_4](BF_4)_2$ with 1,4-thioxane at room temperature (Moullet et al., 1997).

The ditungsten(III) tris-bridged cyclic thioether complex with the formula $Cl_3W(\mu\text{-}1,4\text{-thioxane})_3WCl_3$ and $[Cl_3W(\mu\text{-}1,4\text{-thioxane})_2(\mu\text{-}Cl)WCl_3]^-$ have been prepared. The coordination of thietane, pms, and 1,4-dithiane were also studied. Thietane and pms were investigated in an attempt to prepare a precursor which, when ring-opened, would create pendant arms of varying lengths. Attempts to see the effect of incorporation of a heteroatom into the thioether ring upon ring-opening were investigated by reaction of 1,4-thioxane and 1,4-dithiane (Boorman et al., 1998).

The reaction of 1,4-thioxane with $CpRu(PPh_3)_2^+$ precedes rapidly. The NMR spectrum confirms the product is $[CpRu(PPh_3)_2(1,4\text{-thioxane})]O_3SCF_3$. Sulfur coordination is suspected due to the affinity of Ru(II) for sulfur, and the fact that in all of the previous examples of 1,4-thioxane coordination, only the sulfur-bound ligand is observed. Also, the charge transfer band at 360 nm is consistent with sulfur coordination of the thioxane ligand. Further studies will look at the potential line broadening of the NMR spectrum due to coupling to the $^{99,\,101}Ru$ (I= 5/2) nuclei and the synthesis of the 1,4-dioxane compound for comparison.

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Literature Cited

Boorman, P. M., N. L. Langdon, V. J. Mozol, and M. Parvez. 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.

Bruce, M. I. and N. J. Windsor. 1977. Cyclopentadienyl-ruthenium and -osmium chemistry. IV. Convenient high-yield synthesis of some cyclopentadienyl rutheni-

Journal of the Arkansas Academy of Science, Vol. 55 [2001], Art.

um or osmium tertiary phosphine halide complexes. Aust. J. Chem. 30:1602-1604.

Buchholz, H. A., G. K. Surya Prakash, J. F. S. Vaughan, R. Bau, and G. A. Olah. 1996. Two types of new polymeric silver(I) complexes from 1,4-thioxane and silver triflate. 35:4076-4077.

Burgarcic, C., K. Lovquist, and A. Oskarsson. 1993. Cis-trans influences in Pt complexes. Crystal structures of cis-[Pt(Cl_2(1,4-thioxane)$_2$] and trans-[Pt(Cl_2(1,4-thioxane)$_2$]. Acta Chem. Scand. 47:554-559.

Green, M., M. Draganjac, Yanjing Jiang, A. W. Cordes, C. D. Bryan, J. K. Dixon, S. L. Folkert, and C.-H. Yu. 2001. Reaction of CpRu(PPh_3)$_2$Cl with Six-member cyclothioethers. Structures of the [CpRu(PPh_3)$_x$L]X Complexes (L = pentamethylene sulfide, x = 2, X = BF_4; L = 1,3-dithiane, 1,3,5-trithiane, x = 2, X = $CF_3SO_3^-$; L = 1,4-dithiane, x = 1, X = BF_4^-). Manuscript in preparation.

Moullet, B., C. Zwahlen, and A. E. Merbach. 1997. Kinetic study and crystal structure of tetrakis(1,4-thioxane)palladium(II). A comparison between platinum(II) and palladium(II) reactivity. Inorg. Chim. Acta. 261:67-75.

Park, H., M. Draganjac, S. R. Scott, A. W. Cordes, and G. Eggleton. 1994. The reaction of CpRu(PPh_3)$_2^+$ with trimethylene sulfide. 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 carbon-chlorine bonds by the electrophilic ruthenium fragment 'Ru(η- C_5Me_5)$^+$'. J. Chem. Soc. Dalton Trans. 1895-1901.

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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.

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The author should submit three copies of the manuscript, tables, and figures. A diskette containing manuscript, table and figure files **MUST** also accompany submitted materials. If at all possible save the document as a Microsoft Word 6.0 document. The figures should be saved as tif, jpeg, or eps files. 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. Set words in italics that are to be in italics (e.g., scientific names). 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.

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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 (*Taxidea taxus*). Pp. 27-45, *In* Comparative biology of reproduction in mammals (I. W. Rowlands, ed.) Academic Press, London. xxi + 559 pp.

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