2000

Journal of the Arkansas Academy of Science - Volume 54 2000

Academy Editors

Recommended Citation

Editors, Academy (2000) "Journal of the Arkansas Academy of Science - Volume 54 2000," *Journal of the Arkansas Academy of Science*: Vol. 54 , Article 1.
Available at: https://scholarworks.uark.edu/jaas/vol54/iss1/1

Journal of the

ARKANSAS ACADEMY OF SCIENCE

VOLUME 54
2000

Library Rate

Arkansas Academy of Science, Dept. of Physiology and Biophysics, University of Arkansas for Medical Sciences

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Charles Brookover, 1917
Dwight M. Moore, 1932-33, 64
Flora Haas, 1934
H. H. Hyman, 1935
L. B. Ham, 1936
W. C. Munn, 1937
M. J. McHenry, 1938
T. L. Smith, 1939
P. G. Horton, 1940
I. A. Willis, 1941-42
L. B. Roberts, 1943-44
Jeff Banks, 1945
H. L. Winburn, 1946-47
E. A. Provine, 1948
G. V. Robinette, 1949
John R. Totter, 1950
R. H. Austin, 1951
E. A. Spessard, 1952
Delbert Swartz, 1953
Z. V. Harvalik, 1954
M. Ruth Armstrong, 1955
W. W. Nedrow, 1956

Jack W. Sears, 1957
J. R. Mundie, 1958
C. E. Hoffman, 1959
N. D. Buffaloe, 1960
H. L. Bogan, 1961
Trumann McEver, 1962
Robert Shideler, 1963
L. F. Bailey, 1965
James H. Fribourgh, 1966
Howard Moore, 1967
John J. Chapman, 1968
Arthur Fry, 1969
M. L. Lawson, 1970
R. T. Kirkwood, 1971
George E. Templeton, 1972
E. B. Wittlake, 1973
Clark McCarty, 1974
Edward Dale, 1975
Joe Guenter, 1976
Jewel Moore, 1977
Joe Nix, 1978
P. Max Johnston, 1979

E. Leon Richards, 1980
Henry W. Robison, 1981
John K. Beadles, 1982
Robbin C. Anderson, 1983
Paul Sharrah, 1984
William L. Evans, 1985
Gary Heidt, 1986
Edmond Bacon, 1987
Gary Tucker, 1988
David Chittenden, 1989
Richard K. Speairs, Jr. 1990
Robert Watson, 1991
Michael W. Rapp, 1992
Arthur A. Johnson, 1993
George Harp, 1994
James Peck, 1995
Peggy R. Dorris, 1996
Richard Kluender, 1997
James Daly, 1998
Rose McConnell, 1999

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George Yatskievych (Missouri Botanical Garden)

COVER: Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) from Columbia County, Arkansas. Photo by David A. Saugey.

ARKANSAS ACADEMY
OF SCIENCE 2000
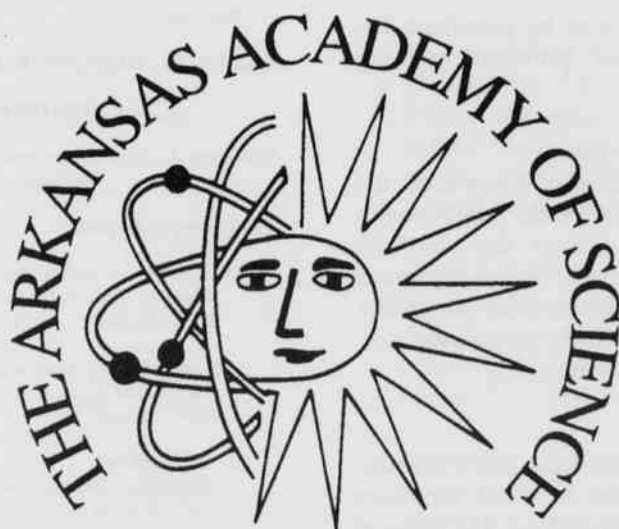
APRIL 7-8, 2000
84th ANNUAL MEETING

Arkansas School for Sciences and Mathematics
United States Forest Service - Ouachita National Forest

Hot Springs, Arkansas

JOURNAL
ARKANSAS ACADEMY OF SCIENCE

ANNUAL MEETING 7-8 APRIL 2000
ARKANSAS TECH UNIVERSITY

Mostafa Hemmati
President

Mark Draganjac
President-Elect

Michael Soulsby
Secretary

Joyce Hardin
Treasurer

Ed Griffin
NAAS Delegate

Henry Robison
Historian

Secretary's Report

MINUTES OF THE 84TH MEETING

FIRST BUSINESS MEETING
7 APRIL 2000

Number present: 15

1. Meeting called to order at 8:40 a.m. by president, Dr. Mostafa Hemmati. Minutes of previous meeting approved.

2. Local Arrangements Committee Chair:
David Saugey, Committee Chairman, recognized the assistance of Dr. Logan, principal of the Mathematics and Science School, and described the activities scheduled during the meeting. At that time, 115 persons were registered and 69 presentations were scheduled. Motion to accept this report was made by Johnson, seconded and passed by the membership.

3. Secretary's Report:
Mike Soulsby distributed minutes from the Executive Committee meeting of September 11, 1999. Members were alerted to change his e-mail address. He inquired whether anyone was aware of the existence of Academy Proceedings for years between 1947 and 1965. These are being requested by Tom Weeks at Marshall University, Huntington, WV. Since no one knew of their presence, he will pursue their retrieval through interlibrary loan within Arkansas. A motion to accept his report was made by David Saugey, seconded, and passed.

4. Treasurer's Report:
Joyce Hardin discussed her report, which is attached to these minutes. She explained the delay in institutional billing, and some possible concerns over interest in Certificates of Deposit. She also expressed concern over the slow decline in both Academy membership and subscriptions to the Journal. Motion to accept her report was made by Henry Robison, seconded, and passed.

FUNDS

	1998	1999
Beginning Balance - 1 January	$22,740.91	$25,166.28
Net Gain	2,425.37	1,002.21
BALANCE - DECEMBER 31	**$25,166.28**	**$26,168.49**

DISTRIBUTION OF FUNDS

	1998	1999
Checking Account (Mercantile Bank, Conway, AR)	$ 4,379.19	$ 3,859.82
Certificates of Deposit		
Dwight Moore Endowment (Mercantile Bank, Conway, AR) 4.35% Interest	$ 3,963.83	$ 4,048.35
Life Membership Endowment (Mercantile Bank, Conway, AR) 4.35% Interest	$13,203.06	$13,260.32
CD Unrestricted (Mercantile Bank, Conway, AR) 5.00% Interest	$ 3,620.20	$ 5,000.00
TOTAL	**$25,166.28**	**$26,168.49**

Respectfully Submitted,

Dr. Joyce M. Hardin, AAS Treasurer

Financial Statement, Arkansas Academy of Science

INCOME:

	1998	1999
1. ANNUAL MEETING	-0-	$ 4,135.30
2. ENDOWMENT AAS Endowment Unrestricted	$ 4,135.30	$ 3,695.03
3. ENDOWMENT DONATIONS		
a. AAS Unrestricted	$ 125.00	
b. Dwight Moore	$ 25.00	
	$ 150.00	
	$ 150.00	$ 150.00

Secretary's Report

		1998	1999
4. INTEREST (Endowment)		-0-	$ 665.97

5. INDIVIDUAL MEMBERSHIPS

a. Associate		135.00
b. Regular		2,505.00
c. Sustaining		245.00
d. Sponsoring		45.00
e. Life		450.00
f. Other		100.00
		$3,480.00
	$ 4,525.00	$ 3,480.00

6. INSTITUTIONAL MEMBERSHIPS	$ 1,700.00	$ 1,000.00
7. MISCELLANEOUS	$ 159.00	-0-

8. JOURNAL

a. Miscellaneous Sales		$ 3,675.43
b. Page Charges		6,360.00
c. Subscriptions		700.00
		$10,735.43
	$ 7,670.00	$10,735.43

9. T-SHIRT (General Endowment)	714.00	-0-
TOTAL INCOME	**$19,053.30**	**$23,329.43**

Financial Statement, Arkansas Academy of Science

EXPENSES:

	1998	1999

1. ANNUAL MEETING

a. Joyce Hardin - plaques (625)		166.83
b. Chartwells (643)		1,020.53
c. ATU Physical Science (644)		681.05
d. Dr. Dawn Bonnell (646)		372.65
e. Dr. Charlie Gagen (647)		279.51
		$2,520.57
	$ 163.64	$2,520.57

2. AWARDS

a. C. Ed Rington (629)		100.00
b. Tut Campbell (630)		50.00
c. Lex Mitchell (631)		50.00
d. Josie Pickens (634)		50.00
e. Elisa Horsch (635)		100.00
f. Eric Anderson (636)		50.00
g. Jonathan Whitlock (638)		75.00
h. Shonda Harris (639)		75.00
i. Conway Trophy for Arkansas Science Talent Search (641)		244.09
j. Arkansas Science Fair Association (641)		450.00
k. Arkansas Junior Academy (642)		250.00
		$1,494.09
	$ 1,444.09	$1,494.09

3. DUES

National Association of Acadamies of Science (649)	$ 62.50	$ 62.50

4. MISCELLANEOUS

a. Ed Griffin Travel to AAS Conference (645)	$ 228.00	$ 218.00

5. NEWSLETTER

a. Kwik Print - January 1999 Newsletter (624)		$513.66
b. UALR - Postage Spring 1999 Newsletter (626)		50.13
	$ 717.73	$ 563.79

6. OFFICE EXPENSES

John Rickett, Secretary (652)	-0-	$ 229.26

7. JOURNAL

a. Stan Trauth - Editorial Consultation and Travel Volume 52 (623)		200.00
b. Pinpoint Color Volume 52 (648)		12,490.59
c. Joy Trauth - Editorial Consultant Volume 53 (650)		500.00
		13,190.59
	$15,008.01	$13,190.59

8. CORRECTION TO DEPOSIT	-0-	$ 20.00

9. TRANSFER

a. To CD (Unrestricted)		$ 5,000.00
b. To CD - Moore		25.00
c. To CD - Life		525.00
		$ 5,550.00
	-0-	$ 5,550.00
TOTAL EXPENSES	**$17,623.97**	**$23,848.80**

5. Editor-in-Chief's Report: Stan Trauth discussed his appreciation that David Saugey had accepted the position of managing editor. Stan also indicated that the Journal cost is somewhat higher this year and his intent to purchase software for computer submission of Journal articles in the future.

6. Managing Editor's Report: David Saugey described his first year as a learning experience and expressed eagerness to serve in this capacity. A motion to accept Stan and David's report made by Joyce Hardin was seconded by Mark Draganjack, and passed.

7. Newsletter Editor's Report: Jeff Robison expressed appreciation for the existence of membership address labels. He displayed a color printed copy of the Newsletter, and indicated that the student award winners and their award categories will be included in the next newsletter. A motion to approve the report was made by Stan Trauth, seconded, and passed by the membership.

8. Historian's Report: Henry Robison indicated that this is the 84th meeting of the Academy, and that it is the first meeting to be held in Hot Springs. Motion to accept the report made by John Rickett, seconded, and passed.

9. 2000 Meeting: Dr. Hemmati announced that this meeting will be held at UCA, and its host will be Dr. Toll, Dean of the Math and Science School.

10. 2001 Meeting: John Rickett announced that UALR will host the 2001 meeting, and that he will acquire a formal invitation to the campus from the new Dean upon his

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arrival at that campus.

10. AAAS Report: Ed Griffin could not be present, but he provided a copy of his report from the AAAS meeting held in Washington, DC. A copy of his report is attached.

11. Arkansas Science Teachers' Association (ASTA) Representative: Dr. Hemmati indicated that he had attended the ASTA meeting this year and, as a result, he had invited Jim Edson to appear before the Executive Committee. Jim proposed that ASTA and AAS hold joint meetings in the future. Members could then make joint presentations. Dr. Hemmati will copy Jim's letter and provide copies to members of the Council. Most Council members seemed in favor of trial joint meetings in the future.

12. BIOTA Committee: No report was presented.

13. Nominations Committee Report: Dr. Daly proposed nominations for vice president: Dr. Walter F. Godwin, Department Chemistry, UAM, and Dr. Clifton Orr, Department Biology, UAPB

    Motion to accept the nominations was made by John Rickett and seconded by Mike Soulsby. Motion passed. Dr. Robert Watson will be Dr. Daly's replacement on the nominations committee, for it is Dr. Daly's last year in this position. Dr. Watson will be followed as chairman by Dr. Scott Kirkconnell A new member of the nominating committee will need to be elected at the Fall meeting.

14. Junior Academy of Science and Arkansas Science Fair Association reports: Dr. Hardin reported for Dr. Skinner, who is attending the Junior Academy of Science meetings, and Dr. Rapp. A written report has been submitted by Drs. Skinner and Rapp, and is attached to these minutes. Among items in that report are:
    (a) a report of Science Fairs and Junior Academy of Science Meetings held in Arkansas during 2000,
    b) a statement that over 250 students are expected to register for the State Science fair and about 70 for the State Junior Academy of Science meeting in Conway, and
    (c) the annual request for $450.00 by the Science Fair Association to cover expenses ($50 for each of the nine fairs) and for $250 to help send students to the American Junior Academy of Science meeting. A motion to approve this amount ($700) was made by Mark Draganjac and seconded by John Rickett. Motion

passed unanimously.

15. Alltel Talent Search: Dr. Hardin reported for Dr. Runge. She stated that the Talent Search committee is requesting a total sum of $281.49 to cover the cost of plaques. A motion to approve this amount was made by Mike Soulsby and seconded by John Rickett. The motion passed.

16. Bids for the 2003 meeting: Suggestions were made that this meeting could be held at either Hendrix College in Conway, Jonesboro, or possibly Fayetteville. It was proposed that we need to generate more interest in the Academy on the Fayetteville Campus, and that a meeting there might help accomplish this goal. Dr. Rickett suggested that we contact department chairpersons and ask them to stimulate interest among their faculty. Jeff Robertson offered to compose a letter to chairpersons, and Mark Draganjac said that he would discuss this concern with Collis Geren at an upcoming ERSCOR meeting. Dr Hemmati indicated that he has an e-mail mailing list of Deans, and that this list could be used to also contact Deans.

17. Old Business: Pictures of the Executive Committee taken during the September 11 meeting at UALR were distributed.

18. Concern that Sigma Xi contributions are dwindling was discussed. A motion to continue requesting funds from Sigma Xi for environmental science students was made by Henry Robison and seconded by Joyce Hardin. This motion passed.

19. John Rickett began a consideration of the George Harp Memorial Fund, when Dr. and Mrs. Harp arrived at the meeting. It was determined that funds from this memorial could be used to reward the outstanding graduate student presentation in Dr. Harp's expertise at the annual meeting.

20. AAS web page is being produced, with a list of the membership. Dr. Robertson is pursuing its development.

21. New Business: Dr. Daly discussed the need to increase the Academy's membership. This could be accomplished by targeting Community College faculty and faculty at newly created Junior Colleges. Dr. Daly volunteered to speak on the Academy's behalf at the Fall meeting of the Community Colleges. Dr. Hemmati accepted this offer of a presentation, and it was decided that a booth might also be beneficial at the Fall meeting. A motion to have a booth was made by Dr. Soulsby and

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seconded by Dr. Hardin. Motion was approved.

APPENDIX A

STATE SCIENCE FAIR ASSOCIATION

Thank you for the support the Academy has provided for the past seventeen 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. 17-18): Gary Earleywine, fair director, and Marian Douglas, Jr. Acad. director.

North Central (Lyon College, Batesville, Mar. 17): Beverly Meinzer, fair director, and Kathy Campbell, Jr. Acad. director.

North East (Ark. State Univ., Jonesboro, Mar. 10-11): Larry Mink, fair director, and Ron Johnson, Jr. Acad. director.

North West (Univ. of Ark., Fayetteville, Mar. 17): Lynne Hehr, director of fair and Junior Academy.

South Central (Ouachita Baptist Univ., Arkadelphia, Mar. 3): Jim Taylor, fair director, and David Brooks, Jr. Acad. director.

South East (Univ. of Ark-Monticello, Mar. 5): Billy Britt, fair director.

South West (Camden, Mar. 3): Joe Giddens, director of fair and Junior Academy.

West Central (ASMS, Hot Springs, Feb. 29-Mar. 1): Shane Willbanks, director of fair and Junior Academy.

Over 250 students are expected to register for the state science fair, and about 70 students for the state Junior Academy of Science meeting, to be held April 7-8 in Conway, on the campus of the Univ. of Central Arkansas. Mike Rapp is the director of the state science fair. Bob & Raynell Skinner are co-directors of the Junior Academy of Science.

With this memo, we are requesting 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 Acad. of Science meeting.

Please offer a resolution of thanks for the work of the individuals indicated above, which could be included in the minutes published in the *Proceedings*, and please bring the request for funding to the members. Resolutions to that effect are given below.

Request for Funding for 2000 Arkansas Science Fair Association and Junior Academy of Science:

"The Arkansas Science Fair Association (ASFA) requests the Arkansas Academy of Science to continue its support for the past seventeen years of $50 to each of the science fairs in Arkansas that will send students and teachers to the International Science and Engineering Fair, to be held in May, 2000, in Detroit. The total contribution being requested by the ASFA is $450. The Arkansas Junior Academy of Science requests the Arkansas Academy of Science to provide $250 for 2000, to help cover the expenses of sending student winners to the American Academy of Science meeting."

Should the membership approve this request, please have the first check made payable "Arkansas Science Fair Association" and mail it to Dr. Michael W. Rapp, College of Natural Sciences & Math, Univ. of Central Arkansas, Conway, AR 72035. The Arkansas Science Fair Association will use this support to help pay expenses for the students attending the International Science & Engineering Fair (ISEF). Each affiliated fair will be credited with $50 for its share of the ISEF expenses.

Please have the second check made payable to "Arkansas Junior Academy of Science" and mail it to Dr. Bob Skinner, Dept. of Anatomy, UAMS Slot 510, 4301 W. Markham, Little Rock, AR 72205. The Junior Academy of Science will use the support to help pay expenses for students and teachers to attend next year's meeting of the American Junior Academy of Science.

Resolution of Appreciation to 2000 Science Fair & Junior Academy Directors:

"The membership expresses its appreciation for the work that the following individuals have done in their roles as directors of science fairs and Junior Academy of Science meetings in 2000:

Central (Little Rock) - Gary Earleywine (Fair) and Marian Douglas (Junior Academy)

North Central (Batesville) - Beverly Meinzer (Fair) and Kathy Campbell (Junior Academy)

North East (Jonesboro) - Larry Mink (Fair) and Ron Johnson (Junior Academy)

North West (Fayetteville) - Lynne Hehr (Fair and Junior Academy)

South Central (Arkadelphia) - Jim Taylor (Fair) and David Brooks (Junior Academy)

South East (Monticello) - Billy Britt (Fair)

South West (Camden) - Joe Giddens (Fair and Junior Academy)

West Central (Hot Springs) - Shane Willbanks (Fair and Junior Academy)

State Fair/Junior Academy - Michael Rapp (Fair) and Bob & Raynell Skinner (Junior Academy)"

APPENDIX B

RESOLUTIONS

BE IT RESOLVED that we, the membership of the Arkansas Academy of Science, offer our sincere thanks to Arkansas School for Mathematics and Sciences at Hot Springs for hosting the 2000 meeting of the Arkansas Academy of Science. In particular, we thank the Local Arrangement Committee for an outstanding job of organizing the meeting: Dave Saugey and Betty Crump (Co-Chair and Local Arrangements Committee), David Saugey and Betty Crump (Abstracts, Scheduling), Ron Periho, Lori Short, and Debbie Rigsby (Registration), David Saugey (Local Treasurer), Betty Crump (Audiovisual), Betty Crump, Debbie Rigsby, Dianne Saugey, and David Saugey (Social Arrangements). Appreication is expressed to the Downtowner Hotel for use of their facilities and the hospitality shown us by all Personnel. The social was excellent.

The Academy recognizes the important role played by various Section chairpersons and expresses sincere appreciation to: Dr. Walter Godwin, Dr. Michael Panigot, Dr. Frank Setliff, Dr. Edmond Wilson, Jr. (Chemistry), Dr. Gerald Walsh and Dr. Marsh (Botany and Environmental Science), Mr. David Jamieson, Dr. Allen Carter, Dr. Henry Robison, and Dr. Phoebe Harp (Vertebrate Zoology), Dr. John Harris, Dr. George Harp (Invertebrate Zoology), Dr. Mostafa Hemmati, Dr. Will Braithwaite (Physics), Dr. Anne Grippo, Dr. David Gilmore (Biomedical).

A special thanks is owed to the individuals who devoted considerable time and energy to judging student papers: Dr. Edmond Wilson, Jr., Dr. Michael J. Panigot, and Dr. Robert Maruca (Chemistry), Dr. Dan Marsh, Mr. Gerald Walsh, and Mrs Susan Hooks (Botany and Environmental Science), Mr. David Jamieson, Dr. Ed Pert, and Dr. Renn Tumlinson (Vertebrate Zoology), Dr. John Harris, Dr. Henry Robinson, and Dr George Harp (Invertebrate Zoology), Dr. Will J. Braithwaite, Dr. Mostafa Hemmati, and Dr. Jeff Robertson (Physics), Dr. Anne Grippo, Dr. Steven Runge, Dr. James Daly, Dr. David Gilmore (Biomedical).

We express gratitude to the various directors of the science and youth activities that are supported by the Academy: Ms. Sherry Lane (President, Arkansas Science Teachers Association), Dr. Michael Rapp (President, Arkansas State Science Fair Association), Dr. Steve Runge and Dr. Dan Magoulick (Co-Directors, Intel Talent Search) and Drs. Robert and Raynall Skinner (Co-Directors, Arkansas Junior Academy of Science), Dr. Doug James (Chair, BIOTA Committee), Dr. James Daly (Chair, Nominating Committee), Dr. Ed Griffin (AAS Representtive to the American Association for the Advancement of Science).

We wish to thank all those who served as directors at science fairs and Junior Academy meetings: Mr. Gary Earleywine (Central Region), Dr. Beverly Meinzer (North Central Region), Dr. Larry Mink (North East Region), Dr. Lynne H. Hehr (North West Region), Dr. Jim Taylor (South Central Region), Dr. Billy Britt (South East Region), Dr. Joe Giddens (South West Region), Mr. Shane Willbanks (West Central), Dr. 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: Dr. Mostafa Hemmati (President), Dr. Mark Draganjac (President-Elect), Dr. John Rickett. (Vice-President), Dr. Michael Soulsby (Secretary), Dr. Joyce Hardin (Treasurer), Dr. Rose McConnell (Past President), Dr. Stanley Trauth (*Journal* Editor-in-Chief), Mr. David Saugey (*Journal* Managing Editor), Dr. Jeff Robertson (Newsletter Editor), and Dr. 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.

Resolutions Committee
Dr. Robert C. Sadoski, Chair
Dr. John Graham
Dr. Frank Hardcastle

APPENDIX C

REPORT
ANNUAL MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE (AAAS)
WASHINGTON, DC, FEBRUARY 17-20, 2000
ED GRIFFIN, REPRESENTATIVE OF THE ARKANSAS ACADEMY OF SCIENCE (AAS)

To assure the greatest diversity of input to the National AAAS there are 24 special interest sections that work within and report to the parent association. Each state Academy of Science is asked to send a representative to the annual meeting of AAAS to serve as a voting member of a section. Historically the representtive from the Arkansas Academy has served on one or two additional sections, like Biological Sciences, Chemistry, etc., but that is often not possible because they schedule their meetings at the same time. Because the interests of the Arkansas Academy are varied in nature, the General Interest section seems appropriate for our primary representation.

One function each section serves is to (competitively) propose symposia for the next Annual Meeting (2001 in San Francisco). One proposal the section submitted for next year was "the benefits of improving the environment on improving public health". The representative from the Ohio Academy and I proposed that we conduct a workshop where invited members of the press perform hands-on discovery exercises generally about "energy use and the environment". If we are fortunate and our proposal gets approved, I will ask you for your favorite "quick-hitter" discovery exercises.

Most national scientific societies are increasingly including sessions in their meetings about way to improve teaching and most of these are emphasizing hands-on, activity based, facilitated discovery learning, instead of extensive lectures and recipe based labs. To emphasize this point, NSF brought approximately 1000 Washington, DC elementary students for a half day of discovering learning activities in huge hotel ballrooms at this meeting.

From the opening remarks until I had to leave the meeting, as usual, was exceptional. There were arrays of concurrent sessions, ranging from cutting edge research papers, to sessions on influencing public policy, and planning for the future. I'll mention only a few especially interesting sessions where I both learned and represented Arkansas. I attended a poster session where Junior Academy and Science winners presented their work. You can be assured I personally congratulated and bragged on each of the four presenters from Arkansas:

> Sima Shah, Immunology, Mills High School, Little Rock
>
> Cate Fox-Lent, Heat Movement, Central High School, Little Rock
>
> William Gulbreath, Computer Operating Systems, Greenwood High School, Greenwood
>
> Claire Nelson, Plastic Film, (now) Hendrix College, Conway

Immediately after that poster session, we attended the conference keynote address by none other than professor evolution himself, outgoing AAAS President, Stephen J. Gould. As usual, he was exceedingly entertaining and informative. He commented that evidence indicates that we can stop worrying about the influence of creationists, because "we've already won", and their sporadic outbursts mostly bring embarrassment to themselves. In a following social event, he chatted enthusiastically with me about the Arkansas court case in which he served as an expert on evolution. I also visited with (our own) Dr. Mary Good, UCA Alumna, the incoming president of AAAS, and a new Dean at UALR. Dr. Good indicated she would participate in the Arkansas Academy. I also heard a lecture by the U.S. Surgeon General, Dr. David Satcher about health and health care in the 21st century. And in an early morning lecture I heard (professor "ant" himself), Dr. E. O. Wilson, speak about "the relation between biology and the humanities".

Through out the meeting, events were too numerous to mention, but another one I was personally interested in was a session organized by NFS to organize and mobilize retired scientists and engineers to volunteer to help enrich science classes in local schools. I hope the Arkansas Academy might participate in this kind of project. As usual the exhibits were slanted greatly toward materials for science education activities (K-college). These exhibits were easily the greatest concentration of such materials I've ever seen. Besides that they gave us free snacks during each afternoon break.

I sensed throughout the meeting an increasing concern about improving/modernizing science (and math) education, especially at the college level. Among the most distinguished organizations promoting and supporting improved science and math teaching in college are the: National Academy of Sciences; AAAS, NSF, and NIH. We are sure to hear more about these challenges in the near future. In fact, I just received an example of the kinds of things being presented to us by some "experts" - http://horizon.unc.edu. And I heard an ominous sounding paper at AAAS entitled, "Can Universities Change Quickly Enough for the Innovation Economy?"

I bet we can/do. Thanks for letting me represent the Arkansas Academy of Science.

CONSTITUTION

ARKANSAS ACADEMY OF SCIENCE

(Revised at the April 1999 Annual Meeting)

ARTICLE I. NAME

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

ARTICLE II. OBJECTIVES

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

ARTICLE III. MEMBERSHIP

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

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

ARTICLE IV. OFFICERS

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

ARTICLE V. MEETINGS

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

ARTICLE VI. PUBLICATIONS

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

ARTICLE VII. AMENDMENTS

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

BY-LAWS

(Revised at the April 1999 Annual Meeting)

1. These by-laws may be altered or amended in the same manner as the constitution.
2. The following standing committees shall be established: Auditing, Awards, Biota, Constitution, Development, Local Arrangements, Nominations, Publications, Publicity, Resolutions, and Science Education. *Ad hoc* committees may be appointed by the President. The make-up, duties and duration of service for members of each standing committee shall be determined by the Executive Committee with members for vacancies to be appointed by the President.
3. Whenever the number of papers to be presented in any field becomes sufficiently large, an additional section may be created at the discretion of the Local Arrangements Committee.
4. Persons presenting papers with the intent of having them published in the *Journal* shall present an original and two copies of the paper to the Chairman of the appropriate section or either of the *Journal* Editors at the annual meeting. The Editors shall be under no obligation to consider papers submitted after this date.
5. Members who shall allow their dues to remain unpaid for two years, having been annually notified of their arrearage by the Secretary, shall lose their status of membership.
6. Expenditures in excess of $200 which have not been specifically authorized by the Academy at a prior annual business meeting require written approval by the President before payment can be made.
7. The fiscal year and the membership year shall begin January 1 and end December 31. A person joining the Academy during the year is entitled to membership privileges for the remainder of that fiscal year.
8. All officers elected at the annual meeting assume their duties at the end of the last business session of that meeting.
9. In the event an officer, except President, Past President, President-elect, and Vice President, is unable to complete a term, the Executive Committee shall appoint a successor to complete that term, or open a new five-year term with an election at the next general meeting.
10. Dues for all categories of members shall be set by the Executive Committee of the Academy and submitted to the membership for approval. Approval by the membership shall be by majority vote of those present. Any change of dues approved by the membership shall be effective January 1 of the year following that in which the change was approved.
11. The price of the *Journal* in sales to non-members of the Academy shall be determined by the Executive Committee.
12. The Academy shall sponsor such activities as it deems necessary to further its objectives. All activities sponsored by the Academy shall be reviewed annually by the Executive Committee.
13. The Academy shall set aside $1,000 or more as a reserve fund which may be withdrawn and used upon expressed consent of the Executive Committee.
14. Notwithstanding any provision of the Constitution or

By-laws which might be susceptible to a contrary construction,

(a) the Academy shall be organized and operated exclusively for scientific and educational purposes;

(b) with the exception of established awards, no part of the net earnings of the Academy shall or may under any circumstances inure to the benefit of any private individual;

(c) no substantial part of the activities of the Academy shall consist of carrying on propaganda, or otherwise attempting to influence legislation;

(d) the Academy shall not participate in, or intervene in (including the publishing or distributing of statements) any political campaign on behalf of any candidate for public office;

(e) the Academy shall not be organized or operated for profit;

(f) the Academy shall not:

   (1) lend any part of its income or corpus, without the receipt of adequate security and a reasonable rate of interest, to;

   (2) pay any compensation in excess of a reasonable allowance for salaries or other compensation for personal services actually rendered to;

   (3) make any part of its services available on a preferential basis to;

   (4) make any purchase of securities or any other property for more than adequate consideration in money or money's worth from;

   (5) sell any securities or other property for less than adequate consideration in money's worth to;

   (6) engage in any other transactions which result in substantial diversion of its income or corpus to any officer of the Executive Committee or substantial contributor to the Academy

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

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

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

APPENDIX A

AAS CONSTITUTIONAL COMMITTEES

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

AAS STANDING COMMITTEES ESTABLISHED BY THE BY-LAWS

1. AUDITING COMMITTEE: The Auditing Committee shall consist of a Chair and three additional members. The President shall appoint the Committee prior to or at the first annual business meeting, and it shall function only for that annual meeting. The Committee shall examine the financial records of the Academy, provided by the Treasurer, and report its findings to the Academy at the second business meeting.

2. AWARDS COMMITTEE: The Awards Committee shall be named by the Local Arrangements Committee for the upcoming annual meeting. The Committee shall consist of a Chair and as many additional members as the Chair and/or Local Arrangements Committee deem necessary. The Awards Committee shall evaluate undergraduate and graduate paper presentations during the annual meeting and make recommendations for the various awards established by the Executive Committee.

3. BIOTA COMMITTEE: The Biota Committee shall consist of a Chair and five additional members, and shall be appointed by the President for undefined terms of service. A term of service may be terminated by the

President, the committee Chair, or the member. The Biota Committee shall collect, organize, and disseminate taxonomic information on the flora and fauna of Arkansas. Reports shall be made available to the members of the Academy and any other interested party when sufficient information exists.

4. CONSTITUTION COMMITTEE: The Constitution Committee shall be appointed by the President whenever a need for constitutional examination exists and consist of the President-elect, Vice President, and one other member. The President-elect shall serve as the Chair. The Committee shall make recommendations on changes in the Constitution and By-laws whenever such changes are deemed necessary.

5. DEVELOPMENT COMMITTEE: The Development Committee shall consist of a Chair and two additional members and be appointed by the President to undefined terms. The President, the committee Chair, or the member may terminate the appointment. The Development Committee shall promote the growth and development of the Academy by contacting private industries to secure endowment funding to support activities of the Academy.

6. LOCAL ARRANGEMENTS COMMITTEE: The Local Arrangements Committee shall consist of a Chair, appointed by the President, and a minimum of two additional members, selected by the Chair. The Local Arrangements Committee shall make the arrangements necessary to host the annual meeting in accordance with the established guidelines for hosting a meeting adopted by the Executive Committee.

7. NOMINATIONS COMMITTEE: The Nominations Committee shall consist of a Chair and two additional members. Each member shall serve a three-year term with staggered expiration dates. The member serving his/her third year shall be the Chair, and the President shall appoint one new member each year prior to the annual meeting. The Nominations Committee shall recommend candidates to the members of the Academy for election. A minimum of two candidates shall be proposed for Vice President, and a minimum of one candidate shall be proposed for each of the other offices (Secretary, Treasurer, Historian, and Editors) as their terms expire.

8. PUBLICATIONS COMMITTEE: The Publications Committee shall consist of the Editor-in-Chief and Managing Editor of the *Journal* and two additional members. The Editor-in-Chief shall be elected by the membership of the Academy to a five-year term and serve as the Chair. The Managing Editor shall be appointed by the Executive Committee and serve a five-year term. The two additional members shall be appointed by the President for undefined terms. The

Committee Chair, President, or the member may terminate a member's appointment. The Chair may select as many Associate Editors as deemed necessary to accomplish the task of manuscript review. The Editor-in-Chief, Managing Editor and Associate Editors shall review manuscripts submitted for publication in the *Journal* and any other publications deemed desirable by the Executive Committee. Manuscripts may also be submitted to selected specialists for review. The Editors, jointly or singly, shall have the primary jurisdiction, but the Committee may be consulted, for decisions regarding acceptance, rejection or revision of all manuscripts.

9. PUBLICITY COMMITTEE: The Publicity Committee shall consist of a Chair and two additional members. The Committee shall be appointed by the President for undefined terms, and the President, committee Chair or the member may terminate the member's appointment. The Publicity Committee shall promote the public image of the Academy with news releases on activities and accomplishments of the Academy. All news releases shall be reviewed and approved by the Executive Committee prior to release to the news media.

10. RESOLUTIONS COMMITTEE: The Resolutions Committee shall consist of a Chair and two additional members. The Committee shall be appointed by the President prior to or at the first annual business meeting and serve only for that annual meeting. The Resolutions Committee shall present appropriate resolutions expressing the appreciation of the Academy to all individuals and organizations involved in activities sponsored by the Academy during the year.

11. SCIENCE EDUCATION COMMITTEE: The Science Education Committee shall consist of a Chair and additional members as deemed necessary by the Chair of the committee. The President shall appoint the Chair and, in consultation with the Chair, additional members for undefined terms. The President, the committee Chair or the member may terminate the member's appointment. The Science Education Committee shall provide information to the Academy on current programs and activities in science education in the state, promote programs, including the Junior Academy, Science/Engineering Fairs, and Science Talent Search(es) and cooperate with state agencies and other educational organizations in the study and development of innovative ideas or activities to improve science education at all levels in the state.

APPENDIX B

DUTIES OF ELECTED OFFICERS

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

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

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

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

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

F. Secretary –
1. Keeps all clerical records of the Academy: memberships by approved categories, *Journal* subscriptions, exchange and abstracting service lists, and other records as deemed necessary and appropriate by the Executive Committee
2. Sends out copies of the *Journal* to members (as needed) and as requested by subscription, exchange, and abstracting service lists
3. Corresponds with members and libraries as appropriate regarding payment of dues and payment of invoices for the *Journal*
4. Furnishes mailing labels to other Executive Committee members and Local Arrangements Committee Chair as appropriate
5. Furnishes membership information, as appropriate, to anyone requesting

6. Corresponds with AAAS (American Association for the Advancement of Science) to receive or provide information as needed and appropriate

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

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

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

Arkansas Academy of Science

MEMBERS 2000

FIRST MI	LAST NAME	INSTITUTION
Al	Adams	University of Arkansas at Little Rock
Max L.	Baker	University of Arkansas for Medical Sciences
Gene Lee	Bangs	University of Arkansas at Little Rock
Gwen	Barber	Arkansas Tech University
Victor	Blunt	University of Arkansas at Pine Bluff
Frank	Bowers	University of Wisconsin-Stevens Point
Jimmy D.	Bragg	Henderson State University
Edwin S.	Braithwaite	Cedarville College
William D.	Brown	University of Arkansas at Fayetteville
Thomas	Buchanan	Westark Community College
John	Bush	University of Arkansas at Little Rock
Michael E.	Cartwright	Arkansas Game & Fish Commission
Stanley L.	Chapman	University of Arkansas at Fayetteville
Vincent A.	Cobb	Ouachita Baptist University
Lynita	Cooksey	Arkansas State University
Marc	Corrigan	University of Arkansas at Monticello
Betty	Crump	U.S.D.A., Forest Service
Donald	Culwell	University of Central Arkansas
James T.	Daniels	Southern Arkansas University
Perry A.	Daniels	Arkansas State University
Jerry A.	Darsey	University of Arkansas at Little Rock
Chris	Davidson	
Patrick	Desrochers	University of Central Arkansas
Peggy Rae	Dorris	Henderson State University
Rudolph J.	Eichenberger	Southern Arkansas University
David	Eller	University of Arkansas for Medical Sciences
Robert	Engelken	Arkansas State University
Don	England	Harding University
James	Engman	Henderson State University
E. P. (Perk)	Floyd	U.S. Public Health Service
Thomas L.	Foti	Natural Heritage Commission
Charlie	Gagen	Arkansas Tech University
Wayne	Gildseth	Southern Arkansas University
Crissy Patterson	Goss	Hampton High School
John P.	Graham	Arkansas Tech University
Wayne L.	Gray	University of Arkansas for Medical Sciences
Reid	Green	U.S. Geological Survey
Brian	Greuel	John Brown University
Richard S.	Grippo	Arkansas State University
Anne A.	Grippo	Arkansas State University
Paul V.	Hamilton	University of Central Arkansas
Earl L.	Hanebrink	Arkansas State University-retired
Franklin D.	Hardcastle	Arkansas Tech University
John L.	Harris	Arkansas Highway & Transportation Dept.
Michael J.	Harvey	Tennessee Tech University
Roger M.	Hawk	University of Arkansas at Little Rock
Marsha	Hendricks	Harding University
Kristine	Herbert	Westpark Community College
Larry R.	Hilburn	Black River Technical College
Jim	Huey	University of Arkansas at Monticello
Philip E.	Hyatt	USDA, Forest Service
M. D.	Jalaluddin	University of Arkansas at Pine Bluff
David	Jamieson	Arkansas State University-Beebe/Newport
James E.	Johnson	University of Arkansas at Fayetteville
Michael I.	Johnson	Nettleton High School
Hugh	Johnson	Southern Arkansas University
Thurman O.	Jordan	Arkansas Audubon Society
Jay	Justice	Arkansas Dept. Pollution Control & Ecology
Mark	Karnes	The Ross Foundation
Philip L.	Kehler	University of Arkansas at Little Rock
Scott W.	Kirkconnell	Arkansas Tech University
Maurice G.	Kleve	University of Arkansas at Little Rock
Richard	Kluender	University of Arkansas at Monticello
Roger E., II	Koeppe	University of Arkansas at Fayetteville
Randall A.	Kopper	Hendrix College
Timothy	Kral	University of Arkansas at Fayetteville
Norman	Lavers	Arkansas State University
Stephen A.	Leslie	University of Arkansas at Little Rock
Hal O.	Liechty	University of Arkansas at Monticello
Brian	Lockhart	University of Arkansas at Monticello
Dan	Magoulick	University of Central Arkansas
Daniel L.	Marsh	Henderson State University
John E.	Marshall	Biotechnical Services Inc.
Robert	Maruca	Arkansas Tech University
H. Michael	Mathews	Henderson State University

FIRST MI	LAST NAME	INSTITUTION
Russell B.	McAllister	Arkansas Dept. Pollution Control & Ecology
V. Rick	McDaniel	Arkansas State University
Richard	Meyer	University of Arkansas at Fayetteville
Muhammad A.	Miah	University of Arkansas at Pine Bluff
Cristin	Milam	Arkansas State University
Lawrence A.	Mink	Arkansas State University
Paul	Mixon	Arkansas State University
Warren	Montague	U.S. Forest Service
Cindy	Moore	Westark Community College
Matthew	Moran	Hendrix College
Leland F.	Morgans	University of Arkansas at Little Rock
Tom	Nelson	Eastern Illinois University
Ronald E.	Nelson	Arkansas Tech University
Russell	Nordeen	University of Arkansas at Monticello
Thomas	Nupp	Arkansas Tech University
Joseph O.	Owasoyo	University of Arkansas at Pine Bluff
Don R.	Owens	University of Arkansas at Little Rock
Michael J.	Panigot	Arkansas State University
Mark A.	Paulissen	McNeese State University
Michael V.	Plummer	Harding University
William R., II	Posey	Department Pollution Control & Ecology
Donna G.	Quimby	University of Arkansas at Little Rock
James A.	Rasmussen	Southern Arkansas University
Darryl K.	Reach	University of Arkansas at Little Rock
Scott W.	Reeve	Arkansas State University
Dennis J.	Richardson	Quinnipiac College
Jeff W.	Robertson	Arkansas Tech University
Joe	Rosen	University of Central Arkansas
Karen	Rowe	Arkansas Game & Fish Commission
Steven W.	Runge	University of Central Arkansas
Charles J.	Scifres	University of Arkansas at Fayetteville
Frank L.	Setliff	University of Arkansas at Little Rock
Larry	Seward	John Brown University
Elwood B.	Shade	University of Arkansas at Monticello
Ali U.	Shaikh	University of Arkansas at Little Rock
William M.	Shepherd	Arkansas Natural Heritage Commission
Robert A.	Sims	University of Arkansas at Little Rock
Robert	Skinner	University of Arkansas for Medical Sciences
Kimberly G.	Smith	University of Arkansas at Fayetteville
Richard D.	Smith	Pulaski Tech College
Roy J.	Smith, Jr.	U.S.D.A./University of Arkansas
Thomas	Soerens	University of Arkansas at Fayetteville
Frederick W.	Speigel	University of Arkansas at Fayetteville
Richard W.	Standage	U.S. Forest Service
Joseph N.	Stoeckel	Arkansas Tech University
Eric	Sundell	University of Arkansas at Monticello
Phil	Tappe	University of Arkansas at Monticello
William R.	Teague	University of Arkansas at Fayetteville
Wayne E.	Throgmartin	Southern Illinois University
D. S.	Tomer	University of Central Arkansas
Staria	Vanderpool	Arkansas State University
Brian	Wagner	Arkansas Game & Fish Commission
Richard B.	Walker	University of Arkansas at Pine Bluff
Stephen A.	Walker	
Gerald	Walsh	
Robert L.	Watson	University of Arkansas at Little Rock
James O.	Wear	V.A. Medical Center
Jerry	Webb	University of Arkansas at Monticello
Rayona	Webster	Cossatot Technical College
Robert	Weih	University of Arkansas at Monticello
Delores	Wennerstrom	Pulaski Academy
David	Wennerstrom	University of Arkansas for Medical Sciences
Todd	Wiebers	Henderson State University
J. D.	Wilhide	Arkansas State University
Edmond W.	Wilson, Jr.	Harding University
Donald C.	Wold	University of Arkansas at Little Rock
Heather L.	Woolverton	University of Central Arkansas
Andrew	Wright	University of Arkansas at Little Rock
Tsunemi	Yamashita	Arkansas Tech University
J. Lyndal	York	University of Arkansas for Medical Sciences

SUSTAINING MEMBERS

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

Secretary's Report

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

SPONSORING MEMBERS

FIRST MI	LAST NAME	INSTITUTION
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

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

STUDENT MEMBERS

FIRST MI	LAST NAME	INSTITUTION
Jennifer	Abbott	Henderson State University
James R.	Anderson	Henderson State University
Brady	Baker	Arkansas State University
Jeremy W.	Bowers	Arkansas State University
Mohanjeet Singh	Brar	University of Arkansas at Fayetteville
Jeff	Briggler	University of Arkansas at Fayetteville
Daniel	Bullock	Arkansas Tech University
Melissa	Camp	Henderson State University

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

PROGRAM
Arkansas Academy of Science
84th Annual Meeting
April 7-8, 2000
Hot Springs, Arkansas

SCHEDULE OF EVENTS

Friday, April 7, 2000

9:00 am. - 4:00 p.m.	Registration	Lobby
8:30 a.m. - 10:00 a.m.	Executive Committee Meeting	Board Room
10:30 a.m. - 11:30 a.m.	First Business Meeting	Board Room
11:30 a.m. - 12:45 p.m	Lunch (See dining info)	

1:00 p.m. - 1:45 p.m.   Welcome and Introductions   Board Room
David Saugey, Co-Chair, Local Committee, USFS
Mostafa Hemmati, President, AAS, Ark. Tech Univ.
Dave Hammond, Deputy Forest Supervisor, USFS
Dr. Vickie Logan, Prinicipal, ASMS
Mr. Paul Griep, Public Affairs/Recruiting, ASMS
Betty Crump, Co-Chair, Local Committee, USFS

2:00 p.m. - 5:00 p.m.   Paper Sessions
	Vertebrate Zoo I	Room 2307
	Invertebrate Zoo	Room 2308/09
	Biomedical, Biochemistry Microbiology, Immunology	Room 2301
	Chemistry I	Room 2401
	Physics I	Room 2402

2:00 p.m. - 5:00 p.m.	Poster Session	Room 2303
3:00 p.m. - 4:00p.m.	Break - Refreshments	Third Floor
5:30 p.m. - 7:00 p.m.	Hospitality Gathering Downtowner Hotel - Crown Room	Second Floor

Saturday, 8 April 2000

8:00 a.m. - 10:00 am.	Registration	Lobby

9:00 a.m. - 11:45 am.   Paper Sessions
	Vertebrate Zoo II	Room 2307
	Botany/Environmental	Room 2308/09
	Chemistry II	Room 2401
	Physics II	Room 2402

9:00 a.m. - 11:00 am.	Poster Session	Room 2303
10:00 a.m. - 10:30 a.m.	Break - Refreshments	Third Floor
12:00 noon	Second Business Meeting	Board Room
Slide Preview Room	Board Room - after 2:00 p.m. Friday	
Sigma XI Breakfast	Jernigan's Restaurant inside the Downtowner Hotel 7:00 a.m. Saturday	

Parking Info   Parking is not available at the Math and Science School. Parking is available in the First Presbyterian Church parking lot directly across the street. Registered Guests of the Downtowner Hotel have ample parking directly behind the Hotel. Parking is available along Central Avenue (meter and fee lot) and Whittingham Avenue in front of the Math and Science School.

Dining Information   Central Avenue (Hwy. 7) is the main thoroughfare in Hot Springs. Travel south from the Downtowner Hotel to find everything from McDonalds to Red Lobster. Jernigan's Restaurant is located inside the Downtowner and a variety of other eating establishments are a short walk from the Hotel and Math and Science School.

SECTION PROGRAMS
* Undergraduate   **Graduate

POSTER SESSION

Friday, April 7, 2000
Location: Room 2303, Third Floor

Time   Topic

Sam Cron and Gary L. Emmert. Program of Environmental Science and Department of Chemistry, Arkansas State University. **COMPARING STANDARD AND NEW REAGENTS FOR MEASURING OZONE CONCEN-TRATIONS IN DRINKING WATER**

Andy Thornton and William Burns, Arkansas State University. **COMPUTATIONAL CHEMISTRY: USING GAUSSIAN 98W**

Malcolm L. McCallum and Stanley E. Trauth, Arkansas State University. **THE ARKANSAS AMPHIBIAN MONITOR-ING PROGRAM (AAMP) IN ARKANSAS: A PROJECT IN ITS INFANCY AND IN NEED OF VOLUNTEERS**

Dru S. Dace and Thomas M. Walker, University of Central Arkansas. **A NOVEL MOUSE MODEL FOR MEASUR-ING MACROPHAGE CYTOTOXIC ACTIVITY DURING PACLITAXEL-BASED CHEMOTHERAPY**

Richard D. Smith and Richard C. Kurten, University of Arkansas for Medical Sciences. **CO-LOCALIZATION OF SORTING NEXIN-1 WITH RAB5 USING IMMUNO-FLUORESCENCE MICROSCOPY**

David Annis, Jr. and Terry Keisling, University of Arkansas Northeast Research Extension Center. **USING DIGITAL INFORMATION TECHNOLOGIES TO PROVIDE ENVIRONTHON EDUCATIONAL MATERIALS TO CONTESTANTS**

PAPER SESSION

Friday, April 7, 2000
CHEMISTRY I
Location: Room 2401, Fourth Floor

Chairperson: Walter E. Godwin, Univeristy of Arkansas at Monticello

Time	Topic
2:00*	Martha Baskett, Rose McConnell, and Walter Godwin, University of Arkansas at Monticello. **PYRROLE-FURAN CO-POLYMERS: A MOLECULAR MODELING STUDY**
2:15*	Amy Morara, Rose McConnell, and Walter Godwin, University of Arkansas at Monticello. **THIOPHENE-FURAN CO-POLYMERS: A MOLECULAR MODELING STUDY**
2:30*	Jestin Thomas and Victor Blunt, University of Arkansas at Pine Bluff. **SNYTHESIS AND CHARACTERIZATION OF NICKEL (II) AND IRON (III) 1,3 ADAMANTANEDICARBOXYLATE**
2:45*	Amber Sawyer and Edmond Wilson, Jr., Harding University. **KINETIC RATE CONSTANTS AND TEMPERATURE DEPENDENCIES FOR THE REACTIONS OF CYCLOPROPANE AND CHF_2OCHF_2(HFOC-134) WITH HYDROXYL RADICALS**
3:00	Break - Refreshments - Third Floor Lobby
4:00*	Shang-U Kim, Jessica Middleton, David Bailey, Amy Bailey, and Michael J. Panigot, Arkansas State University. **SYNTHESIS OF AN ETHYNYL-C-GLYCOSIDE AND ATTEMPTED COUPLING TO POLYHALOGENATED ARENES TO FORM C-GLYCOSIDE DENDRIMERS**
4:15*	William Tyler, Victor Blunt, Vincent Litman, Aslam Chowdhury, Shaheen Khan, and William Willingham, University of Arkansas at Pine Bluff. **DETERMINATION OF POTASSIUM CHLORATE AND LACTOSE IN SMOKE MUNITIONS**
4:30	Rodney Rowland, Robert E. Maruca, and Justin Charton, Arkansas Tech University. **ORGANIC SYNTHESIS OF A HEXADENTANE COMPLEXING COMPOUND**

PHYSICS I
Location: Room 2402, Fourth Floor

Chairperson: Mostafa Hemmati, Arkansas Tech University

2:00*	Mostafa Hemmati and Rory Andrew Roberts, Arkansas Tech University. **WAVE PROFILE FOR ANTIFORCE CLASS II WAVES**

2:15*	MikeBuck, R. Engelken, C. Chastain, and J. Meyer, Arkansas State University. **UNCONVENTIONAL MEDIA OR EXTREME CONDITIONS FOR ELECTROPLATING DIFFICULT-TO-PLATE METALS**
2:30*	D. W. Bullock, Z. Ding, C. Emery, M. Filipkowski, V. P. LaBella, M. Mortazavi, G. Salamo, and P. M. Thibado, University of Arkansas at Fayetteville and University of Arkansas at Pine Bluff. **ELECTRON SPIN SCATTERING ACROSS A P-TYPE GAAS (110) STEP USING A FERROMAGNETIC-METAL STM TIP**
2:45*	Chad Chastain, R. Engelken, M. Buck, and J. Meyer, Arkansas State University. **TUNGSTEN, MOLYBDENUM, AND OTHER OXIDE FILMS BY SPRAY PYROLYSIS AND OTHER LIQUID SOLUTION METHODS**
3:00	Break - Refreshments - Third Floor Lobby

PHYSICS I
Location: Room 2402, Fourth Floor

Chairperson: Will Braithwaite, University of Arkansas at Little Rock

4:00*	Christine A. Byrd, Jeff L. Shaw, Dawn M. Wolford, W. J. Braithwaite, and Edwin S. Braithwaite, University of Arkansas at Little Rock, and Cedarville College, Cedarville, Ohio. **TESTING ACCEPTANCE/EFFICIENCY OF STAR'S MAIN TPC WITH REALISTIC DATA**
4:15*	Justin Meyer, R. Engelken, M. Buck, and C. Chastain, Arkansas State University. **ENHANCEMENT OF METAL SULFIDE FILMS CHEMICALLY DEPOSITED FROM THIOLACETIC ACID BATHS THROUGH SUBSTRATE PROCESSING**
4:30**	Steve Nicoletti and Al Adams, University of Arkansas at Little Rock. **OPTICAL TRANSMITTANCE OF RICE LEAVES**

VERTEBRATE ZOOLOGY I
Location: Room 2307, Third Floor

Chairperson: David Jamieson, Arkansas State University at Newport

Time	Topic
2:00**	Mitch Wine, Steve Blumenshine, and George Harp, Arkansas State University. **CURRENT POPULATION DENSITY OF THE YELLOWCHEEK DARTER**
2:15*	Daniel Brown and Steven Beaupre, Hendrix College, and University of Arkansas at Fayetteville. **MAPPING KERNEL HOME RANGE ESTIMATES OF THE TIMBER RATTLESNAKE**
2:30	Tommy Finley, Renn Tumlison, and John Hardee, Henderson State University. **PRELIMINARY STUDY OF THE INCIDENCE OF LEAD IN MOURNING DOVES IN ARKANSAS**
2:45**	Stanley E. Trauth and Malcolm L. McCallum, Arkansas State University. **CURLY-TAIL MALFORMITY IN HATCHLINGS OF THE ALLIGATOR SNAPPING TURTLE, *MACROCLEMYS TEMMINICKII* (TESTUDINES: CHELYDRIDAE), FROM NORTHEASTERN ARKANSAS**
3:00	Break - Refreshments - Third Floor Lobby

VERTEBRATE ZOOLOGY I
Location: Room 2307, Third Floor

Chairperson: Allen Carter, Arkansas Game and Fish Commission

Time	Topic
4:00	Stanley E. Trauth, Arkansas State University. **WINTER BREEDING AS A COMMON OCCURRENCE IN THE RINGED SALAMANDER,** *AMBYSTOMA ANNULATUM* **(CAUDATA: AMBYSTOMATIDAE), IN THE OZARK NATIONAL FOREST OF NORTHCENTRAL ARKANSAS**
4:15	Thomas M. Buchanan, Jerry Smith, Diana Saul, Jeff Harwick, Tim Burnley, Mark Oliver, and Ken Shirley, Westark College, and Fisheries Division, Arkansas Game and Fish Commission. **NEW ARKANSAS RECORDS FOR TWO NONINDIENOUS FISH SPECIES, WITH A SUMMARY OF PREVIOUS RECORDS OF NONNATIVE FISHES FROM ARKANSAS**
4:30	Leo Carson Davis, John Scoggins, and J. Alan Holman, Southern Arkansas University, Fouke High School, and Michigan State University. **LARGE PLEISTOCENE BOX TURTLE FROM SOUTHWEST ARKANSAS**
4:45	Betty G. Crump and Henry W. Robison, U.S. Forest Service, and Southern Arkansas University. **A RECORD OF THE LAKE STURGEON,** *ACIPENSER FULVESCENS* **RAFINESQUE, FROM THE CADDO RIVER (OUACHITA RIVER DRAINAGE), ARKANSAS**

INVERTEBRATE ZOOLOGY
Location: Room 2309/2309, Third Floor

Chairperson: John Harris, Arkansas Highway and Transportation Department

Time	Topic
2:00**	Camille Flinders and Dan Magoulick, University of Central Arkansas. **SCALE DEPENDENT SPECIES ASSOCIATION OF LOTIC SYSTEM CRAYFISH IN THE SALEM PLATEAU REGION OF NORTHERN ARKANSAS AND SOUTHERN MISSOURI**
2:15	Henry W. Robison and John R. Holsinger, Southern Arkansas University, and Old Dominion University, Norfolk, Virginia. **FIRST RECORD OF THE SUBTERRANEAN AMPHIPOD CRUSTACEAN,** *ALLOCRANGONYX HUBRICHTI* **(ALLOCRANGONYCTIDAE), IN ARKANSAS**
2:30	Jim Edson, University of Arkansas at Monticello. **MONARCH BUTTERFLIES IN ARKANSAS**
2:45*	Karen Arbuckle, Southern Arkansas University. **HYPOTHETICAL ORIGINS OF PALEOZOIC FOSSILS FROM THE GULF COASTAL PLAIN**
3:00	Break - Refreshments - Third Floor Lobby

INVERTEBRATE ZOOLOGY
Location: Room 2309/2309, Third Floor

Chairperson: George Harp, Arkansas State University

Time	Topic
4:00	George L. Harp and Phoebe A. Harp, Arkansas State University. **OCCURRENCE OF** *OPHIOGOMPHUS WESTFALLI* **(GOMPHIDAE: ODONATA) IN MISSOURI**

Time	Topic
4:15	Alan D. Christian, Chris L. Davidson, William R. Posey, Peter J. Rust, Jerry L. Farris, John L. Harris, and George L. Harp, Arkansas State University. **GROWTH CURVES OF FOUR SPECIES OF COMMERCIALLY VALUABLE FRESHWATER MUSSELS (BIVALVIA: UNIONIDAE) IN ARKANSAS**

BIOMEDICAL
Location: Room 2301, Third Floor

Chairperson: Anne Grippo, Arkansas State University

Time	Topic
2:00**	W. D. Bryant, W. Humphrey, and A. Grippo, Arkansas State University. **THE EFFECTS OF ESTROGENIC AGENTS ON RAM SPERM ACROSOME REACTION**
2:15**	D. DeLynn Holleman and Steven W. Runge, University of Central Arkansas. **A COMPARISON OF APOTOTIC INDUCTION IN THE GUT OF** *APLYSIA CALIFORNICA* **AND THE SPRAGUE-DAWLEY RAT**
2:30*	David Gilmore, Barbara Murphy, April Stewart, Amanda Smith, and Holly Harrell, Arkansas State University. **CONVERSION OF GRAY WATER TO BACTERIAL PLASTIC**
2:45**	R. L. Jordan and W. L. Gray, University of Arkansas for Medical Sciences. **CHANNEL CATFISH HERPESVIRUS GENE EXPRESSION IN INFECTED FISH**
3:00	Break - Refreshments - Third Floor Lobby

BIOMEDICAL
Location: Room 2301, Third Floor

Chairperson: David Gilmore, Arkansas State University

Time	Topic
4:00	H. B. Starnes, M. W. White, R. Mahalingam, and W. L. Gray, University of Arkansas for Medical Sciences. **THE COMPLETE SEQUENCE OF THE SIMIAN VARICELLA VIRUS GENOME AND COMPARATIVE ANALYSIS WITH THE VARICELLA ZOSTER VIRUS**
4:15	Lisa Mullis and Wayne L. Gray, University of Arkansas for Medical Sciences. **CHARACTERIZATION OF THE SIMIAN VARICELLA VIRUS GLYCOPROTEIN E**

PAPER SESSION

Saturday, April 8, 2000
CHEMISTRY II
Location: Room 2401, Fourth Floor

Chairperson: Frank Setliff, Univeristy of Arkansas at Little Rock

Time	Topic
9:00*	Melissa Arnold, David Bailey, and Michael J. Panigot, Arkansas State University. **SELECTIVE FUNCTIONALIZATION OF THE 6-HYDROXYL GROUP OF METHYL ALPHA-D-GLUCOPYRANOSIDE: APPLICATION TO THE PREPARATION OF C-GLYCOSIDE BASED DENDRIMERS**
9:15*	Amy Bailey and Michael J. Panigot, Arkansas State University. **PREPARATION OF A GALACTOSE-**

DERIVED LACTONE AND CONVERSION TO AN ALKYNL C-GALACTOSIDE FOR USE IN THE PREPARATION OF C-GLYCOSIDE CONTAINING DENDRIMERS

9:30** Layla Bland and Michael J. Panigot, Arkansas State University. **REACTION OF ALPINE-BORANE WITH ALDEHYDES: REACTIVITY RATE ASSESSMENT BY OBSERVATION OF THE DISAPPEARANCE OF THE CARBONYL n - π PEAK BY UV - VISIBLE SPECTROMETRY**

9:45* Jason Boggs, Mariah McMasters, and Michael J. Panigot, Arkansas State University. **PREPARATION OF AN ELECTROPHILIC 3-METHYLINDOLE DERIVATIVE: DIFFICULTIES IN FORMING A STABLE, SUITABLE MATERIAL FOR THE PREPARATION OF TRYPTOPHAN**

10:00 Break - Refreshments - Third Floor Lobby

CHEMISTRY II
Location: Room 2401, Fourth Floor

Chairperson: Michael J. Panigot, Arkansas State University

Time	Topic
10:30	Frank L. Setliff and Tyson K. Spradlin, University of Arkansas at Little Rock. **HAMMETT CORRELATIONS OF THE SULFONAMIDE PROTON CHEMICAL SHIFT IN A SERIES OF N-(SUBSTITUTED ARYL)-p-TOLUENESULFONAMIDES**
10:45*	Frank L. Setliff and Melody K. Harrison, University of Arkansas at Little Rock. **HAMMETT CORRELATIONS OF THE AMIDE PROTON CHEMICAL SHIFTS IN A SERIES OF 1-TOSYL-3-(4-SUBSTITUTED PHENYL) UREAS**
11:00	Robert E. Maruca, Rodney Rowland, and Justin Charton, Arkansas Tech University. **SYNTHESIS OF SOLID MATRIX BOUND METAL ION COMPLEXING AGENTS**
11:15	Alan Ford, Pam Ramage, and Scott Reeve, Arkansas State University. **INFRARED DIODE LASER SPECTROSCOPY OF JET COOLED IRON PENTACARBONYL**

PHYSICS II
Location: Room 2402, Fourth Floor

Chairperson: Mostafa Hemmati, Arkansas Tech University

Time	Topic
9:00*	Ann Wright, Larry Dunn, Brian Alford, and Justin Patton, Hendrix College. **A STUDY OF THE AMPLITUDE OF PRESSURE AND THRUST OSCILLATIONS IN A LAB-SCALE HYBRID ROCKET**
9:15	Christine A. Byrd, Jeff L. Shaw, M. Wolford, W. J. Braithwaite, and Edwin S. Braithwaite, University of Arkansas at Little Rock, and Cedarville College, Cedarville, Ohio. **USING REALISTIC DATA FOR ISOTROPIC MESON DECAYS IN STAR'S MAIN TPC**
9:30	Tim Schroeder and Jon Carnahan, Southern Arkansas University, and Northern Illinois University, DeKalb, Illinois. **LASER EXCITATION ATOMIC FLUORESCENCE SPECTROSCOPY IN A HELIUM MIP**

9:45 Andrew Wright, University of Arkansas at Little Rock. **MECHATRONIC DESIGN OF A TREADED MOBILE ROBOT FOR MINE SWEEPING**

10:00 Break - Refreshments - Third Floor Lobby

VERTEBRATE ZOOLOGY II
Location: Room 2307, Third Floor

Chairperson: Henry W. Robison, Southern Arkansas University

Time	Topic
9:00	Gregory G. Humphreys and Thomas A. Nelson, Deltic Timber Company, El Dorado, Arkansas, and Eastern Illinois University, Charleston, Illinois. **MORTALITY OF ADULT WHITE-TAILED DEER ON FORT CHAFFEE, ARKANSAS**
9:15	John P. Hart and David H. Jamieson, USDA Wildlife Services, Grand Rapids, Minnesota, and Arkansas State University at Newport. **ESTIMATING THE WEIGHT OF EASTERN GRAY WOLVES (*CANIS LUPUS LYCAON*) FORM CHEST GIRTH MEASUREMENTS**
9:30	Hubert Hervey, Bird Study Group, LSUS Museum of Life Sciences, Louisiana. **LEAST TERN: SUCCESS OF NESTING COLONIES ON RED RIVER**
9:45	Renn Tumlison and Anthony Rocconi, Henderson State University. **OCCURRENCE OF A SECOND SUBSPECIES OF BOX TURTLE (*TERRAPENE CAROLINA*) IN ARKANSAS**

10:00 Break - Refreshments - Third Floor Lobby

VERTEBRATE ZOOLOGY II
Location: Room 2307, Third Floor

Chairperson: Phoebe Harp, Arkansas State University

Time	Topic
10:30*	Allyson R. Neely and Edmond J. Pert, University of Arkansas at Pine Bluff. **FEEDING RELATIONS BETWEEN TWO SYNTOPIC, MORPHOLOGICALLY SIMILAR FISHES, THE BLACKSPOTTED TOPMINNOW, *FUNDULUS OLIVACEUS* AND WESTERN MOSQUITOFISH, *GAMBUSIA AFFINIS***
10:45	David A. Saugey, J. D. Wilhide, and Betty G. Crump, U.S. Forest Service, Ouachita National Forest, and Arkansas State University. **OCCURENCE AND DISTRIBUTION OF THE SILVERHAIRED BAT, *LASIONYCTERIS NOCTIVAGANS*, IN ARKANSAS**
11:00	Stanley E. Trauth, Malcolm L. McCallum, and Michael E. Cartwright, Arkansas State University, and Wildlife Management Division, Arkansas Game and Fish Commission. **BREEDING MORTALITY IN THE WOOD FROG, *RANA SYLVATICA* (ANURA: RANIDAE), FROM NORTHCENTRAL ARKANSAS**
11:15	Gregory G. Humphreys and Thomas A. Nelson, Deltic Timber Corporation, El Dorado, Arkansas, and Eastern Illinois University, Charleston, Illinois. **HOME RANGE AND MOVEMENTS OF WHITE-TAILED DEER ON FORT CHAFFEE, ARKANSAS**

BOTANY and ENVIRONMENTAL SCIENCE
Location: Room 2308/2309, Third Floor

Chairperson: Gerald Walsh

Time	Topic
9:00**	Michael R. McCallum, Shauntee Moore, and Jon Russ, Arkansas State University. **HPLC ANALYSIS OF LICHEN ACIDS IN BIOGENIC ROCK CRUSTS**
9:15**	John W. Prather, Kimberly G. Smith, Cecilia Riley, and Mike Mlodinow, University of Arkansas at Fayetteville, and Gulf Coast Bird Observatory, Lake Jackson, Texas. **CHARACTERISTICS OF SOME FRUITING PLANT SPECIES IN NORTHWEST ARKANSAS, AND THE AVIAN ASSEMBLAGES THAT FEED ON THEM**
9:30	James H. Peck, University of Arkansas at Little Rock. **FLORISTIC STATUS OF LOG FERNS (*DRYOPTERIS*) IN ARKANSAS**
9:45	Ronald L. Johnson, Danny Ward, and Richard S. Grippo, Arkansas State University. **TEMPORAL VARIATION OF BIOTIC AND ABIOTIC FACTORS OF THE SOUTH FORK OF THE SPRING RIVER, ARKANSAS**
10:00	Break - Refreshments - Third Floor Lobby

BOTANY and ENVIRONMENTAL SCIENCE
Location: Room 2308/2309, Third Floor

Chairperson: Dan Marsh, Henderson State University

Time	Topic
10:30	Robert Brewington, Richard Williams, and Jeff Earl, Arkansas Agricultural Experiment Station, and University of Arkansas at Monticello. **TRAVEL COST MODEL FOR DETERMING PROCUREMENT ZONES USING GIS**
10:45	Jeff Earl, Richard Kluender, and Robert Brewington, Arkansas Agricultural Experiment Station, and University of Arkansas at Monticello. **A METHOD TO PREDICT THE REGIONAL LONG-TERM TIMBER SUPPLY USING GIS AND OTHER PUBLICLY AVAILABLE DATA**
11:00	Jeff Earl, Robert Brewington, and Richard Kluender, Arkansas Agricultural Experiment Station, and University of Arkansas at Monticello. **COMMODITY AND NON-COMMODITY VALUATION OF A SMALL ACREAGE NON-INDUSTRIAL LANDOWNER HOLDING**
11:15	William R. Teague, University of Arkansas Cooperative Extension Service, Little Rock. **LATITUDE, LONGITUDE AND THE PYTHAGOREAN THEOREM IN ARKANSAS**
11:30	Miah M. Adel, University of Arkansas at Pine Bluff. **IN QUEST OF GLOBAL WARMING SIGNATURES IN COASTAL CLIMATE DATA**

Hypothetical Origins of Paleozoic Fossils from the Gulf Coastal Plain of Arkansas

Karen Arbuckle
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Abstract

A fauna of reworked Paleozoic fossils has been found in chert pebbles from the Gulf Coastal Plain in eastern Columbia County, Arkansas, although the nearest mapped exposure of Mississippian and Pennsylvanian rocks are fifty-five miles northward in the southern edge of the Ouachita Mountains. The surficial rocks at the collection site have been referred to the Claiborne Group of Eocene age by the authors of the geological map of Arkansas. Additional outcrops containing similar Paleozoic fossils have been found within a 15-mile radius. The fauna includes both lacy and twig-like bryozoans, articulate brachiopods, tabulate and rugose corals, stalked echinoderms, gastropods, fusulinids and two trilobite pygidia (17 mm wide by 15 mm long and 16 mm wide by 5 mm long) of two distinct taxa. The fossils resemble those of a carbonate platform such as northern Arkansas but would have to be delivered southward before the Arkansas River drainage developed. The possibility of an origin from the south is being considered.

Introduction

The surficial rocks of Columbia County, Arkansas, have been referred to the Claiborne Group of Eocene Age by the geological map of Arkansas; but recently, a fauna of silicified, reworked, Paleozoic fossils has been discovered in the eastern part of the county. Searching the exposed gravels of the area has resulted in the recovery of Paleozoic species fossilized among cherts, quartz, and some exotic lithologies that have yet to be identified. The general lithology of the fossiliferous rocks is of shallow water limestone silicified into chert. The purposes of this investigation are to establish the paleoenvironmental implications of the fossils and their age and to explain their hypothetical origins.

Materials and Methods

Specimens were collected from the site (an exposed gravel bed, see Fig. 1 for a map of the sites) and then examined with stereo-microscopes. Pictures were taken of the more photogenic specimens and were sent to various paleobiology experts selected from those with recent publications of relevant taxa in the *Journal of Paleontology*. The experts' specialties include trilobites, bryozoans, brachiopods and blastoids.

Latex peels of the trilobite pygidia and a few bryozoans were also enclosed with the photographs. Eight sets of photographs/peels were dispatched in the initial mailing and half of the experts responded. Two other individuals were contacted later for additional information and to have the fusulinids identified. The *Treatise on Invertebrate Paleontology* (Moore, 1953) was consulted for confirming identifications and for paleoenvironmental information.

Results and Discussion

Bryozoans are the most numerous group among the fossils recovered to date. Some of the bryozoan specimens are now referred to the Family Rahbdomesidae by their characteristic elongate, tubular zooids that are typically curved or bent to the surface and their generally solid stems that may be branched or unbranched. Species from this family appear in the Silurian and disappear in the Permian. Other specimens were identified as belonging to the Family Fenestellidae by the way the zoaria form fan-shaped fronds in which the fenestrules (open spaces) are of circular, elliptical, or quadrangular form that extends through the zoarium. Fenestellid bryozoans appear in the geologic record from the Ordovician to the Permian (Moore, 1953). Petrographic thin sections may be helpful in further identification of these specimens since important taxonomic information is at the scale of the individual zooid.

However, colony formation can be a paleoenvironmental indicator. The Rahbdomesid forms recovered grow away from the sea floor as brittle bushes made of round stems. Fenestillid forms grow as bushes of flattened branches. When these delicate forms are preserved in their entirety, as observed in specimens from the collection, it is believed that they grew in a quiet environment (McKinney and McKinney, 1996). The abundance of fenestrate fronds indicates that they were probably the most important aspect of the multitiered, epifaunal, suspension-feeding community. One specimen of *Archimedes*, a fenestellid with lacy fronds attached to a spiral axis, has recently been discovered (6/10/00), which leads us to believe that part of the fauna may represent the Mississippian Period. That genus is abundant in rocks of this period in northern Arkansas.
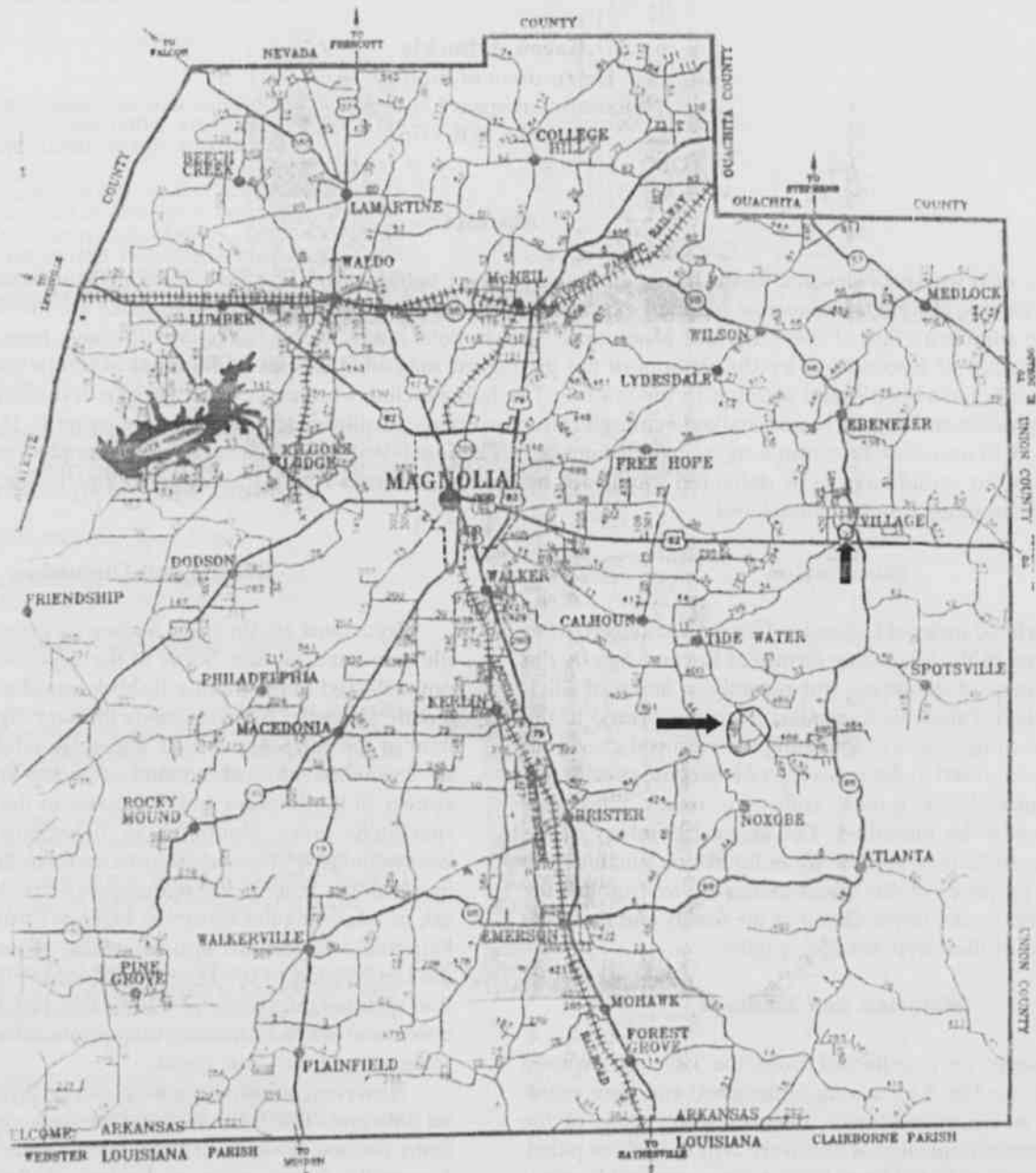
Fig. 1. A map of the eastern Columbia County site area. The two main collection sites are indicated by the arrows.

Among the more interesting finds are two trilobite pygidia of different taxa. The first pygidium found (specimen no. 7) isn't well preserved but does resemble forms that would occur in the Carboniferous (D. K. Brezinski, pers. comm.). However, James D. Loch has suggested that it may be consistent with the Family Bathyuridae (Lower to Upper Ordovician). The characteristics that specimen no. 7 exhibits include a strong axis, convex pleural fields (the

slopes beside the axis) and a poorly defined border (J. D. Loch, pers. comm.). The second pygidium (specimen no. 41) has two possible identifications. It may belong to the Family Trinucleidae and may even be of the genus *Cryptolithus* or *Trinucleus* (Brezinski, pers. comm.; Loch, pers. comm.). If truly a member of either of those genera, then the specimen is most likely Middle to Upper Ordovician in age since all close relatives of *Cryptolithus* occurred during this

time. Alternatively, specimen no. 41 may belong to the Family Raphiophoridae (including the genera *Ampyx, Ampyxina, Cnemidopyge,* and *Lonchodomas*) which is also Middle to Upper Ordovician in age. Both families exhibit a short, broad tail which looks triangular in outline with a low axis (central ridge) which reaches the posterior edge (Loch, pers. comm.). This identification raises the possibility of a mixed fauna as many of the other taxa seem to represent an Upper Carboniferous age.

Specimens from several groups of brachiopoda have also been identified. The specimens resemble those seen in the mid-continent Carboniferous (Paul Cooper, pers. comm.). No typical Ordovician brachiopods were identified from the photographs sent to paleobiologists. Taxonomy and identifiable characteristics include the following:

1) Order Terebratulida - Specimen 15 and 16 agree with the following terebratulid characteristics as given by the *Treatise on Invertebrate Paleontology* (Moore, 1964): 1) a punctate nature 2) the common teardrop shape 3) usually smooth surface which may be finely to coarsely plicate with folds and sulci. (Late Devonian - Recent)

2) Order Rhynchonellida - Specimen numbers 3, 20, 36, 38, and 39 agree with the following rhynchonellid characteristics as given by the *Treatise on Invertebrate Paleontology* (Moore, 1964): 1) rostrate shell 2) developed functional pedicle 3) normally impunctate shell. (Middle Ordovician - Recent)

3) Order Orthida - Specimen no. 5 agrees with the following orthid characteristics as given by the *Treatise on Invertebrate Paleontology* (Moore, 1964): 1) biconvex strophic shell 2) shell substance normally impunctate 3) well developed hinge line. (Late Cambrian - Upper Permian)

4) Order Productidina - Specimen no. 17 agrees with the following productid characteristics as given by the *Treatise on Invertebrate Paleontology* (Moore, 1964): 1) pseudopunctate shell 2) flat or concave brachial valve. (Late Devonian - Upper Permian)

5) Order Spiriferida - Specimen no. 14 agrees with the following spirifid characteristics as given by the *Treatise on Invertebrate Paleontology* (Moore, 1964): 1) long hinge line 2) mostly biconvex valves with relatively large body cavity. (Middle Ordovician - Jurassic)

The collection also contains specimens of rugose and tabulate corals, stalked echinoderms (including both crinoids and blastoids), gastropods, and planispiral fusulinids. These specimens remain to be identified to lower taxonomic levels but are consistent with a Pennsylvanian age for the fauna. Identification of the fusulinids may be the crucial factor for determining the source area of the fauna since their wide geographic range, large numbers, and narrow stratigraphic interval make them an excellent index fossil (Moore, 1964).

It has been called to our attention that deposits contain-

ing fusulinids are found among terrace deposits along the Arkansas River but these large forams are not seen in north Arkansas rocks (McFarland, pers. comm.). These fusunlinids are thought to be of early Permian Period and may have originated in Oklahoma. Further identification of the fusulinid species and their age from the eastern Columbia County sites will be pursued to confirm this hypothesis.

There are three hypothesized source areas for the gravels: northern Arkansas, Oklahoma or other areas west of the Ozark Dome, or Gondwana.

***I. Northern Arkansas as Source.*--**The fossils resemble those of a carbonate platform (multitiered, epifaunal, suspensionfeeding, reef community with deposit feeders) such as in northern Arkansas during the Mississippian and Early Pennsylvanian Periods. If the assemblage did originate in northern Arkansas, then it would have had to be transported southward before the Arkansas River drainage developed or the specimens would have been transported eastward, away from Columbia County (Fig. 2). A three-step process is hypothesized to explain such an event:

1) The shallow-water reef fauna of northern Arkansas was fossilized, erosion took place, and the fauna was trans-
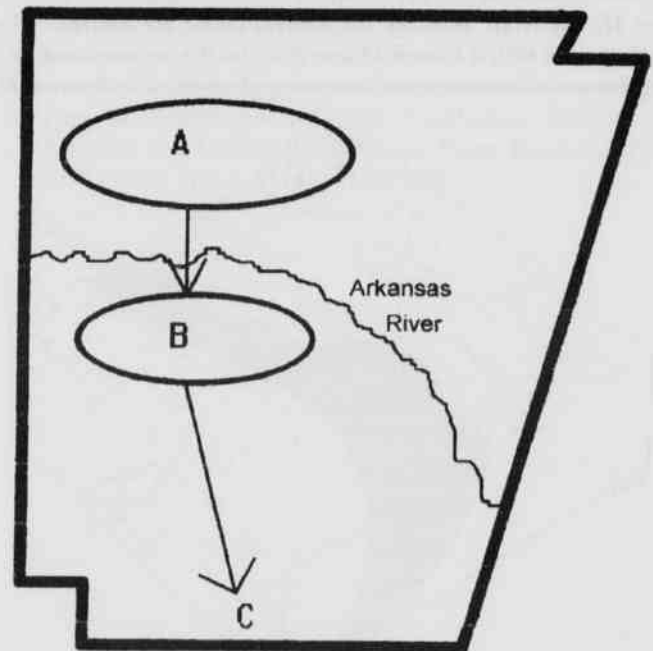
Fig. 2. Northern Arkansas as a source (diagram by Karen Abruckle and Leo Carson Davis).

ported south to the Ouachita Trough before the Middle Pennsylvanian, when the trough would have been closed as a result of the collision of Laurasia and Llanoria (Guccione, 1999). It is possible that a reworked Ordovician fauna was

eroded and deposited along with the Pennsylvanian. In theory, both could have been exposed, eroded and transported simultaneously which would account for the Ordovician trilobites that were recovered among Pennsylvanian specimens.

2) During the Middle to Late Pennsylvanian Period, the uplift of the Ouachitas exposed the fauna, along with deep ocean basin sandstone and chert that had been accumulating during the Paleozoic

3) The fossils could have been transported south to the Columbia County area by rivers during the Triassic Period. During the Triassic sand and gravel from the high Ouachita Mountains was eroded, transported south and filled the troughs formed as South America split apart from North America, and blocks were down faulted as a result (see Fig. 3). Another possibility is that the fauna was transported by turbidity currents during wide-spread inundation of the Jurassic to Early Tertiary (Fig. 4). With the Ouachita Mountains above sea level, sand and gravel was eroded and deposited in streams, beaches, and deltas. This would have positioned the material so that a turbidity current could transport it southward to the Columbia County area where it would have been buried by younger material until the recent erosion of the area exposed it once again.

II. An Area West of the Ozark Dome as Source.–The region west of the Ozark Dome may be the source area and

Fig. 4. Paleogeography of Arkansas during the Cretaceous Period (block diagram from *Geologic History of Arkansas Through Time and Space*, Guccione, 1993).

River) may have been progressively beheaded (Fig. 5), first by the Red River and later by the Arkansas River and then the Missouri River. The Red River would then be the agent that transported sediments eastward and deposited the assemblage in the Columbia County area.

III. Gondwana as Source.--A southern origin from a Gondwana-Llanoria landmass is also being considered (Fig.

Fig. 3. Triassic rifting of Pangaea in Arkansas (block diagram from *Geologic History of Arkansas Through Time and Space*, Guccione, 1993).
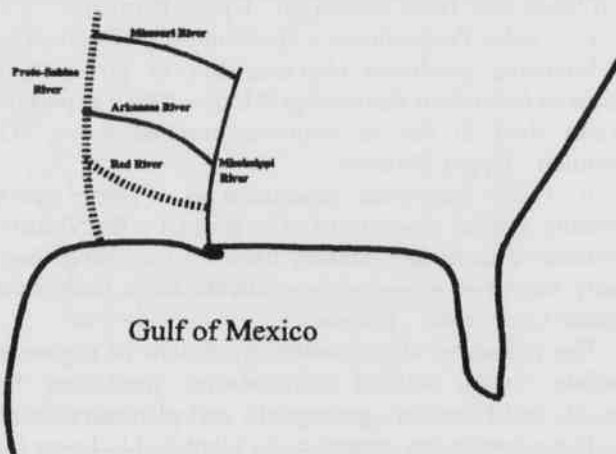
Fig. 5. A diagram depicting a hypothetical western drainage system (diagram by Karen Arubuckle and Leo Carson Davis).

eastward flowing rivers transported the fauna to southern Arkansas. A river flowing to the south on the west side of the Ozark Dome (hypothetically referred to as the proto-Sabine

6). The collision of the Llanorian and Laurasian plates provided significant quantities of sediment from the southeast

and south to the Ouachita Trough during the Late Mississippian to the Middle Pennsylvanian time (Gordon and Stone, 1977). Fossils with a Gondwana origin could have been transported into the trough at the same time. Uplift and erosion of the Ouachita Mountains could have exposed the material and allowed it to be transported south to Columbia County by the processes previously described in stage 3 for a "northern origin".

An eastern origin has also been considered but is regarded as being less likely. In order for the fauna to be

Fig. 6. Middle Pennsylvanian paleogeography of Arkansas (block diagram from *Geologic History of Arkansas Through Time and Space*, Guccione, 1993).

deposited in the Ouachita Trough, it must have been fossilized and transported before the Ouachita Trough closed in the Middle Pennsylvanian. Since some of the fossils are referred to the Pennsylvanian Period, it seems unlikely that this process could have taken place in such a short time.

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Reaction of Alpine-Borane with Aldehydes: Reactivity Rate Assessment by Observation of the Disappearance of the Carbonyl n - π* Peak by UV-Visible Spectroscopy

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Abstract

Due to an unexpectedly difficult reduction of indole-3-carbaldehyde and of isobutyraldehyde using the chiral reducing agent Alpine-Borane, the reactivity of several aliphatic, aromatic, and unsaturated aldehydes was investigated. This was done in order to determine whether there was a relationship between aldehyde structure and reduction rate. It was found that aliphatic aldehydes and aromatic aldehydes with no strongly electron-donating groups on the arene ring reduced faster than unsaturated aldehydes.

Introduction

As part of an ongoing project to synthesize chiral beta-deuterated amino acids, the asymmetric reduction of deuterated indole-3-carbaldehyde or an N-protected derivative thereof needed to be pursued. This proved unexpectedly difficult, yielding unchanged starting material after prolonged periods. Therefore, an investigation of the reactivity of aldehydes containing various alkyl and aryl structures with Alpine-Borane as a suitable chiral reducing agent was undertaken.

Why Use a Chiral Reducing Agent?--Sterochemistry is very important to biological molecules. Each enantiomer has very different properties when interacting with other chiral molecules. One may give a desired effect while the other gives no effect or an adverse effect. One example is thalidomide, a drug used in the 1960's to treat morning sickness in pregnant women. In this case, one isomer is an effective drug, but the other causes serious birth defects (Dhar, 1994).
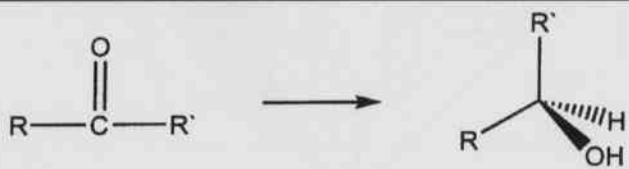
Fig. 1. Reaction of a prochiral ketone to an optically active secondary alcohol.

The reduction of a prochiral ketone to an optically active secondary alcohol (Fig. 1) is one of the most common ways to produce asymmetry in a molecule. Optically active secondary alcohols are found in natural compounds, bio-
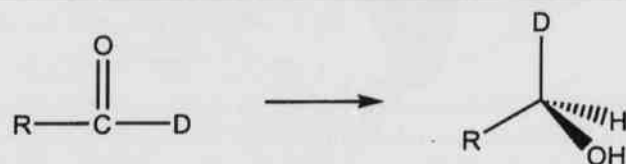

Fig. 2. Reaction of a deuterated aldehyde to an optically active primary alcohol.

compounds, liquid crystals, and are synthetic intermediates (Dhar, 1994). The reduction of a deuterated aldehyde gives an optically active primary alcohol (Fig. 2), which can then be used for mechanistic studies of chemical and biochemical processes (Midland et al., 1979).
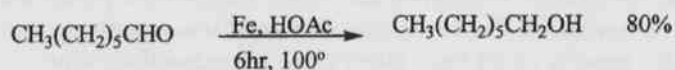

Fig. 3. Metal-Acid reduction of an aldehyde.

Early Reducing Agents.--Before the discovery of boranes as reducing agents, reduction methods often involved high temperatures, long reaction times, and low yields of the desired products. One way of reducing an aldehyde to an alcohol was a metal-acid procedure (Fig. 3; Brown and Krishnamurthy, 1979). Ketones could be reduced to alcohols by sodium in ethanol or zinc-sodium hydroxide in ethanol (Brown and Krishnamurthy, 1979). Both aldehydes and ketones could be reduced to the corresponding carbinols by the Meerwein-Ponndorf-Verley reduction (Fig. 4). Esters could by reduced to alcohols by the Bouveault-Blanc method (Fig. 5). Although the discoveries

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of the Bouvealt-Blanc method and the Meerwein-Ponndorf-Verley reduction were improvements in reduction methods, better procedures were needed.
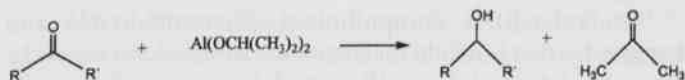

Fig. 4. Meerwein-Pondorf-Verley reduction of a ketone.

Fig. 5. Bouveault-Blanc reduction of an ester.

Discovery of Diborane as a Reducing Agent.--In 1936 H.C. Brown, then a graduate student at the University of Chicago, began to study the reaction of diborane with aldehydes and ketones in order to better understand the structure of newly synthesized borane-carbonyl. He soon discovered that aldehydes and ketones reacted quickly with diborane to form dialkoxyboranes, which gave the corresponding alcohols upon hydrolysis (Fig. 6; Brown and Krishnamurthy, 1979).
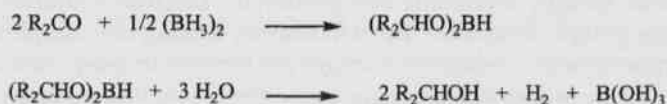
Fig. 6. Reduction of a ketone to an alcohol using diborane.

Unfortunately, diborane was in short supply at the time, so interest in the compound was marginal. During World War II, efforts to produce uranium borohydride for military testing led to new syntheses of diborane and sodium borohydride. These developments initiated new interest in borohydrides and changed procedures for the reduction of functional groups. Many more borane compounds for organic reductions have since been produced. Super-Hydride®, L- and K- Selectrides®, and LS- and KS-Selectrides™ (Figs. 7-9) are examples of alkali metal trialkylborohydrides which are capable of stereo- and regioselective reductions. Dialkylboranes and trialkylboranes have also been synthesized to achieve selective reductions (Brown and Krishnamurthy, 1979).

Dialkylboranes.--The dialkyborane 9-borabicyclo[3.3.1]nonane (9-BBN) can be synthesized by the hydroboration of 1,5-cyclooctadiene (Fig. 10; Knights and Brown,

1968). The reaction proceeds through an organoborane intermediate and leads to a 1,5 isomer, which is much more stable than the 1,4 isomer because it is composed of two fused six-membered rings, whereas the 1,4 isomer is composed of a seven-membered ring fused to a five-membered ring. (Knights and Brown, 1968).
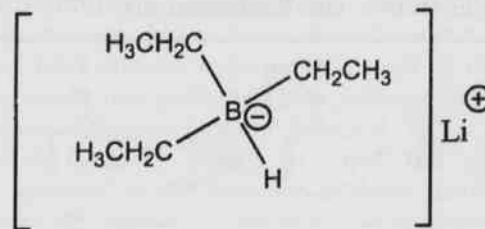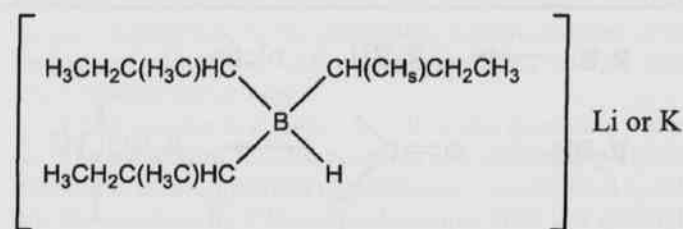

Fig. 7. Super-Hydride
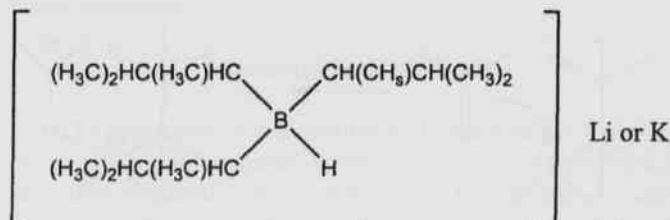

Fig. 8. L- and K-Selectrides
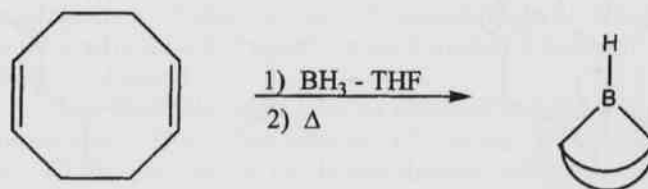

Fig. 9. LS- and KS-Selectrides

Fig. 10. Synthesis of 9-BBN.

9-BBN is superior to other dialkylboranes in that it is not sensitive to oxygen and offers a faster rate of hydrobo-

ration. The faster reaction time is due to the exposed position of the boron atom, which makes 9-BBN especially good for trapping carbanions, carbenes and similar intermediates (Knights and Brown, 1968a). 9-BBN reduces α,β-unsaturated aldehydes and ketones to allylic alcohols (Fig. 11) and is mild enough to not reduce almost all other functional groups, such as ester, amide, carboxylic acid, nitro, halogen, and nitrile. (Brown and Krishnamurthy, 1979).
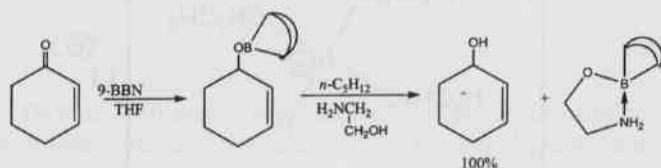

Fig. 11. Reduction of an unsaturated ketone to an allylic alcohol using 9-BBN.
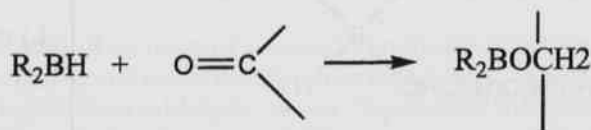
Fig. 12. Schematic of the dehydroboration - reduction process.
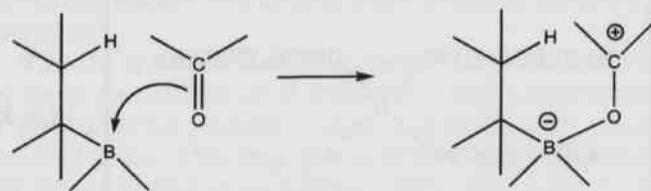
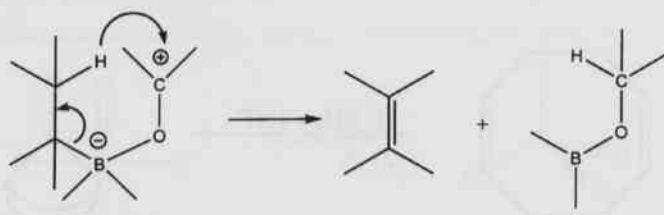Fig. 13. Formation of the aldehyde - borane complex.

Fig. 14. Hydride delivery from the aldehyde - borane complex.

Trialkylboranes.--The addition of an alkyl group to 9-BBN expands its uses greatly. *B*-alkyl-9-BBN compounds are tolerant of many functional groups, as is 9-BBN, but *B*-alkyl-9-BBN compounds are so mild that they are capable

of reducing aldehydes in the presence of ketones, which are less reactive. They are chemo- and enantioselective reducing agents whose efficiency and rate of reaction depend on the structure of the alkyl group on 9-BBN (Midland and Tramonato, 1978).

B-alkyl-9-BBN compounds reduce aldehydes and ketones by two possible mechanisms: a cyclic process and a two-step dehydroboration-reduction process. The cyclic mechanism has been shown to dominate the reduction of aldehydes, whereas the dehydroboration-reduction process takes place when hindered or unreactive ketones are reduced. The dehydroboration-reduction process begins by a slow dissociation of the trialkylborane (Fig. 12; Midland, 1989).

Evidence that the cyclic process predominates is based on second-order kinetics data, the change in rate with structural and electronic changes in the aldehyde, and the results of asymmetric reductions. (Midland and Zderic, 1982). The cyclic reduction of aldehydes involves a complex between the organoborane and the carbonyl oxygen followed by a β hydride transfer to the carbonyl carbon (Figs. 13 and 14; Midland, 1989). The yellow color when an aldehyde is added to an organoborane is due to the aldehyde-organoborane complex. Tertiary hydrogens preferentially react in presence of secondary or primary β hydrogens (Midland et al., 1979).

Mechanism and Rate of Reaction of Trialkylboranes.-- Electron donating groups on benzaldehyde slow the reaction by stabilizing the positive charge on the carbonyl carbon, thereby increasing complexation. Electron-withdrawing groups destabilize the carbocation, making the complex more reactive, which encourages the hydride transfer. Since electron-withdrawing groups cause the reaction to go faster, the hydride transfer must be the rate-determining step. More evidence that the hydride transfer is the rate-determining step is the fact that hindered boranes provide faster reaction times, although they decrease complexation. This bimolecular process must also be faster than internal rotation of the complex for the hydride transfer to occur, since rotation would prevent the proper orientation for transfer (Midland and Zderic, 1982).

The rate of reduction of aldehydes by *B*-alkyl-9-BBN compounds depends on the structure of the alkyl group on 9-BBN and the structure of the aldehyde. Electron-withdrawing groups on the aldehyde increase the rate of reaction due to destabilization of the aldehyde-organoborane complex. Electron-donating groups slow down the reaction and lead to lower enantiomeric purities, possibly due to introduction of the dehydroboration-reduction side-reaction (Midland, 1989). Greater substitution at the β position of the **B**-alkyl-9-BBN compound increases the rate of reaction because it does not favor complexation, making the complex more reactive. (Midland and Zderic, 1982).

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The rate of reduction is also increased if the alkyl group of the organoborane can form a favorable syn coplanar B-C-C-H conformation. This arrangement leads to overlap of the developing pi system of the liberated olefin (Midland, 1989).

Alpine-Borane®--Alpine-Borane®, *B*-3-pinanyl-9-BBN, is one of the fastest and most efficient chiral reducing agents that can be prepared from 9-BBN. It reduces aldehydes with an enantiomeric purity that approaches enzymes (Midland et al., 1979). It can be synthesized by the hydroboration of (+)-a-pinene with 9-BBN (Fig. 15; Brown and Krishnamurthy, 1979).
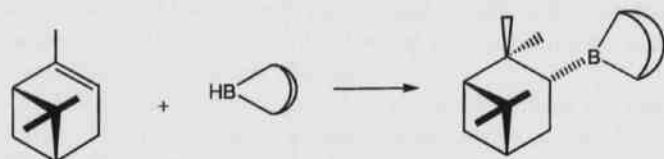

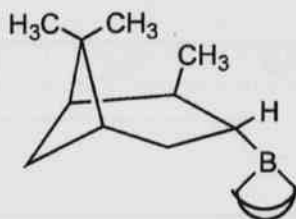Fig. 15. Synthesis of Alpine-Borane.

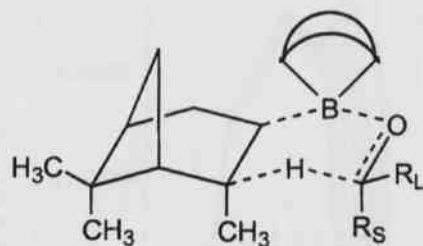Fig. 16. Steric strain of methyl groups in Alpine-Borane.

Fig. 17. Boatlike transition state of Alpine-Borane.

Several factors contribute to Alpine Borane®'s unusual reactivity. It has an ability to form a favorable coplanar B-C-C-H arrangement, which allows for favorable formation of the displaced olefin. (Midland, 1979)

Alpine-Borane® also has a buildup of steric strain which is relieved upon going to the -pinene product. This strain is caused by the *cis*-1-methyl group being forced into the gem-dimethyl groups on the four-membered ring (Fig. 16; Midland, 1979). The transition state of the reduction of

an aldehyde by Alpine-Borane® resembles a boat-like cyclohexane structure (Fig. 17). Large groups are in the equatorial position, which places them as far as possible from the pinanyl group. Small groups occupy the axial position. In aldehydes, this position is occupied by a hydrogen. In ketones, an alkyl group must occupy the axial position, which leads to steric interactions with the methyl of the pinanyl group. These interactions can impede the cyclic process. In this case, Alpine-Borane® will eventually dissociate into 9-BBN and the reduction proceeds by the dehydroboration-reduction pathway. This pathway gives longer reaction times and less selectivity (Midland, 1979).

Research Goals.--In order to study the effects of aldehyde structure on the reduction of those aldehydes by Alpine-Borane®, numerous aldehydes were reduced and the reactions followed by Fourier Transform Infrared (FTIR) Spectroscopy and later, by UV-visible (UV-vis) spectroscopy. Compounds of interest included aromatic, aliphatic, para-substituted, meta-substituted, α,β-unsaturated aldehydes, and aldehydes with electron-donating and/or electron-withdrawing groups.

FTIR was the first choice to follow the reactions, where we hoped to follow the disappearance of the carbonyl peak. When this method proved unsatisfactory, we decided to follow the reactions by UV-vis spectroscopy. With this method, we were able to follow the disappearance of the carbonyl n→π* transition. We were also able to obtain spectra in quick succession, which became necessary for following the faster reactions.

Materials and Methods

The reduction of one millimole of each of these aldehydes was studied: trimethylacetaldehyde (pivaldehyde, 2,2-dimethylpropanal); *p*-anisaldehyde (4-methoxybenzaldehyde); isobutyraldehyde (2-methylpropanal); butyraldehyde (butanal); citral; citronellal; benzaldehyde; *m*-anisaldehyde (3-methoxybenzaldehyde); salicaldehdye (2-hydroxybenzaldehyde); 3-nitrobenzaldehyde; 4-nitrobenzaldehyde; trans-2-hexenal; 2-ethylbutyraldehyde (2-ethylbutanal); cinnamaldehyde (3-phenylpropenal); crotonaldehyde (2-butenal, predominantly trans); trans-2-methyl-2-butenal; 3-methyl-2-butenal

Most aldehydes were used as obtained without further purification. Due to the presence of a strong -OH peak in the FTIR spectrum of the butyraldehyde used, this compound was distilled and stored over anhydrous $MgSO_4$.

Initially, 1 millimole of each compound was reacted with 1.5 millimoles of Alpine-Borane® (0.5 M in tetrahydrofuran, obtained from Aldrich Chemical Co.), and the reactions were followed by FTIR. (Fig. 18 and 19) Approximately one analysis of 32 scans was taken per hour. Using this method, little or no change was seen in spectra

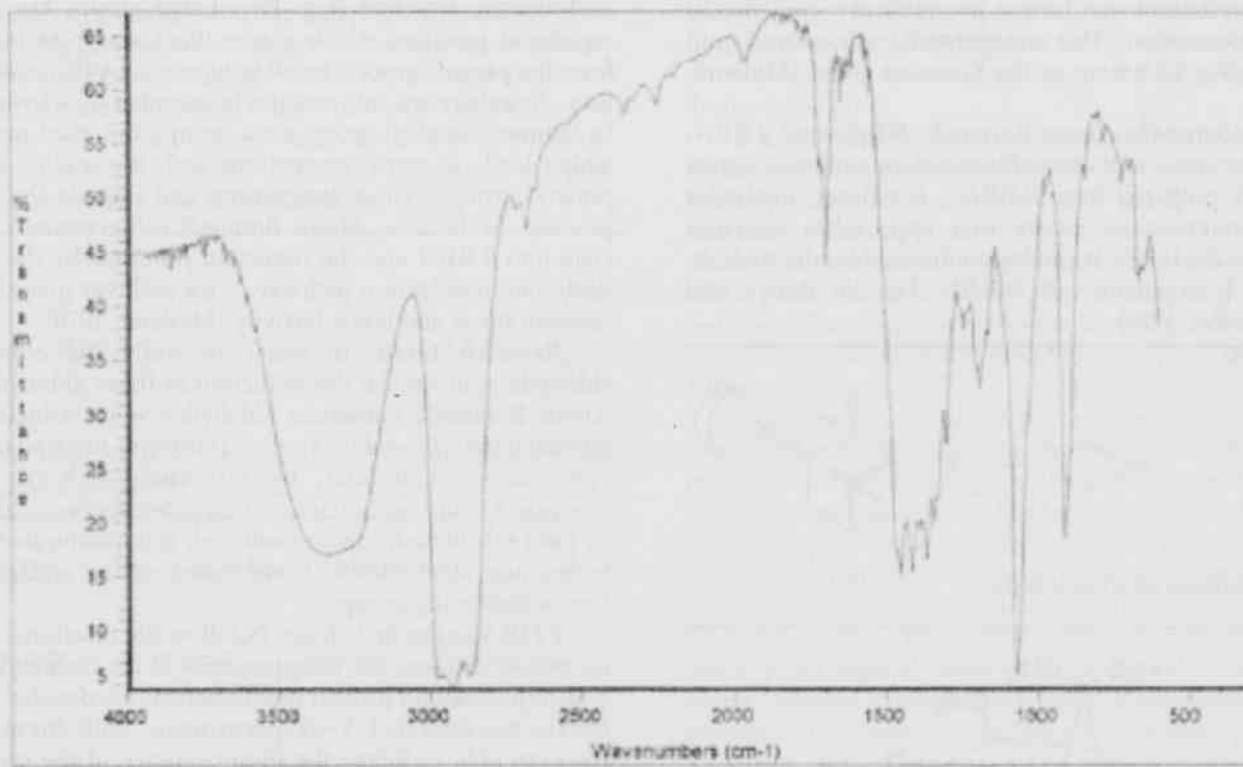**Layla Bland and Michael J. Panigot**

Fig. 18. FT-IR spectrum of Alpine Borane (0.5 M solution in THF).
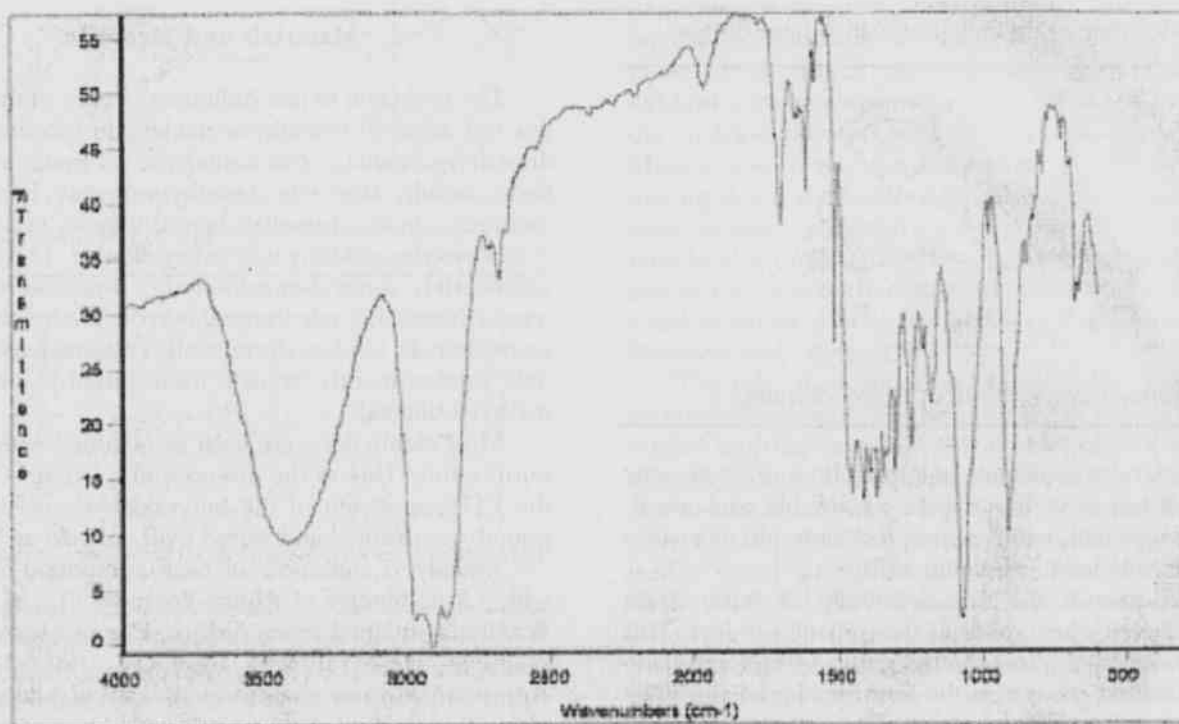
Fig. 19. FT-IR spectrum of 1 mmol p-anisaldehyde in 3 mL Alpine-Borane solution (0.5 M in THF)

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over several analyses. To test the effectiveness of the Alpine-Borane® used, the reaction of benzaldehyde and Alpine-Borane was followed by thin-layer chromatography against benzaldehyde and benzyl alcohol. This test showed that the benzaldehyde had not been reduced, so a new supply of Alpine-Borane® was used thereafter. Even using the new bottle of Alpine-Borane®, no change was seen in the FTIR spectrum of benzaldehyde over several hours. Then the reduction was attempted using 3 millimoles of Alpine-Borane®, and the spectrum still showed no change. Thus, it was found that the FTIR was not an acceptable method for following these reactions for two reasons: (1) the solutions were too dilute in Alpine-Borane® to follow the disappearance of the carbonyl peak, and (2) the reduction happened so quickly that only one or two subsequent scans would have shown any change.

UV-Visible spectroscopy was chosen to follow the reactions. There were several advantages to this method over FTIR: the $n \rightarrow \pi^*$ transition in the spectrum would not be masked by the Alpine-Borane® (Figs. 21 and 22), the spectra could be taken more frequently, as often as once every seven seconds, and the spectra could easily be overlaid to show the disappearance of the $n \rightarrow \pi^*$ peak (Fig. 20).

The reactions of 1 millimole of aldehyde and 1.5 millimoles of Alpine-Borane® were run directly in the cuvette.

Spectra were taken as often as the machine would allow, which was about every seven seconds. Because many of the reductions were quite rapid and essentially complete in less than one minute, this was quite helpful. The reduction times given in the next section were obtained by timing the disappearance of the $n \rightarrow \pi^*$ peak.

Results and Discussion

As expected, aliphatics were reduced very quickly. Hindered compounds, notably trimethyacetaldehyde, were reduced slightly slower than less hindered compounds.

The presence of multiple bonds did not seem to affect the reduction unless the compounds were α,β-unsaturated. In this case, resonance interactions caused the reductions to take place significantly more slowly.

Aromatics were expected to be reduced at about the same rate as alkenes or aliphatics. We found that aromaticity did not slow the reaction. Within the groups of aromatics, electron-withdrawing groups caused the reaction to proceed very quickly. Electron-donating groups slowed the reaction, but not significantly.

Tables of results for each group of compounds and discussions of individual compounds are presented. The mechanism of the reduction of isobutyraldehyde shown in Fig. 23
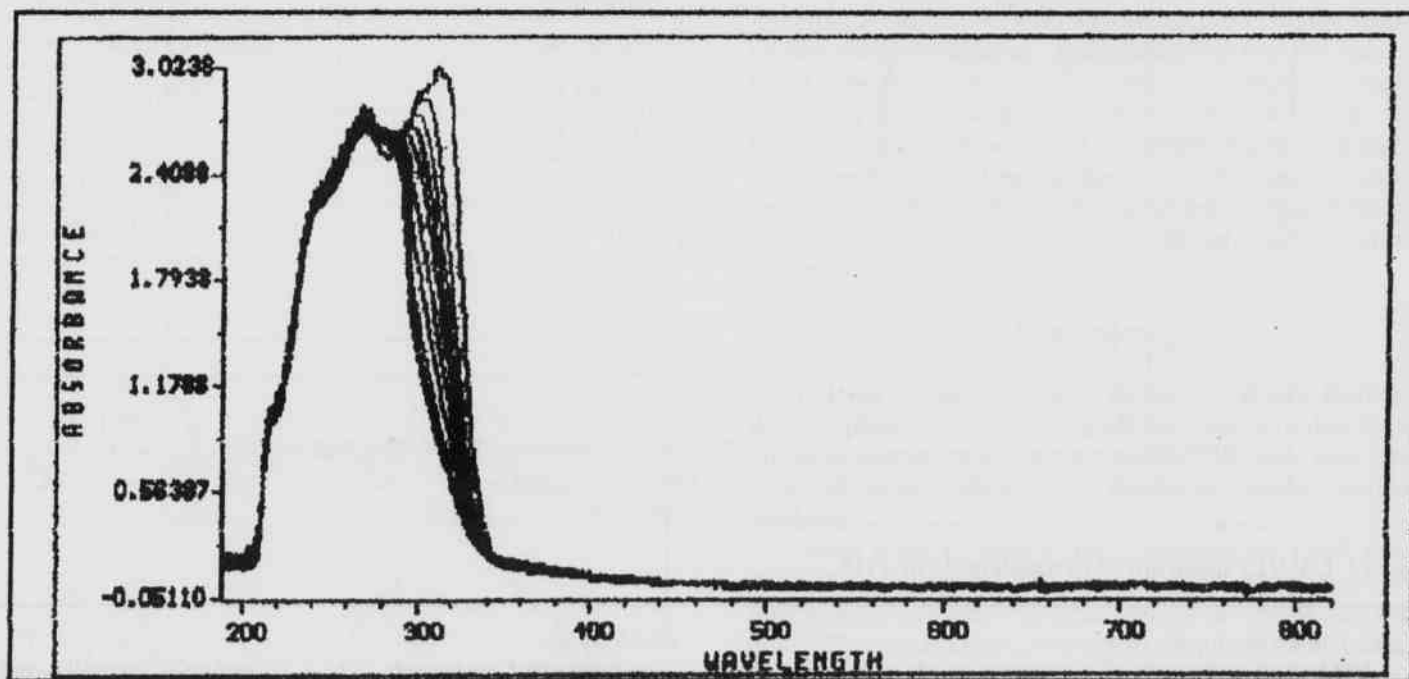

Fig. 20. Overlaid spectra of the reduction of trimethylacetaldehyde.

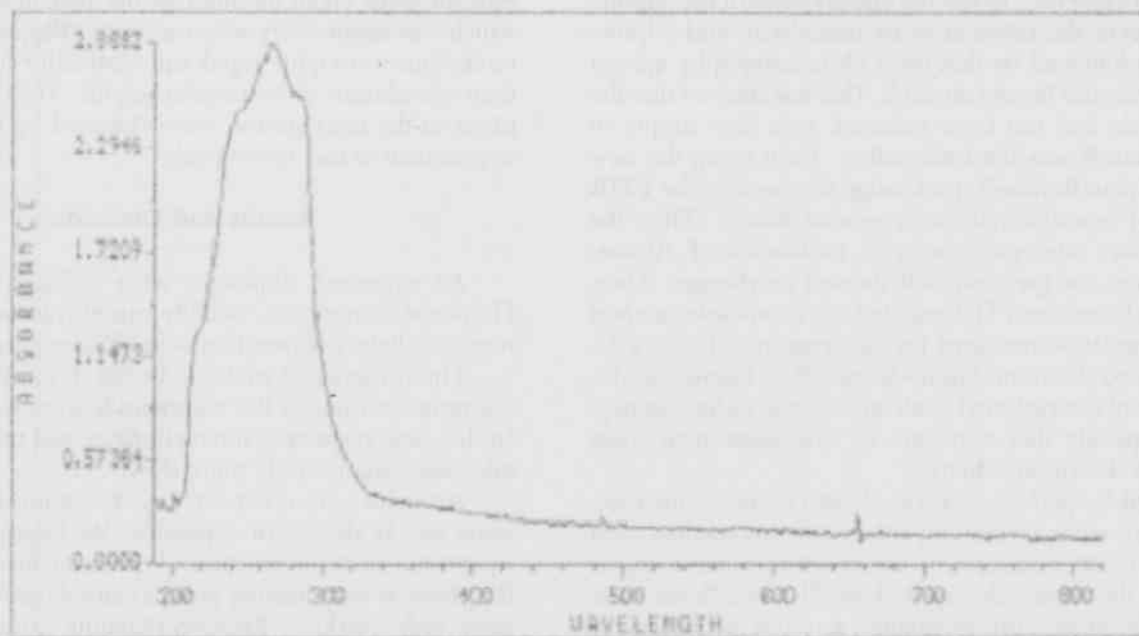Journal of the Arkansas Academy of Science, Vol. 54, 2000

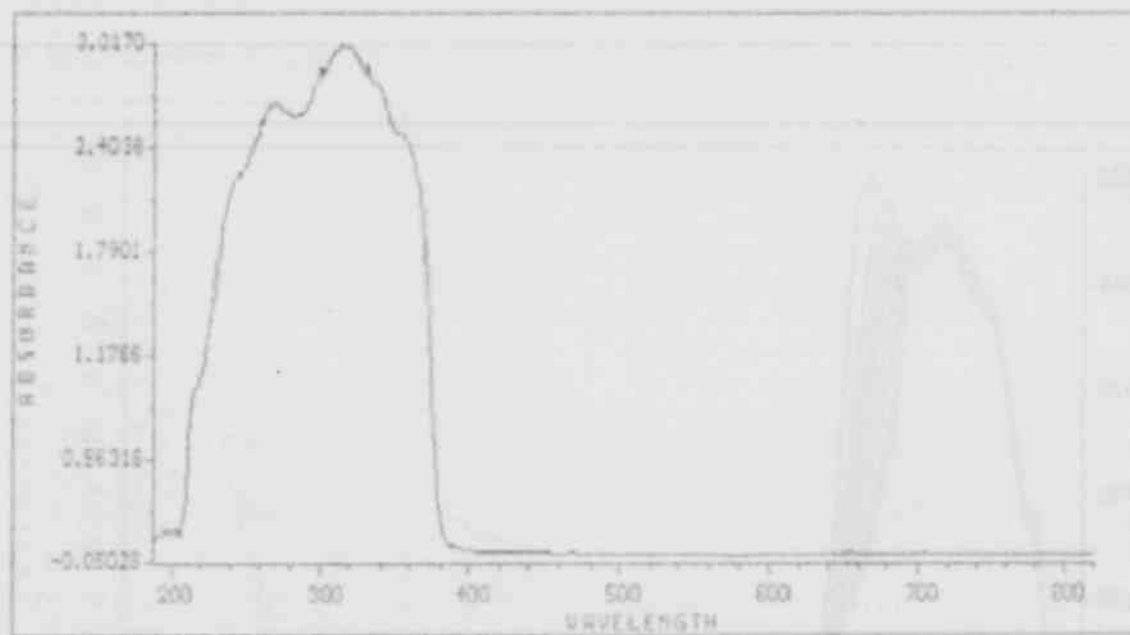Fig. 21. UV-VIS spectrum of Alpine-Borane (0.5 M in THF)

Fig. 22. UV-VIS spectrum of benzaldehyde in THF.

is given as an example.

Aliphatic Compounds.--These compounds were reduced very quickly, because minimal steric hindrances and no resonance effects were present. Significant reduction in rate occurred only when the carbon was tertiary (trimethylac-etaldehyde).

Aromatic Compounds.--These compounds, overall, were reduced slightly slower than the aliphatic compounds, due to steric hindrance, and in the case of *p*-anisaldehyde, resonance effects.

Table 1

Compound	Reaction Time
citronellal	30 seconds
butyraldehyde	1 minute
isobutyraldehyde	1 minute
2-ethylbutyraldehyde	1 minute
trimethylacetaldehyde	5 minutes

Table 2

Compound	Reaction Time
3-nitrobenzaldehyde	1 minute
4-nitrobenzaldehyde	1 minute
benzaldehyde	3 minutes
m-anisaldehyde	5 minutes
p-anisaldehyde	30 minutes

Table 3

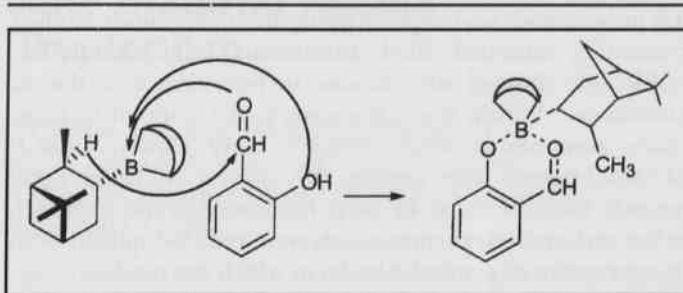| Compound	Reaction Time
3-methyl-2-butenal	15 minutes
crotonaldehyde	20 minutes
trans-2-methyl-2-butenal	30 minutes
cinnamaldehyde	30 minutes
citral	40 minutes
trans-2-hexenal	40 minutes
salicylaldehyde	did not reduce

Fig. 24. Reaction of salicylaldehyde with Alpine-Borane®.

The addition of the electron-withdrawing nitro group to benzaldehyde caused 3-nitrobenzaldehyde and 4-nitrobenzaldehyde to be reduced more quickly than benzaldehyde. p-Anisaldehyde is reduced slowly because the methoxy group is electron-donating by resonance, stabilizing the complex. Since the hydride transfer is the rate-determining step, complex stabilization increases the reaction time for this compound. The methoxy group on m-anisaldehyde is in the wrong position to donate by resonance and is electron-withdrawing inductively, causing the reaction to be faster than the reduction of p-anisaldehyde.

α,β-*unsaturated Compounds.*--These compounds were reduced slowly because resonance decreased the double bond character of the carbonyl group. Within this group, the long-chain compounds were reduced more slowly than the shorter ones.

Trans-2-methyl-2-butenal was reduced more slowly than 3-methyl-2-butenal because the methyl group on the second carbon causes hindrance. Salicylaldehyde was not reduced by Alpine-Borane®, possibly due to a boron complex involving both oxygens of the compound (Fig. 24). Overlaid spectra show a peak moving to higher and higher wavelengths, supporting this idea. Also, the solution turned red when the Alpine-Borane® was added, instead of the yellow color that was observed with the addition of Alpine-Borane® to the other compounds.

Conclusions

Interest in the rates of reduction by Alpine-Borane® was stimulated due to the sluggish reactivity of indole-3-carboxaldehyde in tryptophan synthesis. We were also interested in future attempts to synthesize chiral primary alcohols.

Initial plans to observe the reductions by FTIR failed due to interference by Alpine-Borane® in the spectra. UV-VIS proved to be an excellent method to follow the reactions. There was no interference in the spectra which could be taken in quick succession and overlaid for easy comparison.

The three classes of compounds that were chosen for this study were aldehydes which contained saturated alkyl,
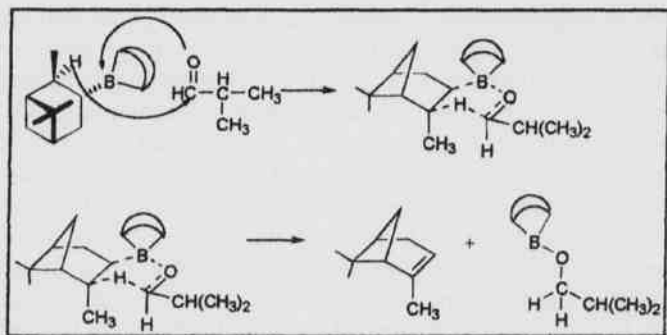

Fig. 23. Reduction of isobutyraldehyde by Alpine-Borane®.

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α,β-unsaturated, and aryl. Among the compounds studied containing saturated alkyl substituents, only trimethylacetaldehyde showed any increase in reduction time due to hindrance. Within the α,β-unsaturated compounds, long-chain compounds were reduced more slowly. *trans*-2-Methyl-2-butene was among the slowest of these compounds, likely because of steric hindrance in the approach to the carbonyl. Aryl compounds were reduced quickly with the exception of *p*-anisaldehyde, in which the methoxy oxygen is capable of electron donation through resonance. *m*-Anisaldehyde was reduced quickly because the methoxy group is in the wrong position to donate by resonance and is electron-withdrawing inductively. 3-nitrobenzaldehyde and 4-nitrobenzaldehyde were reduced very quickly due to the presence of the electron-withdrawing nitro group.

Each group of compounds was reduced as predicted, although we expected more variation in the reduction times among the aliphatic compounds, due to varying amounts of steric hindrance.

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Preparation of an Electrophilic 3-Methylindole Derivative: Difficulties in Forming a Stable, Suitable Material for the Preparation of Tryptophan

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Abstract

In an attempt to prepare stereoselectively beta-deuterated tryptophan, N-protected indole-3-methanol compounds were prepared with model studies being done on undeuterated material. Conversion of these compounds to electrophilic species proved exceptionally difficult and resulted in very low yields or recovered starting material only. A summary of the current results utilizing N-tosyl indole-3-methanol will be presented as well as efforts using N-Boc indole-3-methanol.

Introduction

In recent years, nuclear magnetic resonance (NMR) spectroscopy has become an important tool in the determination of the three-dimensional structure of proteins in solution (Wuthrich, 1989), complementing X-ray diffraction structures obtained in the solid state. The advent of 2-D and higher-dimensional NMR techniques (Bax, 1989; Clore and Gronenborn, 1991) have permitted this approach to develop, providing solution phase structures of moderate size (ca. 30 kDa) proteins. Of particular utility in NMR-based structure solutions are methods which utilize selective (Otting and Wuthrich, 1990) or general (Fesik and Zuiderweg, 1990; Hansen et al. 1992) stable isotope labeling of the protein amino acids.

The amino acids which we were trying to prepare were leucine and tryptophan as shown in Fig. 1. Both of these amino acids as well as other amino acids bearing a beta methylene group have a pair of diastereotopic hydrogens at the beta position. Assignment of the two prochiral hydrogens is simplified by the stereospecific introduction of deuterium at either the pro-R or pro-S position while leaving the remaining hydrogen unchanged. Conformational analysis using coupling constants and the Karplus relationship to predict dihedral angles or using nuclear Overhauser effect (NOE) experiments to determine through-space proximity of atoms is facilitated by stereospecific deuteration of the diastereotopic prochiral hydrogens. Previous synthetic work toward the preparation of isotopically labeled amino acids involved the preparation of chiral deuterated glycine containing a 15-N label (Curley et al., 1994). Additional synthetic studies had utilized the alkylation of an enolate derived from ethyl hippurate (prepared as the 15-N and 13-C labeled compound from labeled 13-C ethyl bromoacetate and 15-N labeled potassium phthalimide followed by depro-
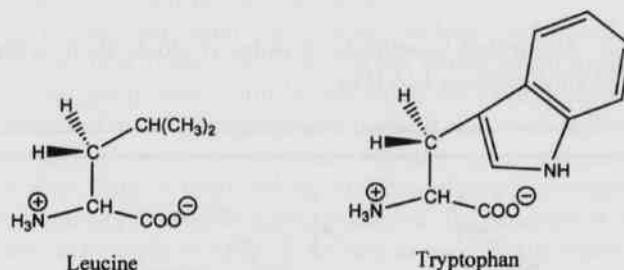

Fig. 1. Synthetic targets leucine and tryptophan. Note the prochiral hydrogens shown on the beta carbon using wedge-dashnotation.

tection to afford uniformly 13-C, 15-N labeled glycine then reprotection) to prepare uniformly labeled cysteine (Fig. 2; Panigot et al., 1995). One advantage of this approach is that any of the carboxyl carbon, the alpha carbon, the beta carbon, and the nitrogen can be selectively labeled or not
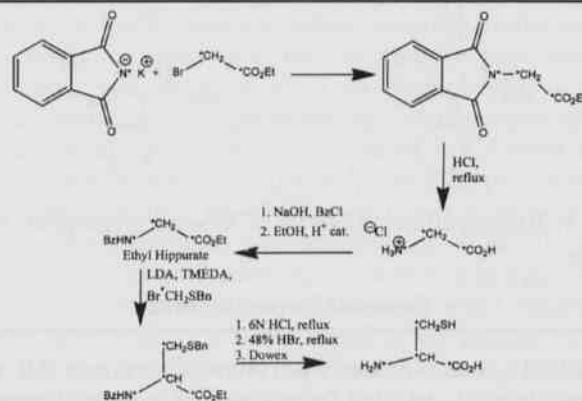

Fig. 2. Synethesis of labeled cysteine by alkylation of ethyl hippurate

labeled depending on the choice of starting materials. In trying this approach with leucine, efforts to prepare the known deuterated aldehyde (Piart-Goypiron et al., 1991) failed to provide usable material due to solvent impurities present and/or unexpected overoxidation of the dideuterated isobutyl alcohol to isobutyric acid instead of isobutyraldehyde-d (Fig. 3). We then focused our efforts on the preparation of tryptophan. The disconnection of tryptophan (Fig. 4) shows that methyl indole-3-carboxylate would be a reasonable starting material.
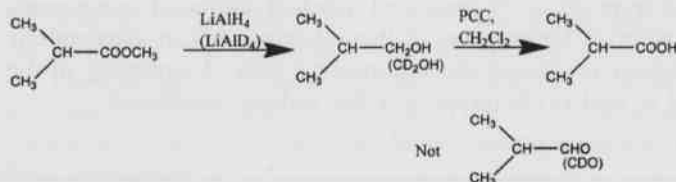

Fig. 3. Attempted synethesis of isobutyr(aldehyde-d) with model studies using LiA1H$_4$.
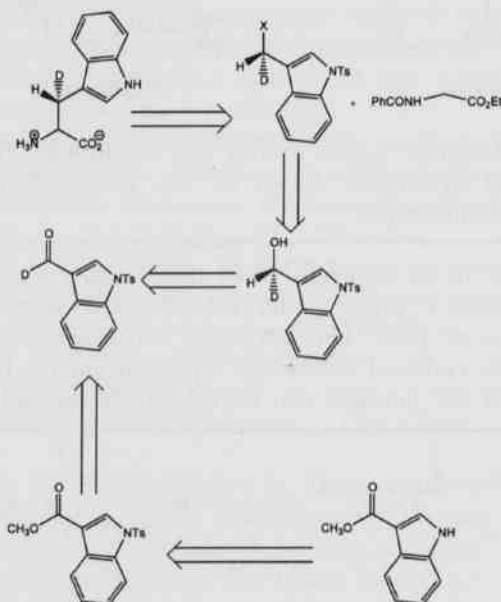

Fig. 4. Retrosynthetic analysis of labeled tryptophan synthesis.

General Experimental

LiAlD$_4$ was obtained from Acros Chemicals. All other chemicals were obtained from Aldrich Chemical Company and used as received. Solvents were used as received.

Anhydrous ether was obtained from Fisher Chemical Company and used as received. Reactions using moisture-sensitive reagents were run in oven-dried glassware under nitrogen. NMR spectra were obtained on a Hitachi R-1200 60 MHz NMR using CDCl$_3$ as solvent and TMS as internal standard. Chemical shift values are given in parts per million (δ) downfield from TMS. FT-IR spectra were obtained on a Nicolet 5PC FT-IR spectrophotometer with samples deposited as films evaporated from CHCl$_3$ on NaCl plates. Column chromatography was performed using Merck 7734-4 silica gel.

N-Tosyl Methyl Indole-3-carboxylate (1) was prepared in a manner analogous to that used for other N-tosylations of indoles and imidazoles (Greene and Wuts, 1999).

N-Tosyl Indole-3-Methanol (2): A suspension of 11.04 g (33.5 mmol) of 1 was suspended in 100 mL of anhydrous ether and cooled to 0 °C. After 10 min. at 0 °C, LiAlH$_4$ (1.28 g, 33.5 mmol) was added. The mixture was allowed to warm to room temperature and stirred for 2 h. The reaction was quenched by the addition of 1.28 mL H$_2$O, 1.28 mL of 15% NaOH solution, and another 3.84 mL of water. The mixture was filtered, dried (MgSO$_4$), and concentrated to yield 7.10 g (70%) of the hydroxymethyl indole. NMR 7.0 - 8.0 (m, 9H), 4.2 (s, 2H), 2.7 (s, 3H). IR 3300 cm^{-1} (br s).

N-Tosyl Indole-3-Carbaldehyde (3): To a solution of 3.03 g (10 mmol) of 2 in 50 mL of CH$_2$Cl$_2$ which was cooled to 0 °C was added 3.23g (15 mmol) PCC. The mixture was allowed to warm to room temperature and stir overnight. It was filtered through Celite, concentrated, and chromatographed (20% ethyl acetate / hexane) to yield aldehyde 3. NMR 9.5 (s, 1H), 7.0 - 8.0 (m, 9H), 2.7 (s, 3H). IR 2720 cm^{-1}, 1705 cm^{-1}.

Sample Attempt to Prepare N-tosyl Indole-3-Methanol Tosylate: A solution of 0.301 g of 2 and tosyl chloride (0.381 g) in pyridine (5 mL) was allowed to stand at 4 °C overnight. On extraction into ether, the only organic material present was unreacted 2. Other variations (room temperature, shorter reaction times at low temperature) also led to recovered starting material.

N-Tosyl 3-Chloromethylindole (4): Compound 2 (0.30 g, 1 mmol) and triphenylphosphine (0.30 g, 1.14 mmol) were combined in 25 mL CCl$_4$ and allowed to stir for 3 days. The mixture was concentrated and chromatographed using 20% ethyl acetate / hexane as eluant yielding 0.04 g (12%) of 4. NMR 7.0 - 8.0 (m, 9H), 4.3 (s, 2H), 2.7 (s, 3H). IR showed no absorbance at 3300 cm^{-1}.

N-Tosyl 3-Bromomethylindole (5): A mixture of 2 (0.10 g, 0.33 mmol), triphenylphosphine (0.105 g, 0.4 mmol), and carbon tetrabromide (0.133g, 0.4 mmol) was allowed to stir in 5 mL DMF for 4 days. The mixture was poured into 50 mL water and extracted with 50 mL ether. The ether extract was dried (MgSO$_4$), concentrated, and chromatographed (20% ethyl acetate / hexane) to yield 0.054g

(45%) of **5**. NMR 7.0 - 8.0 (m, 9H), 4.2 (s, 2H), 2.7 (s, 3H). IR showed no absorbance at 3300 cm^{-1}.

Results and Discussion

The planned synthesis of the O-tosylate of indole-3-methanol, to be alkylated with ethyl hippurate dianion to provide tryptophan after protecting group removal, is outlined in Fig. 5. The initial attempt at the preparation of indole-3-methanol from methyl indole-3-carboxylate by LiAlH$_4$ reduction gave rise to a material which was less polar than the starting material using thin-layer chromatography (TLC). In reviewing the known reactivity of 3-substituted indoles with LiAlH$_4$ (Silverstein et al., 1954; Leete and Marion, 1953) it was found that LiAlH$_4$ reacted with indole aldehydes and esters to provide 3-methylindole (Fig. 6). Reaction of NaBH$_4$ with indole-3-carbaldehyde would provide indole-3-methanol, however, this approach was unsatisfactory for the preparation of the dideuterio alcohol required. Additionally, as expected, NaBH$_4$ failed to reduce the methyl ester. Thus, an alternative synthetic approach was required.

Fig. 5. Planned synthesis of indole-3-methanol tosylate

Fig. 6. Reaction of methyl indole-3-carboxcylate to give 3-methylindole instead of the desired indole-3-methanol

In considering the mechanism of formation of 3-methylindole by LiAlH$_4$ reduction, one possible approach to avoiding elimination would be to decrease the electron density of the indole nitrogen. One possible means of doing this would be to make a sulfonamide derivative of the indole ester. N-Tosyl methyl indole-3-carboxylate was prepared by reacting the indole ester with tosyl chloride in triethylamine as outlined for the corresponding imidazole (Greene and Wuts, 1999). The sulfonamide derivative was chosen due both to its electron withdrawing ability and its stability toward LiAlH$_4$ reduction. The compound was successfully reduced with LiAlH$_4$ to N-tosyl indole-3-methanol and oxidized to the corresponding aldehyde using PCC to demonstrate the viability of the methodology before incorporation of the deuterium label using LiAlD$_4$. Having demonstrated the viability of this synthetic approach, the compound was then reduced with LiAlD$_4$ and oxidized to provide the deuterated aldehyde. The deuterated aldehyde was reduced using Alpine-Borane under standard conditions to provide a chiral deuterated primary alcohol.

Having prepared the N-tosyl indole-3-methanol, the focus shifted to the conversion of the hydroxyl group into a leaving group that could be alkylated with ethyl hippurate dianion. The initially proposed method was to directly convert the alcohol to the tosylate. All attempts to prepare the tosylate from N-tosyl indole-3-methanol were unsuccessful and starting materials were recovered. Preparation of tosylates of benzylic systems is known to be difficult under the standard tosylation conditions (Fieser and Fieser, 1967) using pyridine and tosyl chloride at 0 $^{\circ}$C overnight (Tipson, 1944). It is believed this may also be a problem in this case due to the benzylic character of the hydroxymethyl group. Additionally, efforts to prepare other sulfonates were also unsuccessful. The reaction with methanesulfonyl chloride led to recovered starting material. Attempted triflate preparation using trifluoromethanesulfonic anhydride led to undetermined decomposition products.

The preparation of halides from alcohols as shown in Fig. 7 became the next target. Fearing reaction or decomposition of the highly sensitive indole structure under acid or base conditions, halide preparations under neutral reaction conditions, such as reaction of an alcohol with a tetrahalomethane in the presence of triphenylphosphine (Hayashi et al., 1973) were the principal aim. Efforts using carbon tetrachloride and triphenylphosphine provided the chloromethyl indole. However, yields after purification by column chromatography were usually quite poor (10 - 15%). The chloromethylated compound failed to undergo alkylation on treatment with the dianion of ethyl hippurate. Similar difficulties were encountered in the attempt to prepare cysteine by alkylation of an alkyl chloride; however, the more reactive alkyl bromide could be alkylated in that instance. As a more reactive halide might be more reactive toward alkylation in this instance as well, an attempt to pre-
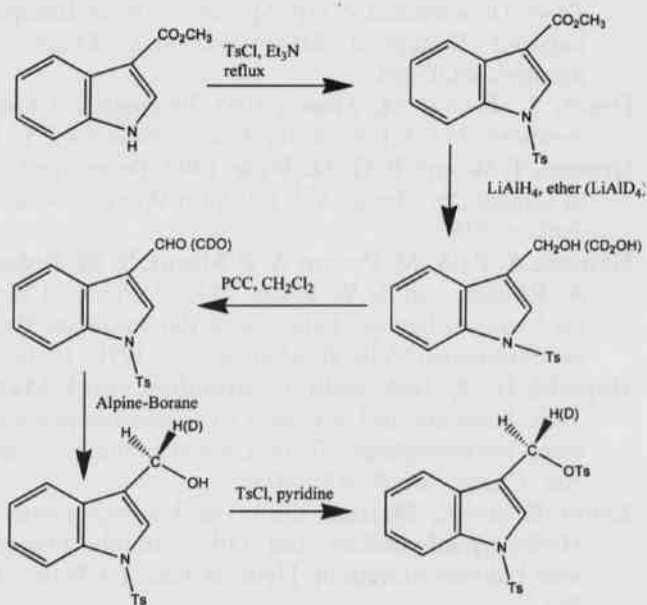
pare the bromomethyl indole was undertaken. Reaction of indole-3-methanol with carbon tetrabromide with triphenylphosphine again provided the desired halide in poor yield after column chromatography. Attempted alkylation of ethyl hippurate dianion with the bromide failed in this instance.
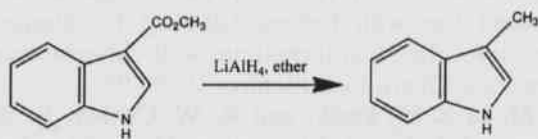
At this point efforts using an alternative protecting group on nitrogen were begun to determine whether the sulfonamide group played a role in the poor yields and low reactivity. One of the few other protecting groups capable both of electron withdrawal and stability toward LiAlH$_4$ is the tert-butoxycarbonyl (Boc) group. Research currently underway involves the preparation of N-Boc methyl indole-3-carboxylate and reduction to N-Boc indole-3-methanol with LiAlH$_4$ (Fig. 8).
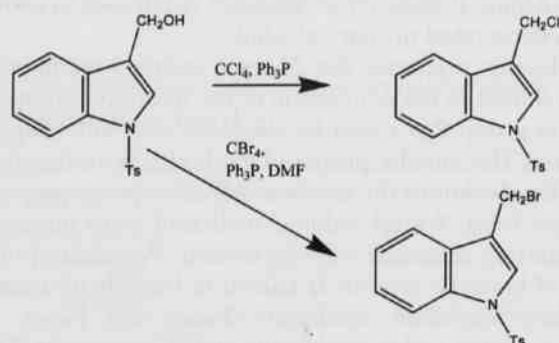

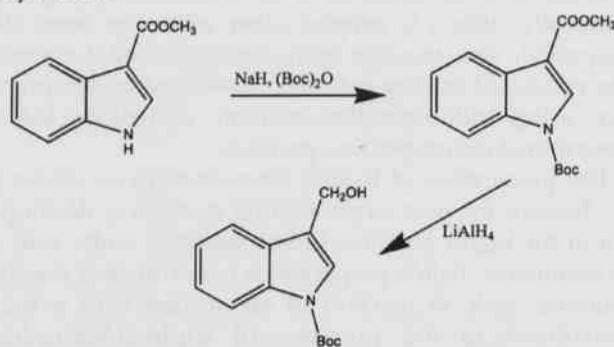Fig. 7. Synthesis of 3-chloromethyl- and 3-bromomethyl N-tosyl indole

Fig. 8. Current effprts utilizing N-Boc protected methyl indole-3-carboxylate

Conclusions

The preparation of leucine via this route was unsuccessful due to problems with purification and oxidation.

Preparation of a suitable electrophilic 3-methylindole derivative proved to be elusive. In those cases where small amounts of electrophile were prepared, alkylation of ethyl hippurate dianion failed to occur. Alternate approaches to the synthesis of labeled tryptophan and preparation of labeled histidine will be investigated.

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Using GIS to Model the Timbershed of a Wood Based Manufacturing Facility

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Abstract

A geographic information system (GIS) is an excellent tool for determining timber procurement zones. This study focuses on the procurement zones of two wood processing facilities in Arkansas, one in Fort Smith and one near Menifee. Since the two mills began operation in 1995, there have been questions about the long-term effect on the hardwood timber resource of the region. The "wood basket" for these mills must first be determined before their effects can be studied. Transportation from the harvest site to the primary processing facility accounts for a large portion of the total mill-delivered cost for raw materials, and this cost limits the range that raw woody material can be shipped. Determining transportation costs using GIS and U. S. Census Bureau topographically integrated geographic encoding and reference (TIGER) line files of existing road systems can aid managers in determining procurement zones. Spatial analysis was conducted using the GIS software ArcView 3.1 (ESRI, Redlands, CA). The ArcView Spatial Analyst extension was used to divide the study area into 30x30 meter cells, and then each cell was queried to determine which of the predetermined road classes exists and a cost per cell was assigned. Total transportation costs were then determined based on road class. The result is a travel cost surface that more accurately predicts transportation costs than the traditional concentric cost rings extending from a mill in specified intervals.

Introduction

This paper deals with determining the procurement zones of two wood processing facilities, one in Fort Smith, AR and one near Menifee, AR. Both mills are located along the Interstate 40 corridor in west central Arkansas. Since the two mills came online in 1995, there have been questions about the long-term effects to the hardwood resource of the region. In order to look at the effects of these mills, we must first determine the timbershed for the two mills. The timbershed is the area from which harvested timber can be affordably delivered to one or both of these two mills. The timbersheds of these wood processing facilities will realize the greatest impacts from their operation. Since these mills could potentially affect the management strategies of private landowners in the region, the first step is to establish where the most harvesting will take place.

Raw woody material is expensive to ship due to low volume-to-weight ratios (R. A. Kluender, pers. comm.). Transportation from the harvest site to the primary processing facility accounts for a large portion of the total mill-delivered cost for raw materials, and limits the range that it can be shipped. Determining procurement zones using geographic information systems (GIS) can provide more accurate determination of these areas. Effective and increased use of remote sensing data in forestry is likely to occur if appropriate procedures are developed to incorporate remote sensing data into operational systems, such as GIS (Roller and Bergen, 2000).

Methods

Wood-based manufacturing facilities typically view their timber draw area (wood basket) as concentric circles radiating from their facilities. This approach assumes that cost for transporting raw woody material increases uniformly with increase in horizontal distance from the wood processing facility. This approach places greater emphasis on areas nearest to the wood processing facilities and theoretically over or under estimates the actual resource area. Figure 1 is an example of a typical wood basket with cost zones set at fixed distances of 80, 160, or 240 km. Each successive zone represents a higher level of transportation cost, and does not

Fig. 1. Traditional procurement zones

take into account the road networks. Using the concentric model, Interstate highways are assigned the same travel cost as state highways or even county roads. However, travel cost decreases with increased speed. Interstates, with their limited access, have higher average speeds than do lower class roads. Shipping costs on high speed roads are less than on lower quality roads. The advances in remote sensing and spatial analysis have provided managers with the means to better estimate costs using total transportation time to a primary processing facility.

Operating Costs.--The operating cost of a tractor trailer is generally established on an hourly basis using a machine rate calculation. A machine rate calculation takes into account both fixed and variable operating costs for the piece of equipment. Table 1 lists the fixed and variable operating cost categories for the tractor machine rate calculation.

Table 1. Fixed and variable operating costs.

Fixed	Variable
Depreciation	Maintenance
Interest rate	Oil cost
Administrative Cost	Fuel cost
Labor rate/hour	Tire cost
Tax	Repair factor
Insurance rate	Hydraulic cost

The cost per hour for the tractor used in this analysis was $55.64. The trailer has an hourly operating cost of $2.96 (Gingras and Favreau, 1996). The combined operating cost is $58.60 per hour ($0.977 per minute) for the tractor/trailer combination.

Assigning Speeds.--Average speeds were assigned by road class. The road classes were delineated using U. S. Census Bureau topographically integrated geographic encoding and reference (TIGER) line files. Four road classes were established Interstate, state & U. S. Highways, secondary/connecting roads and no roads.

Interstate highways have been assigned a speed of 104.65 kilometers per hour (kph). State and U. S. Highways have an assigned speed of 80.5 kph. Secondary or connect-

ing roads have a speed of 56.35 kph, and the no-road class has a speed of 32.2 kph. Areas classified with "no-roads" may or may not have an improved road but were not classified by the TIGER files. Roads in no-road areas are more likely gravel or unimproved roads. The intention of the no-road class was to average the speeds of unpaved roads and use this to represent transportation time until a loaded truck of logs reached a higher road class.

Spatial Classification.--Spatial analysis was conducted using the geographic information system (GIS) software ArcView 3.1 (ESRI, Redlands, CA). An extension called Spatial Analyst was used to divide the study area into 30 x 30 meter cells, and then each cell was queried to determine which of the road classes was represented.

Cost Per Cell.--Following the separation of the study area into 30 x 30 meter cells, the cost per cell for each road class was determined. The first step was to determine the distance traveled in cells per min: for each road class, compute the distance traveled (m) per min and divide by 30 m (representing the width of one cell). Because a log truck travels across a particular cell twice (once loaded and once unloaded), we must divide the cells per minute value by two. To find the cost of travel per cell, we simply divide the cost per minute by the cells per minute. The interstates have the lowest cost per cell, and the no road class has the highest cost per cell (Table 2).

Cumulative Costs.--The final step in developing a cost surface for transportation was to arrive at a cumulative cost to transport the raw woody material to one of the mill locations based on the road networks. Spatial Analyst's cost distance modeling was used to keep a running tally of costs from the mill location out to the boundaries specified in Fig.1 (ESRI, 1996). Every cell in the entire area has a total cost assigned to it which represents haul costs from that cell to the mill. The end product is an accumulated cost map that illustrates the transportation cost from any location within the study area.

Results

The cost surface resulting from the spatial analysis gives managers a better understanding of the transportation costs

Table 2. Cost per cell for each road class.

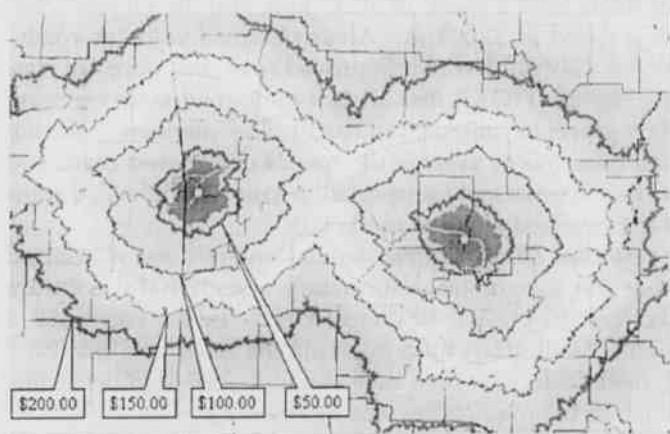| Road Class	Cells per minute	Cost per minute	Cost per cell
Interstate	9.08	$ 0.977	$ 0.034
State and U. S. Highways	22.38	$ 0.977	$ 0.044
Secondary Roads	13.42	$ 0.977	$ 0.073
No-roads	8.96	$ 0.977	$ 0.109

Fig. 2. Cost surface for two new wood processing facilities.

to a particular mill location (Fig. 2). Mill managers can use this cost structure to determine how far away they can afford to purchase raw woody materials to supply the mill. The average volume for a tractor trailer load of logs is fairly constant. Therefore, differences between stumpage price, the price paid to the owner of standing trees, and the mill-delivered price will determine the distance a producer can purchase raw woody material. Using the average tractor-trailer load volume along with differences between stumpage and mill-delivered prices gives the total amount available for cutting trees and getting them delivered to a wood processing facility.

Figure 2 displays the iso-cost lines which represent an area of equal cost. To make the map readable, several iso-cost lines were combined to develop a transportation cost zone. One can observe in Figure 2 that the two mills start competing for the trees outside of the $100.00 transportation cost zone. Which means that both mills should be in a favorable position to purchase trees inside that zone.
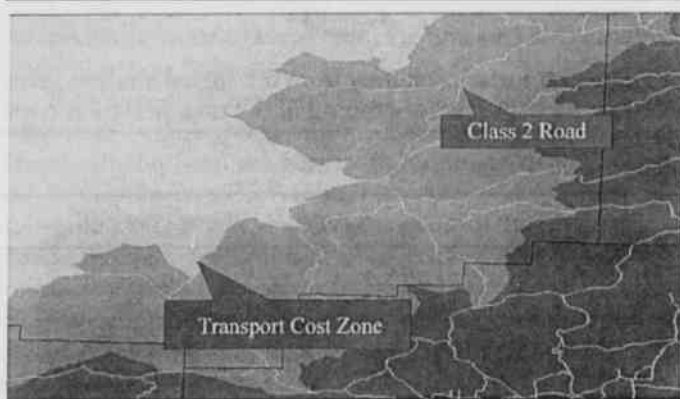
The actual haul distance will be determined by the

product being purchased. High quality oak sawtimber can be purchased at greater distances than hardwood pulpwood, due to higher mill-delivered prices. The inherent value of the finished product will determine how far it is profitable to purchase the raw material. Figure 3 illustrates how the road surfaces allow trees to be shipped greater distances along major travel corridors. Note how the transportation cost zones stretch further along the roads.

Conclusions

The method of determining the cost-effective procurement zones discussed in this paper has several advantages. Wood processing companies can evaluate potential areas for new mills based on the road networks and the available wood resource. These wood based companies can more effectively use their procurement teams in obtaining the raw materials for their mills. This approach can identify areas with the potential to supply a mills wood needs. By incorporating transportation costs with growth and removal data, potential areas of wood surplus can be identified.

Sample areas for surveys can be determined for any area using this procedure. Expansion of current facilities or new wood processing facilities could create a need for studying the timber resources in a particular region. Also, species composition can be compared between the different procurement cost regions such as the $50, $100, and $150 zones.

These procurement areas and associated transportation cost zones can be combined with forest inventory data to project a wood processing facility's ability to sustainably supply itself. If one transportation cost zone is inadequate to supply a wood-based manufacturing facility, this procedure can be used to determine the cost and direction the manager needs to use to meet their supply needs. The ultimate goal is to extract meaningful information and communicate it to support effective decision-making (Brown, 2000).

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Fig. 3. Class 2 roads extend a lower cost transportation zone.

Growth Curves of Four Species of Commercially Valuable Freshwater Mussels (Bivalvia: Unionidae) in Arkansas

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Abstract

North American freshwater mussels (Bivalvia: Unionidae) have been exploited commercially for over 100 years and have been regulated using shell size limits and/or harvest seasons. Presently, freshwater mussels are considered a threatened faunal group in North America due to the large numbers of endangered, threatened or special concern species. Therefore, management of this fauna should emphasize their long-term sustainability. The objectives of this study were 1) to construct von Bertalanffy growth curves for selected "commercially-most-valuable" species, *Fusconaia ebena, Megalonaias nervosa, Amblema plicata* and *Quadrula quadrula,* from five rivers and two reservoirs, 2) to compare species-specific von Bertalanffy growth curves from different rivers and reservoirs, and 3) to provide information on size at onset of sexual maturity in *F. ebena* and *A. plicata.* Von Bertalanffy growth curves of four commercially valuable Ambleminae species were used in this study to compare drainage-specific growth. Growth curves for all four species investigated were significantly different between pairs of drainages. Approximate size at onset of sexual maturity was determined for Arkansas *F. ebena* and *A. plicata.* Von Bertalanffy growth curves, coupled with life history and population dynamics information, could be useful in assessing and determining national/state harvest sizes and/or drainage specific harvest sizes once annual growth line formation is confirmed.

Introduction

North American freshwater mussels (Bivalvia: Unionidae) have been exploited through commercial harvest for the past 125 years. Between the late 1800s and early 1900s, North American harvesters sold tons of thick-shelled unionid species to the button industry (Coker et al., 1921). After the shell button industry was all but eliminated by the advent of plastics in the 1940s, a second wave of North American harvesting began in the 1960s. As recently as the mid 1990's, thousands of tons of shells per year were converted into spheres for transplant into oysters, driving the multi-million dollar cultured pearl industry (Williams et al.,

1993). Commercial harvest today and the recent past is conducted by brailing and diving. In brailing, dragging treble hooks across the open gape of the unionid stimulates the closure of the valves onto the treble hook. Individuals are then lifted to the surface for processing. Brailing is a harvest method that extracts freshwater bivalves burrowed in the substrate, regardless of size or species. A more conservative and efficient method is hand collection via Hookah diving techniques. Divers descend to the bottom of the lake, reservoir or river and selectively harvest legal size specimens of target species. Because approximately 72% of the 297 native North American freshwater mussels (Bivalvia: Unionidae and Margaritiferidae) are endangered, threatened or of spe-

cial concern (Williams et al., 1993), much management attention has become focused on developing harvest regulations and management goals that ensure the long-term sustainability of this faunal group and fishery.

Historically, several methods have been employed to limit the harvest of unionids. Early regulations set by government agencies lacked size limits or employed size limits that did not adequately protect the resource (Thiel and Fritz, 1993). Since these early regulations, states such as Ohio and Mississippi have completely closed their commercial fisheries of unionids, while other states have set limited harvest seasons and size limits (Thiel and Fritz, 1993). Currently, efforts are being made to standardize size limits of harvestable species in the United States (J. Garner, Alabama Game and Fish, personal communication). However, development of effective size limits is hampered by the lack of life history and population information about commercially harvested species. Governmental agencies (e.g. Arkansas Game and Fish Commission; Wisconsin Department of Natural Resources (DNR), Kansas DNR, United States Fish and Wildlife Service) have established freshwater mussel refuges, thereby protecting some habitats from harvesting and physical habitat degradation.

If size limits are to be used for regulating harvest and assuring sustainability, basin-specific growth curves for individual species need to be generated and compared before appropriate standardized size limits are implemented. Growth curves are generated using length (or some measure of size) at age for different aged organisms. In a comparison of four shell-aging techniques (ashing, thin sectioning, acetate peels and counting external annuli), thin sectioning was found to be the best method of accurate age determination (Neves and Moyer, 1988). Using this technique, age is determined by counting the internal annuli of shells sectioned to a thickness of 350 microns (Neves and Moyer, 1988). While single annuli have been used to represent one year of growth, recent reports suggest that any non-annual external annuli (i.e. less than one annulus per year) used with growth curves can greatly over estimate growth and under estimate age of unionids (Downing et al., 1992; Downing and Downing, 1993; Kesler and Downing, 1997).

Although internal growth lines may not always coincide with absolute measures of periodicity (regarding number of days), growth curves could be used to compare shell growth within drainage basins experiencing similar energetic processes. For example, thin-sectioning techniques were used to age *Elliptio complanata* from different substrata in a Rhode Island lake. Von Bertalanffy growth curves generated from those measurements showed that growth rate was more related to substratum types than calendar days for *E. complanata* (Kesler and Bailey, 1993). Other authors have also shown that mussels grow at different rates under differ-

ent environmental conditions (e.g. Negus, 1966; Stansbery, 1967; Bailey and Green, 1988; Hinch et al., 1989). Therefore, it seems that growth curves generated from thin-sectioning techniques and von Bertalanffy growth equations can be used to investigate basin-specific growth and are reflections of the organisms' interactions with the environment via nutrient and energy expenditures.

This study is a component of a larger project that surveyed the commercial freshwater mussel beds in 10 rivers and three reservoirs in Arkansas between 1991 and 1997. The objectives of this study were 1) to construct von Bertalanffy growth curves for selected "commercially-most-valuable" species, (i.e. *Fusconaia ebena, Megalonaias nervosa, Amblema plicata* and *Quadrula quadrula*), from each of the five rivers or two reservoirs investigated, 2) to compare species-specific von Bertalanffy growth curves from pairs of rivers and a pair of reservoirs, and 3) to provide information about size at onset of sexual maturity in *Fusconaia ebena* and *Amblema plicata*.

Methods and Materials

Study Areas.--The White River originates in northwest Arkansas and flows for approximately 1,210 km. It drains approximately 75,520 km^2 of the Ozark Plateau and Mississippi Alluvial Plain physiographic provinces before entering the Arkansas River 16 km above its confluence with the Mississippi River. The White River was surveyed for freshwater mussel aggregations from the mouth to 416 km upstream (Fig. 1; Christian, 1995). The lower 240 km of the Black River that was surveyed in Arkansas is located in the Mississippi Alluvial Plain and drains approximately 22,165 km^2 before joining the White River (Rust, 1993). The Cache River, another tributary of the White River, is 229 km in length and drains 5,227 km^2 of the Mississippi Alluvial Plain. Only the lower 68 km of the Cache River, which is the portion of the river that is commercially harvested for unionids, was surveyed (Christian, 1995). The St. Francis River is a tributary of the Mississippi River and in Arkansas drains 13,466 km^2 within the Mississippi Alluvial Plain. The lower 200 km of the St. Francis River were surveyed (Posey, 1997). The Ouachita River, a tributary of the Red River, drains 17,411 km^2 of the Gulf Coastal Plain physiographic province. The lower 248 km of the Ouachita was surveyed (Posey, 1997). Ozark and Dardanelle lakes, formed by lock and dam units of the Kerr-McClellan Arkansas River Navigation System, were surveyed in 1996. They have surface areas of 4,291.5 and 12,591 ha, respectively (Davidson, 1997). All study drainages are located in the lower Mississippi River Basin.

Experimental Design.--The commercially-most-valuable unionid species, based on Arkansas Game and Fish harvest records, was collected from each river during sever-

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Fig. 1. Study areas (shaded) in the White, Black, Cache, St. Francis and Ouachita rivers and Ozark Lake and Lake Dardanelle (Arkansas River), Arkansas.

al field seasons plus an additional population of *Amblema plicata* was collected from the White River to compare with the Ouachita River *A. plicata* (Table 1). These four species of Unionidae, *Fusconaia ebena*, *Megalonaias nervosa*, *A. plicata* and *Quadrula quadrula*, belong to the subfamily Ambleminae, whose species are characterized by large thick shells, a lack of sexual dimorphism, hook-less glochidia, and

a relatively long life span. These four species are generally widely distributed in the Mississippi River Basin (Oesch, 1984; Cummings and Mayer, 1992; Vidrine, 1993).

Fusconaia ebena broods from April to September (Gordon and Layzer, 1989), has five known fish hosts from the families Centrarchidae (4) and Clupeidae (1) and reaches a maximum depth (dorsal to ventral margin of the shell) of 10.2 cm (Cummings and Mayer, 1992). *Megalonaias nervosa* is one of the largest unionid species reaching a depth of 27.9 cm (Cummings and Mayer, 1992), and there are 18 known fish hosts from the families Centrarchidae (5), Ictaluridae (5), Clupeidae (2), Amiidae (1), Anguillidae (1), Catostomidae (1), Percichthyidae (1), Percidae (1) and Sciaenidae (1). *Megalonaias nervosa* has been reported as both a short term and long term (bradytactic) brooder (Gordon and Layzer, 1989) with embryos or glochidia reported in the marsupium from September through February and also in April and May. *Amblema plicata* reaches a maximum depth of 17.8 cm (Cummings and Mayer, 1992), is a short-term (tachytictic) brooder from May to August, and 13 fish species representing the families Centrarchidae (7), Percidae (2), Esocidae (1), Ictaluridae (1), Lepisosteidae (1) and Percichthyidae (1) are known as hosts to the larval mussel stages (Gordon and Layzer, 1989; Watters, 1994). *Quadrula quadrula* reaches a maximum depth of 14 cm (Couch, 1997), broods young from April through August (Gordon and Layzer, 1989), and only one fish species, the ictalurid *Pylodictus olivaris*, has been reported as a fish host (Oesch, 1984).

Each species was collected from a variety of substrate types, water depths, and locations while diving within each water body. Specimens were fixed in a 10% formalin solution for transport to the laboratory. All soft tissue of each individual was removed in the laboratory, and shells were numbered and allowed to dry. Shell length (anterior to posterior margin), shell depth (dorsal to ventral margin) and shell width (right to left umbonal region) were measured in

Table 1. Commercially-most-valuable species collected.

Species	Location	Collection dates	Number collected
Fusconaia ebena	White River	July - October 1991-1994	52
	Black River	May - October 1991-1992	39
Megalonaias nervosa	Cache River	May - July 1993	38
	St. Francis River	May - July 1994	48
Amblema plicata	White River	June 1997	22
	Ouachita River	May - October 1993-1995	50
Quadrula quadrula	Ozark Lake	May - September 1996	49
	Lake Dardanelle	May - September 1996	49

mm using dial calipers. Age was estimated for each individual using internal growth lines visible following the thin-sectioning of shells after the methods of Neves and Moyer (1988). Growth curves were estimated for each population using the von Bertalanffy growth equation (Ricker, 1975), defined as:

$$1_t = L \infty \left(1 - e^{-k(t-t_0)} \right)$$

where 1_t is the length at time (t, years) of capture, $L \infty$ is the asymptotic length, k is the growth constant and t_0 is length at time zero. In addition to calculating the von Bertalanffy growth equation for length, equations were also developed for depth and width measurements. All four species investigated in this study are regulated by size limits based on shell depth, therefore growth estimates and models were developed for shell depth in order to relate to the harvest size parameter. Fitted von Bertalanffy growth curves were created in SAS using the Gauss-Newton method of non-linear least squares iterative phase (SAS INSTITUTE, 1988). For each size prediction of an age, 95% confidence intervals (CI) were estimated. To test whether there were significant differences in growth curves between populations, calculated F values were determined using methods reported in Chen et al. (1992) and compared with critical F with the appropriate degrees of freedom of the numerator and denominator. This method compares the summed residual sum of squares (RSS) error of individual growth models to the RSS error of a pooled data model. A significant difference between estimated parameters (i.e., L, k or t_0) of each

von Bertalanffy model was based on non-overlapping ranges of the 95% CI.

Sexual maturity (i.e. production of gametes) was determined for two species, *Fusconaia ebena* and *Amblema plicata*, for which published data on sexual maturity are minimal to non-existent. No determination of *Megalonaias nervosa* sexual status was attempted because information was available on *M. nervosa* from Pool 10 in the upper Mississippi River which reported this species to become reproductively mature by age eight (Woody and Holland-Bartels, 1993). Individuals used for sexual maturity analysis were collected in the summer of 1997 from the White River between Newport and Augusta, AR and collected separately from individuals used for shell thin-section analysis. No determination of *Quadrula quadrula* sexual status was attempted because no individuals were collected for analysis in 1997. Size measurements were recorded in the same fashion as reported previously. Sexual maturity was determined by removing gonadal tissues using a biopsy needle, smearing gonadal tissue on a standard microscope slide, and determining the presence of gametes in each individual using a compound microscope under 10x, 100x and 400x magnification.

Results

Growth parameters for depth, length and width measurements for the Black River and White River *Fusconaia*
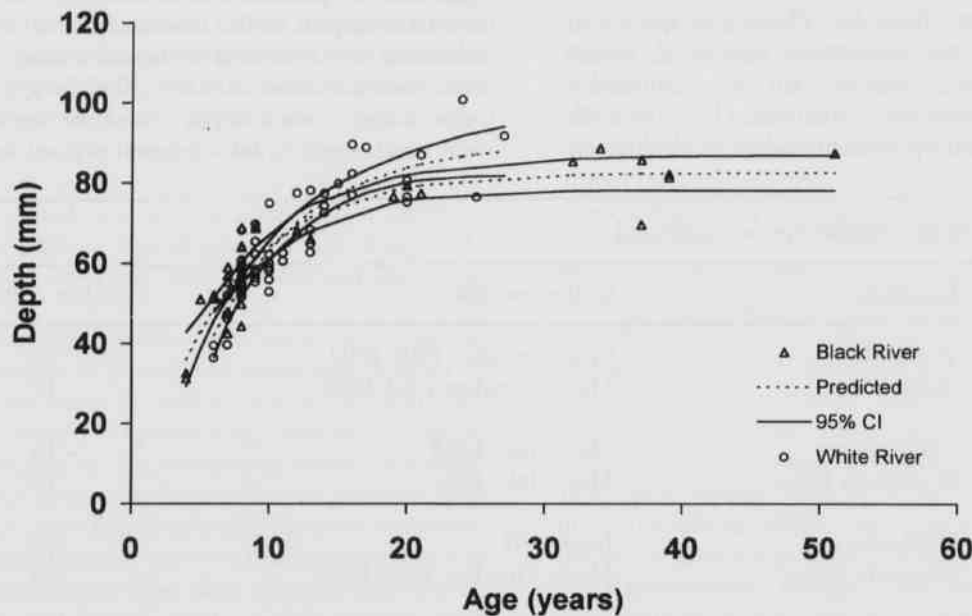

Fig. 2. Estimated von Bertalanffy growth curve with 95% confidence intervals and observed age vs. depth of *Fusconaia ebena* of the Black and White rivers, Arkansas.

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ebena are reported in Table 2. The fitted von Bertalanffy growth curves for the depth measurement of *F. ebena* from the Black and White rivers are illustrated in Fig. 2 and were found to be significantly different based on a comparison of pooled versus summed individual RSS models ($P < 0.001$, Table 3). Sexual maturity, or first sign of gametes, in *F. ebena* was determined to occur at a depth of at least 46.7 mm in individuals ranging in depth from 46.7 to 81.0 mm (n = 26),

however, production of gametes probably occurs at a smaller size than our size range.

Fitted growth curves for *Megalonaias nervosa* from the Cache River and St. Francis River are illustrated in Fig. 3. There was a significant difference between the Cache River and St. Francis River growth curves for the depth measurement based on a comparison of pooled versus summed individual RSS models ($P < 0.001$, Table 3). Table 2 sum-

Table 2. Estimated von Bertalanffy growth parameters, asymptotic length (L∞), growth constant (k) and length at time zero (t_0), for selected species and drainages with 95% confidence interval (CI) in parentheses. Superscripted letters a-d indicate significant differences in growth parameters based on non-overlapping 95% CI.

| Species	Parameter	Location	L	k	t_0
Fusconaia ebena					
	Depth	Black	82.61 ± (4.42)	0.16± (0.06)	0.35 ± (1.94)
		White	90.30 ± (9.46)	0.14± (0.06)	1.62 ± (2.30)
	Length	Black	102.19 ± (5.98)	0.14± (0.06)	0.41 ± (2.0)
		White	115.91 ± (13.48)	0.13± (0.06)	2.09 ± (1.88)
	Width	Black	57.88 ± (3.22)	0.18± (0.06)	0.54 ± (1.98)
		White	61.30 ± (7.16)	0.16± (0.10)	1.35 ± (3.26)
Megalonaias nervosa					
	Depth	Cache	131.06 ± (14.36)	0.06± (0.02)	0.16 ± (1.52)
		St. Francis	144.83 ± (45.10)	0.03± (0.04)	-24.50 ± (25.20)
	Length	Cache	239.22 ± (43.92)	0.08 ± (0.02)	-1.07 ± (2.04)[a]
		St. Francis	217.79 ± (42.52)	0.04± (0.04)	-14.33 ± (11.96)[a]
	Width	Cache	184.73 ± (224.10)	0.01± (0.02)	-4.98 ± (5.78)
		St. Francis	70.62 ± (4.32)	0.07± (0.06)	-6.16 ± (9.10)
Amblema plicata					
	Depth	White	100.20 ± (25.86)[b]	0.11± (0.14)	1.01 ± (8.18)
		Ouachita	61.69 ± (3.96)[b]	0.17± (0.06)	-0.03 ± (1.34)
	Length	White	137.96 ± (42.10)[c]	0.09± (0.12)	0.83 ± (8.04)
		Ouachita	87.02 ± (7.80)[c]	0.13± (0.04)	-0.34 ± (1.50)
	Width	White	57.70 ± (5.68)[d]	0.19± (0.16)	3.19 ± (4.84)
		Ouachita	39.37 ± (2.90)[d]	0.17± (0.8)	-0.51 ± (1.88)
Quadrula quadrula					
	Depth	Dardanelle	73.14 ± (4.84)	0.14± (0.40)	0.10 ± (0.86)
		Ozark	8.08 ± (31.28)	0.09± (0.06)	0.01 ± (1.64)
	Length	Dardanelle	99.36 ± (11.32)	0.09± (0.03)	-0.88 ± (0.58)
		Ozark	19.96 ± (36.90)	0.10± (0.08)	-0.03 ± (0.85)
	Width	Dardanelle	49.16 ± (3.66)	0.13± (0.02)	0.01 ± (0.94)
		Ozark	60.07 ± (14.88)	0.11± (0.08)	0.08 ± (0.77)
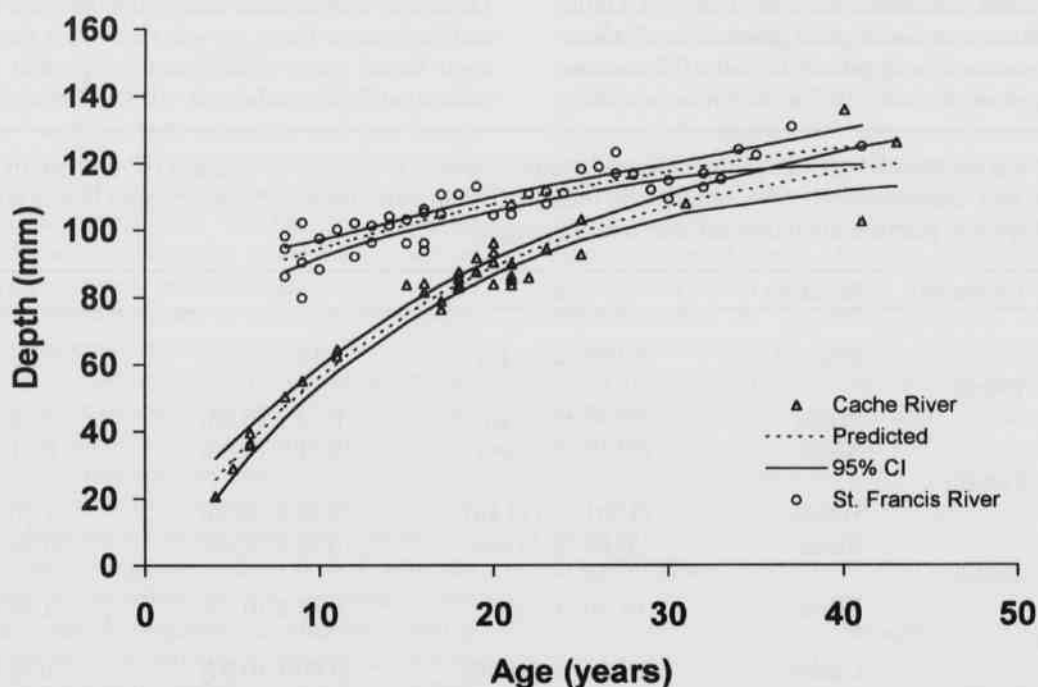
Fig. 3.   Estimated von Bertalanffy growth curve with 95% confidence intervals and observed age vs. depth of *Megalonaias nervosa* of the Cache and St. Francis rivers, Arkansas.

marizes growth parameters for all size measurements.

    Amblema plicata depth measurement growth curves for the Ouachita River and White River are shown in Fig. 4 and were found to be significantly different based on a comparison of pooled versus summed individual RSS models ($P <0.001$, Table 3). Growth parameters for all size measurements are summarized for this species and were found to be significantly different in the L growth parameter (asymptotic depth, length and width) based on non-overlapping 95% confidence intervals (Table 2). In *A. plicata* from the White

River, gametes were first observed at 21.9 mm in depth from individuals (n = 25) ranging from 16.4 to 41.3 mm.

    Growth curves for the depth measurement of *Quadrula quadrula* from Ozark Lake and Lake Dardanelle are illustrated in Fig. 5 and were found to be significantly different based on a comparison of pooled versus summed individual RSS models ($P <0.001$, Table 3). *Quadrula quadrula* size measurement growth parameters for Ozark Lake and Lake Dardanelle are reported in Table 2.

Table 3.   Species comparisons of growth modeled by von Bertalanffy growth formula by means of residual sum of squares (RSS) for pooled data (RSSp) and summed data (RSSs) including statistical significance.

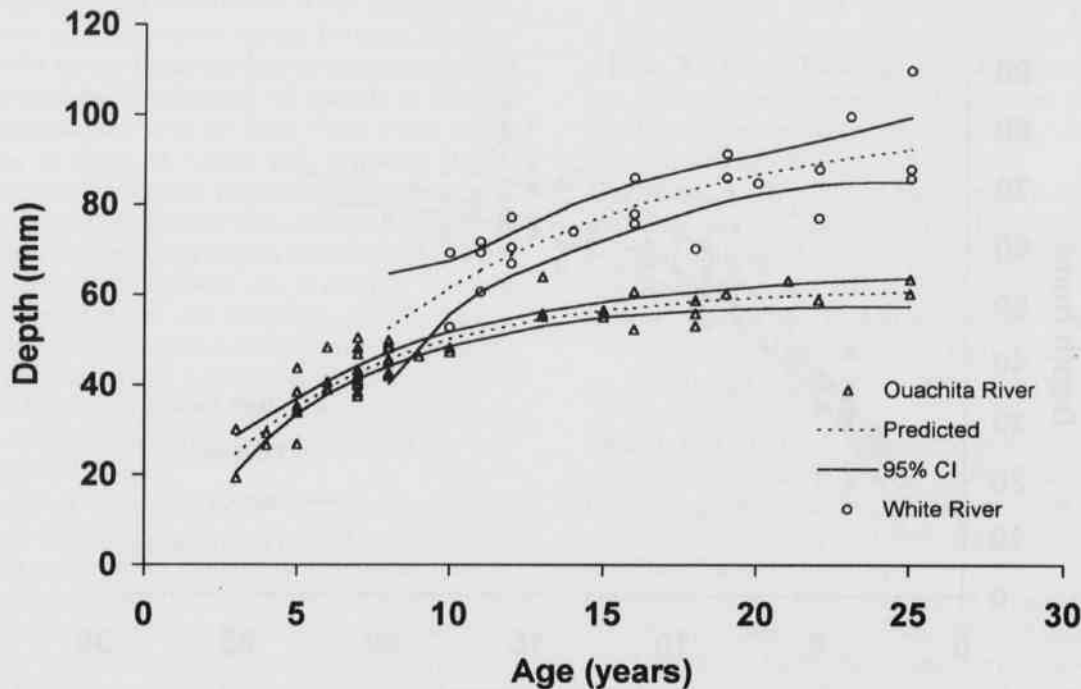| Species	RSSp	DF	RSSs	DF	F	Pr>F
Fusconaia ebena	3738.20	88	3317.56	85	67.44	<0.0001
Megalonaias nervosa	16434.87	83	2446.89	80	510.66	<0.0001
Amblema plicata	4374.40	95	3290.34	92	91.64	<0.0001
Quadrula quadrula	7215.25	70	1940.77	67	226.75	<0.0001

Amblema plicata

Fig. 4. Estimated von Bertalanffy growth curve with 95% confidence intervals and observed age vs. depth of *Amblema plicata* of the Ouachita and White rivers, Arkansas Predicted and 95% CI lines illustrated.

Discussion

The error of the pooled *Fusconaia ebena* models was greater than the individual summed models for depth indicating that the individual models for each river best explain the data. *Fusconaia ebena* from the Black and White rivers had significantly different growth (Fig. 2) even though individuals were taken from portions of their respective rivers found in the same Mississippi Alluvial Plain physiographic province. Whereas many of the mussel bed substrata were at least qualitatively similar, either soft-to-hard clay or gravel substrata (Rust, 1993; Christian, 1995), it is likely that some abiotic and/or biotic factors differed in the rivers. For example, the White River flows approximately 800 km in the Ozark Plateau physiographic province upstream of the study area and has different limnological parameters, such as calcium concentrations, than the Black River which is located mainly in the Mississippi Alluvial Plain. In addition, temperature differences due to hypolimnetic release dams on the White River (Miller et al., 1987), may also influence growth which may explain the slight differences in the growth rates (k) between White River and Black River models.

Megalonaias nervosa individuals were also collected from rivers that are located in the same physiographic province, the Mississippi Alluvial Plain, even though the headwaters of the St. Francis originate in the Missouri Ozarks. Again, abiotic and biotic factors are assumed to be similar. For example, substrates of defined mussel beds were qualitatively similar between the Cache and St. Francis rivers with mostly soft-to-hard clay to silty substrates mixed with sand (Christian, 1995; Posey, 1997). Nevertheless, the pooled RSS was much greater than the summed individual models suggesting differences in the models. One possible explanation for differences in the growth models may be the lack of small individuals collected from the St. Francis River (Figure 3). Asymptotic size seems similar in both rivers as does growth rate, but size at age zero is quite different. Lack of small *M. nervosa* individuals in the St. Francis River model may have influenced this parameter.

The pooled *Amblema plicata* model reflected more variance than the summed individual models suggesting differences between the individual models (Fig. 4, Table 3). The non-overlapping 95% confidence intervals in asymptotic (L) length, depth and width between the Ouachita River and White River suggest that some species of freshwater mus-
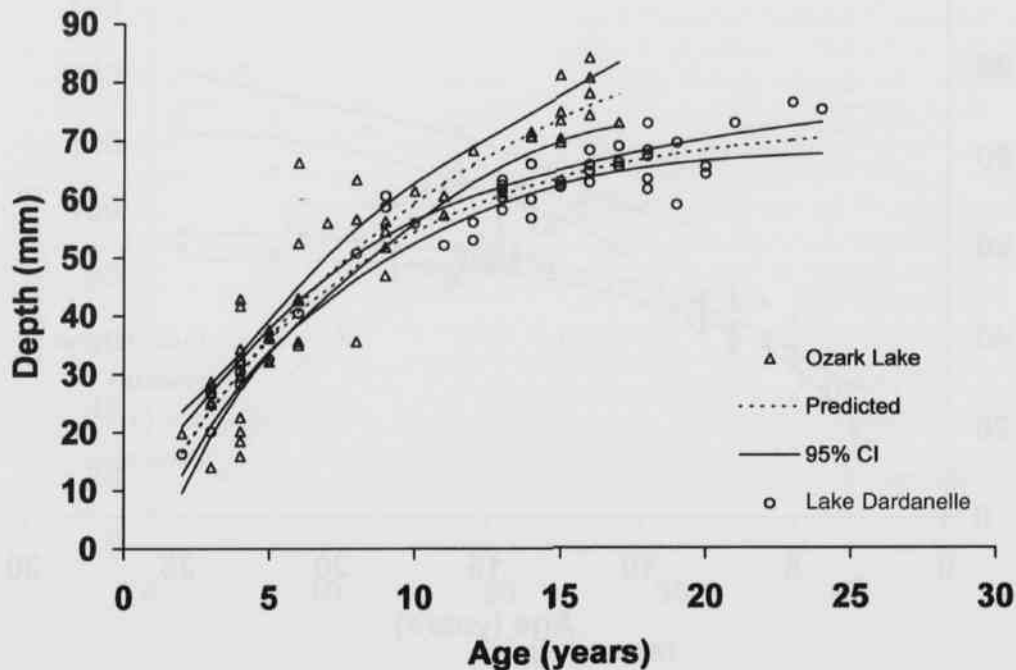
Growth Curves of Four Species of Commercially Valuable Freshwater Mussels (Bivalvia: Unionidae) in Arkansas

Quadrula quadrula

Fig. 5. Estimated von Bertalanffy growth curve with 95% confidence intervals and observed age vs. depth of *Quadrula quadrula* of the Ozark Lake and Lake Dardanelle, Arkansas.

sels, including *A. plicata*, in the Ouachita mid-order stream reaches tend to be smaller in overall size than in other streams in Arkansas (Fig. 4; WRP and JLH, pers. observ.). Within our survey sites, the Ouachita River basin substrate has a greater component of gravel compared to the dominant clay/sand substrates of the lower White River (Christian, 1995; Posey, 1997). Bailey and Green (1988) found that mussels in areas of high turbulence and sandy substrate had thicker shells than those from less turbulent areas. In addition, mussels from more turbulent areas grew at a faster rate. Alternatively, Kesler and Bailey (1993) reported that *Elliptio complanata* grew at a faster rate in the silt substratum. However, they speculated that individuals in the silt substratum may have had a richer food supply, which increased their growth rate, or that the individuals in the sand substratum were located in extreme turbulence, reducing their growth. Ambient water quality conditions can also contribute to the above mentioned basin habitat factors to differentiate growth. Low water hardness of 20 mg $CaCO_3$/L as in the Ouachita River would be sufficient to reduce shell size when compared to individuals from the White River with calcium hardness of 140 mg/L (Posey, 1997).

Growth rate (k) of *Amblema plicata* was not significantly different, based on overlapping 95% confidence intervals, between the Ouachita River and White River, which would not have been predicted because asymptotic growth is different between the two populations. This suggests that while rates are similar, there comes a point at which growth decreases earlier in Ouachita River than the White River. Growth senescence as indicated by a flattening of the growth curve might suggest the occurrence of a life history trade-off. Use of energy and mineral resources for reproduction may be a trade-off in locations where calcium or other resources are limited (e.g., Ouachita River).

Similarities in growth parameters of *Quadrula quadrula* populations from the two reservoirs were expected due to the similar abiotic and biotic conditions of the reservoirs; however, summed individual reservoir models were less variable than a pooled model again indicating that the individual models for each reservoir best explained the data (Fig. 5, Table 3). Substrata of mussel beds were similar, consisting of silt (Davidson, 1997).

While we acknowledge the controversy as to whether an annulus is deposited each year, we still believe that thin-sectioning combined with von Bertalanffy growth curves

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can be used effectively to compare growth between populations within a region. It is understood that these models can underestimate age and overestimate growth (Kesler and Downing, 1997), but within the context of our comparisons, we assumed these processes to be similar between the populations. In order to use these models to estimate age and growth of populations, verification of annuli is needed through experimentation over at least three years using methods similar to those of Kesler and Downing (1997). While assuming that ecological processes, (e.g. those that influence energy expenditures and allocations in mussels) of rivers and/or reservoirs within a region are similar, we have shown that differences in growth are occurring between mussels from different rivers and reservoirs. These growth differences could have management implications, especially when considering size/age at legal harvest. Therefore we have shown that basin specific growth in these species needs to be considered when managing the commercial component of this imperiled fauna.

The thin-section aging and von Bertalanffy growth curve techniques utilized in our study could contribute to components of a multi-phase management scheme consisting of 1) employment of standardized sampling methods by managers to consistently estimate population size and monitor population dynamics (e.g. dominant cohorts), 2) investigation of life history characteristics such as drainage-specific growth, sexual dimorphism, age at sexual maturity, brood size, brooding strategies (short-term versus long-term) and characterization of size class survivorship for individual species, 3) establishment and maintenance of regional refuge areas along the stream system, and 4) reporting of specific harvest locations and numbers taken by commercial harvesters at shell buying sites.

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A Method to Predict the Potential Regional Long-Term Timber Supply Using GIS and Other Publicly Available Data

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Abstract

While the global demand for wood products is on the rise, timber production has shifted from the Pacific Northwest to the southeastern United States in recent times. The increase in harvesting makes accurate assessment of the South's wood supply essential. A new method is proposed for looking at the potential supply of raw woody material. The test area was three southeastern Arkansas counties. A geographic information system (GIS) using ArcView software incorporates two sources of public information. First, Forest Inventory and Analysis (FIA) data from the USDA Forest Service were queried to find land areas and volumes by timber type, as well as growth and removals. Second, Gap Analysis Program (GAP) data were included to delineate land cover patterns. FIA growth rates were applied to the corresponding timber types. Additionally, vector layers such as roads, streams, and power lines were buffered, and those areas were then subtracted from forested land cover types. The losses to buffered areas were approximately 7 percent. The FIA data were manipulated to determine a cubic meter growth rate per year. The study revealed that the study area is capable of supplying 2,034.7 thousand cubic meters of wood per year, while the FIA data for the same area showed 2,150.9 thousand cubic meters. With both the FIA and GAP data being updated every 5-10 years, values can easily be updated to reflect changes.

Introduction

Global demand for wood products is on the rise. Timber production has shifted from the Pacific Northwest to the southern and eastern United States in recent times. The increases in harvesting make accurate inventories of the South's wood supply essential. This report looks at a method for determining the potential raw woody material supply in three southeastern Arkansas counties: Drew, Ashley and Bradley (situated within the coastal plain). All three counties have private industrial forest (timber company) lands, non-industrial private forest (NIPF) land ownerships and various state and federal holdings. The area is under intensive forest management, predominantly loblolly pine production. Several primary wood processing facilities are located within the counties, and these require a constant flow of raw materials. Accurate assessments of the timber supply within the procurement zones of these facilities are critical to the long term sustainability of the mills and the timber resource.

There are two sources of public information that are available to help predict the timber supply. The USDA Forest Service conducts its forest inventory and analysis (FIA) program approximately every 8 years to provide forest statistics for each state; the latest available data for Arkansas is 1995. Their reports include the hectares and volumes by timber type and county, as well as the growth and removals. Published tables enable one to calculate the potential average volume growth per hectare by county and timber type. The other source of information is the Gap Analysis Program (GAP). The GAP data are sponsored by the Biological Resources Division of the U.S. Geological Survey and are produced from Landsat Thematic Mapper (TM) satellite imagery. Arkansas GAP data were completed in 1998, and the project's mission is to update the imagery (and data) every 5-10 years (Scott and Jennings 1997). The GAP coverages are in the form of delineated polygons that represent different land cover patterns. The objectives of this paper are to use both sources to determine the productive timber-growing areas of the three counties, attach a growth rate to those regions, and finally to estimate the annual sustainable timber supply.

Methods

Using the Geographic Information Systems (GIS) software ArcView 3.1 (ESRI, Redlands, CA), the data for the land cover classes was analyzed and manipulated. All the data files used in the process are available on the internet from the Natural State Digital Database (NSDD) at the University of Arkansas at Monticello (Weih 2000). Most county coverages are at a spatial resolution of 1:100 000 but some of the statewide data is 1:250 000. USDA data for growth rate is also available on the worldwide web at the Southern Region Forest Inventory and Analysis (USDA Forest Service 2000). At their website, one can specify the

county(ies) of interest and either get the standard forest statistics tables or request custom ones.

Several steps were involved in determining productive timber-growing regions in the three county area. Our approach was to use a 1:100 000 land cover file from the GAP data to group the timber into our areas of interest. In our three-county area, there were 10 or 12 categories of forested land, and we collapsed those into three: pine, hardwood, and swamp hardwood. Pine includes loblolly and shortleaf pine areas, as well as any oak/pine polygons. The oak/pine category was lumped in with pine because it is assumed that these primarily upland sites will be converted to pine production in the future. Hardwoods are generally those species represented in bottoms, such as willow oak, sugarberry, nuttall oak, and anything else that cannot survive in swampy areas. Swamp hardwoods include cypress, gum, and overcup oak. These categories were chosen in part to correspond with the FIA data. After collapsing the timber categories, the next step was to clip out urban areas since there were some timber areas that overlapped these boundaries (Fig. 1). At this point, there are three timber types and the areas representing each are computed.

There are interruptions in the form of roads, power lines, railroads, and streams that need to be removed from timber-growing consideration. The vector coverages for these linear features were available from the NSDD; they were therefore incorporated into the analysis. A line itself does not do an adequate job of representing the space taken up by one of these corridors, so buffering was necessary. We decided to use 18.3 meters total width for all roads and railroads and 61.0 m for utilities. A common practice along streams is to leave a management zone approximately one tree height on either side, so we chose 20.1 m on each side for a total width of 40.2 m along streams. As each vector coverage is buffered, the software computes the total area inside the new boundaries. Although this buffered area is spread over the entire county, and our interest lies only inside the polygons represented by non-urban forests. Fortunately, there is an extension for ArcView called Xtools available from the Oregon Department of Forestry (DeLaune 1999) that allows one to clip out the buffered areas by timber type. For each of the three timber types, all four buffers are clipped out separately (Fig. 2), and the result is twelve new coverages. Now all that is required is to subtract the buffered areas from each timber type to get productive hectares (Fig. 3). The ability to account for this reduction in usable hectares is what provides the accuracy to this method of supply analysis.

Attaching a growth rate to the productive timber was our next goal. One technique that was considered (but not used) required the determination of a productivity measure such as site index. Soils coverages from the NSDD were available at a 1:100 000 level, but we felt that this was too coarse a resolution to accurately assign productivity. For each soil type, an average site index could have been gathered from soil surveys and applied to the tree timber types. Instead, the FIA data were manipulated to get a cubic meter growth per year. The FIA website supplied customized tables for "Areas of Timberlands" and "Growth of Growing Stock" for each forest type group (Appendix A). By grouping the FIA forest types to match ours, it was possible to create the basis for computing a growth rate. The FIA "Growth" table represents net annual growth, so dividing forest type growth by the number of hectares yields net annual growth per hectare.

The accuracy of the data is always of some concern. In

Fig. 1. Assigning timber types to the GAP data. Each land cover class is represented by a polygon in (a). In (b), the timber cover classes have been collapsed down into three categories: pine, hardwood and swamp hardwood. Note that the blank areas represent non-timber classes such as agriculture, pasture, water, or bare ground. Also, the urban areas are outlined and you can see that there is some overlap with the timber types. Therefore, (c) shows urban areas clipped out of the timber. The clipped timber regions represent the starting point for determining productive timber-growing areas.
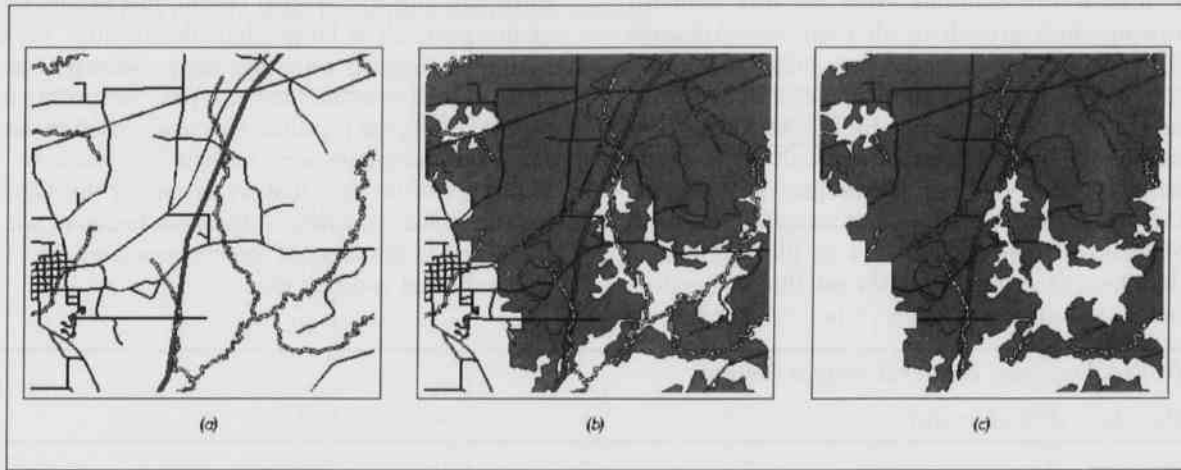
Fig. 2. The process of removing buffered areas from timber types. In (a), the streams, roads, utilities and railroads are assigned buffers of 40.2 m, 18.3 m, 61.0 m, and 18.3 m, respectively. Next, you can see the overlay of the pine timber type in (b). Finally, the buffered areas are clipped to the boundaries of the pine areas (c). The areas for the buffers can then be subtracted from timbered areas to get only timber areas in production, and this step is repeated for all three timber types.

LEGEND

Pine	282,948.3 ha
Hardwood	124,274.5 ha
Swamp hardwood	33,163.0 ha
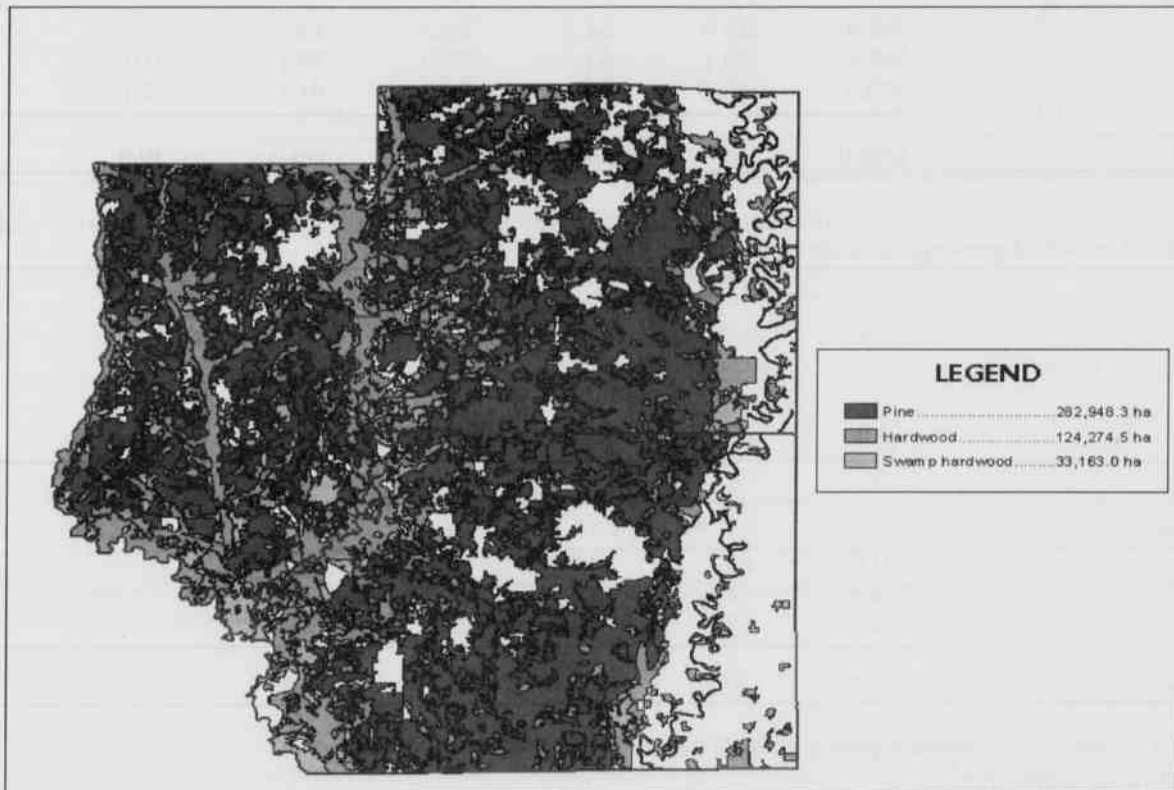
Fig. 3. Three counties showing areas classified as pine, hardwood, and swamp hardwood. Areas are based on original GAP data with subtractions for buffered corridors and cities.

the FIA publication, the sampling error (for one standard error) of growing stock growth in all southwest Arkansas counties is 2.7 percent (Rosson and others 1995). If we narrow that to the three counties of interest, the sampling error is approximately 6.7 percent (Appendix B). The GAP data certainly has error, but it is more difficult to quantify because each state uses different techniques to meet the national GAP standards. Because the original source is Landsat TM imagery, there will always be the problem of mixed pixels, where each pixel from the satellite image does not represent a homogenous cover type. According to

Burrough and McDonnell (1998), this occurs when the size of the grid cell is larger than the feature on the ground. Error is associated with both the positional accuracy as well as classification of land cover types. According to the CAST report (1998), the positional accuracy is 50 m, and several of the forest categories were at least 75% accurate. While that is not great, we feel that by grouping the GAP categories together, the accuracy improved because we were only interested in the areas of forests associated with upland, bottomland, and swampy sites.

Appendix A. FIA Database Retrieval System Output

Custom table - Area of timberland

			Forest type group			
County	All	Loblolly-shortleaf pine	Oak-pine	Oak-hickory	Oak-gum cypress	Elm-ash-cottonwood
			-thousand acres-			
Arkansas						
Ashley	387.0	218.0	54.5	54.5	54.5	5.5
Bradley	377.4	170.4	54.8	73.0	79.1	0.0
Drew	373.5	163.7	87.0	56.3	61.4	5.1
All counties	1138.0	552.2	196.3	183.8	195.0	10.6

Custom table - Growth of growing stock on timberland

			Forest type group			
County	All	Loblolly-shortleaf pine	Oak-pine	Oak-hickory	Oak-gum cypress	Elm-ash-cottonwood
			-million cubic feet-			
Arkansas						
Ashley	31.6	23.7	2.8	2.4	2.7	
Bradley	22.4	14.4	3.3	1.9	2.9	
Drew	22.5	12.1	5.4	2.7	2.3	
All counties	76.6	50.2	11.4	7.0	8.0	

- Timberland consist of nonreserved land only in this table
  for the following states: (AR).
- Numbers in rows and columns may not add to totals due to rounding.
- The data are derived by sampling and are subject to statistical error.
- Source Southern FIA : Asheville, NC
    States:(AL,AR,FL,GA,KY,LA,MS,NC,OK,SC,TN,TX,VA)
    For assistance contact: Joe Glover 704-257-4350
    homepage http://www.srsfia.usfs.msstate.edu

Jeffrey Earl, Richard Kluender, and Robert Brewington

Appendix B. Calculation of Sampling Error for Counties of Interest

Custom table - Growth of growing stock on timberland on Southwest Arkansas counties

County	All	Loblolly-shortleaf pine	Oak pine	Oak hickory	Oak-gum cypress	Nontyped
				-million cubic feet-		
Ashley	31.6	23.7	2.8	2.4	2.7	0.0
Bradley	22.4	14.4	3.3	1.9	2.9	0.0
Calhoun	25.8	17.6	5.2	1.4	1.5	0.0
Clark	26.6	16.7	6.5	2.6	0.8	0.0
Cleveland	24.5	12.1	6.1	4.2	2.1	0.0
Columbia	30.3	18.7	4.2	4.7	2.7	0.1
Dallas	27.5	19.5	4.4	2.0	1.7	0.0
Drew	22.5	12.1	5.4	2.7	2.3	0.0
Grant	26.7	20.2	2.0	3.2	1.3	0.0
Hempstead	27.0	15.2	4.1	6.2	1.6	0.0
Hot Spring	23.5	13.1	6.0	2.2	2.3	0.0
Howard	22.5	15.6	3.6	2.5	0.9	0.0
Lafayette	16.4	10.8	1.9	3.2	0.5	0.0
Little River	13.4	7.7	2.1	1.6	2.1	0.0
Miller	10.4	4.3	3.2	1.2	1.7	0.0
Nevada	22.7	14.2	3.8	4.1	0.5	0.0
Ouachita	25.2	14.7	5.8	1.5	3.3	0.0
Pike	23.3	18.0	1.6	3.5	0.2	0.0
Sevier	11.5	5.8	1.7	3.0	1.0	0.0
Union	40.8	24.7	7.2	3.2	5.6	0.0
All counties	474.5	298.9	80.8	57.0	37.6	0.1

Custom table - Growth of growing stock on timberland in Ashley, Bradley, and Drew counties

County	All	Loblolly-shortleaf pine	Oak pine	Oak hickory	Oak-gum cypress	Nontyped
				-million cubic feet-		
Ashley	31.6	23.7	2.8	2.4	2.7	
Bradley	22.4	14.4	3.3	1.9	.9	
Drew	22.5	12.1	5.4	2.7	2.3	
All counties	76.6	0.2	11.4	7.0	8.0	

The overall sampling error (SE_t) for Growing Stock Growth in southeast Arkansas is 2.7 percent. To compute sampling error for only the three counties of interest, this formula may be used:

$$SE_g = SE_t \frac{\sqrt{X_t}}{\sqrt{X_g}}$$

where

SE_g = standard error of the estimate (expressed as a percentage) for the group of counties
SE_t = standard error of the estimate (expressed as a percentage) for the total counties
X_g = total volume for the group of counties
X_t = total volume for the total counties

If you insert the total growth volume from the two tables above into the formula, you get the following:

$$SE_g = 2.7 \frac{\sqrt{474.5}}{\sqrt{76.6}} = 6.7$$

Journal of the Arkansas Academy of Science, Vol. 54, 2000

Table 1. Areas and usable areas by timber type for three counties

	Ashley County Hectares		Bradley County Hectares		Drew County Hectares	
Pine area	114,088.0		82,027.9		105,772.4	
Buffers:						
Streams		4,398.8		2,454.8		4,957.9
Roads		2,493.7		1,795.6		1,904.1
Railroads		110.2		69.6		75.2
Utilities		250.9		187.7		223.6
TOTAL Buffers	7,253.6		4,507.7		7,160.8	
Usable pine area	106,834.4		77,520.2		98,611.6	
Hardwood area	37,075.7		56,827.6		42,060.8	
Buffers:						
Streams		2,479.4		3,784.9		3,265.2
Roads		524.2		708.0		571.5
Railroads		36.8		57.0		15.6
Utilities		56.0		87.4		95.7
TOTAL Buffers	3,096.4		4,637.3		3,948.0	
Usable hardwood area	33,979.3		52,190.3		38,112.8	
Swamp hwd area	12,547.3		15,509.5		7,024.4	
Buffers:						
Streams		552.7		470.6		297.3
Roads		167.9		262.9		115.5
Railroads		10.3		11.8		3.8
Utilities		0.0		23.3		0.0
TOTAL Buffers	730.9		768.6		416.6	
Usable swmp hwd area	11,816.3		14,740.9		6,607.8	
Total Timber hectares	163,710.9		154,365.0		154,857.6	
Total Usable hectares	152,630.0		144,451.5		143,332.3	
Percent usable	93.2%		93.6%		92.6%	

Results and Discussion

Areas by county and timber type (using the GAP data), as well as the areas removed by buffered corridors are shown in Table 1. The three-county area has approximately 283,000 hectares of pine and 157,000 hectares of hardwoods in productive use (after the buffered areas were subtracted). The percent of total pine contained in the buffers ranged from 5.5 to 6.8 percent. Hardwood losses were from 8.2 to 9.4 percent, while swamp hardwoods lost 5.0 to 5.9 percent to buffers. Overall, buffers accounted for between 6.4 and 7.4 percent

Table 2 shows the production volumes for using both the FIA and GAP data, although the GAP volumes are based on the usable area. Because of this, there may be an overestimation of the timber supply using FIA hectare estimations. For instance, there is a discrepancy of over sixteen thousand cubic meters between the FIA and the GAP methods of determining supply for pine, and this is based solely on the differences between our method of area calculation and the FIA's method. By delineating the areas which are not in production, the GAP method should provide more accuracy, although it still relies on the FIA data for growth rates. So for the three counties, our annual projection for timber supply is 1,620.8 thousand cubic meters of pine, 318.0 thousand cubic meters of hardwood, and 93.5 thousand cubic meters of swamp hardwood. The inclusion of the 6.7 percent sampling error in these estimates using a 95

Table 2. Comparison of FIA and GAP data for three counties

FIA Data

Timber type	County		
	Ashley	Bradley	Drew
	Land Area (ha)		
Pine	110,236.5	91,175.8	101,495.3
Hardwood	22,014.9	29,542.1	22,783.8
Swamp	24,362.1	32,010.7	24,847.7
	Production (m³/yr)		
Pine	744,737.6	498,379.6	489,884.5
Hardwood	67,960.8	50,970.6	73,624.3
Swamp	79,287.7	84,951.1	59,465.7
	Growth rate (m³/ha/yr)		
Pine	6.8	5.5	4.8
Hardwood	3.1	1.7	3.2
Swamp	3.3	2.7	2.4

GAP Data

Timber type	County		
	Ashley	Bradley	Drew
	Land Area (ha)		
Pine	106,827.6	77,515.3	98,605.4
Hardwood	33,977.1	52,187.0	38,110.4
Swamp	11,815.6	14,740.0	6,607.4
	Production (m³/yr)		
Pine	721,446.4	423,556.1	475,763.4
Hardwood	104,850.5	90,008.6	123,106.4
Swamp	38,440.5	39,103.3	15,807.2

percent confidence interval yields the following computations:

Pine: $1620.8 \pm 1.96(.067*1620.8) = 1620.8 \pm 212.8$ thousand cubic meters

Hardwood: $318.0 \pm 1.96(.067*318.0) = 318.0 \pm 41.8$ thousand cubic meters

Swamp Hardwood: $93.4 \pm 1.96(.067*93.4) = 93.4 + 12.3$ thousand cubic meters

The usable areas have the potential to produce these amounts of raw woody materials available for purchase. Another big assumption is that this production will remain constant, which may or may not be realistic given the nature of forest cutting trends.

Conclusions

This model allows resource managers to look at the growth trends for an area from one period to the next.

Comparing growth to removals gives insight to the sustainability of the area's timber resources during the period. There is a definite imbalance in hardwood production and hardwood removals. The removals were far greater than the growth for all counties at the time the FIA data were published. This is due largely to the fact that pine plantations are replacing hardwoods on sites that are suitable for pine growth (mostly industrial forests), and this trend will probably continue until the sites able to grow pine have been converted. At that time the hardwood areas should stabilize and growth will remain fairly steady. It remains to be seen if there will be a large enough hardwood base to supply the wood needs of the hardwood processing facilities. Clearly the burden will fall on NIPF lands to make up for any shortcomings in hardwood supply. Comparing this period with future periods should uncover long-term trends in timber supply. With the GAP update every 5 to 10 years and the FIA data published every eight years, the two sources should never be more than five to eight years apart and can be used for future updates to a model like this.

Another potential use of supply information could be locating new mills. Timber companies could find areas with a potential wood supply that would sustain a new mill. It could also play a part in whether a mill decides to expand its current operation or keep operating at the same capacity. Accurately predicting the capabilities of an area to produce raw materials will be of increasing concern to mill operators in the coming years as the demand for wood products increases. This technique combined with FIA or some other method of determining growth could help to better predict an areas production potential.

We found this method to be fairly easy using ArcView and the resources of the worldwide web. It can also be customized to look at specific areas and specific species. Because the method uses FIA data, it does represent a dynamic growth model since FIA incorporates the previous survey's data with its newest data to produce the statistical reports. As noted earlier, caution should be taken when extracting individual counties or small groups of counties from the FIA data because the potential for sampling error is high.

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Home Ranges and Movements of Adult Deer on Fort Chaffee, Arkansas

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Abstract

We radio-tracked 27 white-tailed deer (*Odocoileus virginianus*) weekly for one year on Fort Chaffee, Arkansas, to investigate their seasonal home ranges and movements between hunted areas and refuges on this military base. This work resulted in 2,123 separate radiolocations, of which 85% (1,799) were suitable for use in home range analyses. We used the McPAAL computer package to estimate home range using the Harmonic Mean and minimum convex polygon (MCP) methods. Harmonic mean estimates were based on 95% contour lines. Home range size differed between the sexes and methods. Male home ranges were larger than those of females ($t = 3.32$, $P < 0.01$; harmonic mean) ($t = 2.07$, $P < 0.05$; MCP). Average home range sizes for males and females based on the harmonic mean method were estimated to be 483 ha and 181 ha, respectively, whereas home range estimates for males and females using the MCP method were 636 ha and 289 ha, respectively. The average home range size for all deer was 259 ha (harmonic mean) and 379 ha (MCP). We found no evidence that females restricted their home ranges during the fawning period. However, females' home ranges expanded during the breeding season, perhaps to find mates. Few deer moved to refuge areas that were off-limits to hunters during the hunting season.

Introduction

White-tailed deer (*Odocoileus virginianus*) generally occupy the same home range throughout their adult lives. This area must be large enough to encompass all the crucial resources necessary for survival and reproduction, yet small enough to allow a degree of familiarity that reduces energy expenditures and enhances survival (Marchinton and Hirth 1984). Consequently, home range size may change seasonally with changes in metabolic requirements, habitat productivity, foraging strategy, and reproductive status (McNab, 1963; Schoener, 1971; Clutton-Brock et al., 1982; Beier and McCullough, 1990; Relyea et al., 2000). Knowledge of the home range requirements of deer within a population can be useful to managers seeking to optimize the spatial distribution of food and cover within a management area. This research was conducted to provide information needed to make sound management decisions regarding deer habitat on Fort Chaffee. To better understand home range use in this population we sought to measure the mean size of annual and seasonal home ranges for adult males and females. We tested the following 4 hypotheses: (1) the annual home ranges of deer on Fort Chaffee would be smaller than those of deer in the Ozarks, (2) adult females would reduce home ranges during the fawning period when they tend to their fawns, (3) adult females would expand ranges during the breeding season, and (4) adult deer would seek the safety of non-hunted refuges within the study area during the hunting season.

Methods

Study Area.--Fort Chaffee is a 29,000 ha military base located approximately 18 km east of Fort Smith in western Arkansas. Most land consists of low east/west running hills typical of the Ouachita Mountain region and lower, more fertile land in the Arkansas River valley. Historically, the study area contained four major vegetation types: oak-hickory (*Quercus* spp.-*Carya* spp.) forests, oak-shortleaf pine (*Pinus echinata*) forests, bottomland hardwood forests, and tallgrass prairie (Braun 1950). With European settlement, farming and overgrazing reduced soil fertility and contributed to wind and water erosion (Sturdy et. al. 1991). Very little habitat improvement was implemented until Fort Chaffee was established in 1940; subsequently, much of the area was reforested by the Army. Current habitats on Fort Chaffee consist primarily of hardwood forests interspersed with early successional fields of various sizes. Excellent deer habitat is provided by extensive forest meadow ecotones, which are maintained by frequent fires ignited accidentally during training activities. This habitat supported a deer population that was approximately three times higher than those on the nearby Ozark and Ouachita National Forests at the time of this study (G. Wilks, Arkansas Game and Fish Commision, pers. comm.).

Hunting is prohibited on several areas of Fort Chaffee during the deer seasons because of their proximity to military activities. These areas comprise approximately 30% of the study area and may serve as refuges for deer during the hunting seasons.

Radio-tracking.--Deer were captured during January-

March 1995 using net guns fired from a helicopter or rocket-nets (Hawkins et al., 1968; Barrett et al., 1982). Each deer was immobilized with a mixture of 2.5 mg/kg of ketamine and 0.5 mg/kg of xylazine, aged (Severinghaus 1949), fitted with radio-collars (Advanced Telemetry Systems Inc, Isanti, MN 55040) and released at their capture site.

Each deer was located at least 3 times each week beginning 2 weeks after capture through January 1996. This 2-week delay allowed time for individuals to recover from the trauma of capture and return to normal daily routines. Individuals often were located more frequently, but access was sometimes restricted by military activities. Telemetry bearings were taken from 68 receiving stations with known UTM coordinates. A compass and yagi antenna were used to obtain the best bearing from receiver to radio-tagged deer.

Three or more bearings taken within a 15-minute interval were considered suitable for estimating a location (White 1990). Bearings were entered into the OTA computer program and the maximum likelihood method of triangulation was used to estimate locations and error ellipses (Lenth, 1981; Hoover, 1991). The average error ellipse of 100 random radio-locations was 1.6 ha. Azimuths derived during beacon tests had a mean error arc of $3.0 + 1.1°$ (x + SD). An alpha-level of 0.05 was used in analyses, indicating that there was a 95% probability that a specific radio-location was found inside its error polygon.

The McPAAL computer package (Stowe and Blowhowiak, 1986) was used to estimate home range using the harmonic mean and minimum convex polygon (MCP) methods (Mohr, 1947; Dixon and Chapman, 1980). The harmonic mean analysis is based on the premise that most animals do not utilize their entire home range areas with equal intensity, but tend to occupy certain core areas within their home range with greater frequency (Hayne, 1949). Harmonic mean estimates were based on 95% contour lines, indicating a 95% probability that the deer will be found inside this line at any given time. We also calculated home range size using the MCP method because its prevalence in the deer literature allowed us to compare our results with previous studies. The shapes of individual home ranges were categorized as circular, elongated or irregular as described by Stumpf and Mohr (1962).

We tested whether adult females restricted their home ranges during the fawning season by comparing mean home range size during this period to home ranges prior to fawning. We considered the fawning period to be May 20-June 20, a period that encompassed the peak of fawning during the first half of June (Nelson 1990). Radiolocations recorded from April 15 to May 15 were used to calculate home ranges prior to fawning. We also tested whether females expanded their home ranges during the breeding season by comparing home range size during this period (November 1-December 15) to range size during the pre-breeding period (September 15-October 31).

Two-sample t-tests were used to test for differences in home range size between the sexes and between deer inhabiting refuge areas versus hunted areas of Fort Chaffee. Paired t-tests were used to test for differences in seasonal range size for females during the fawning versus pre-fawning periods and during the breeding versus pre-breeding periods (Spatz 1993).

Results

Twenty-seven deer (7 males, 20 females) were radio-collared and located on 2,123 occasions from February 1995 through January 1996. Of these, 1,799 (85%) locations were suitable for use in home range analyses. Home range size differed between the sexes and methods (Table 1). Male home ranges were larger than those of females ($t = 3.3$, $P < 0.01$; harmonic mean) ($t = 2.1$, $P < 0.05$; MCP) than those of females. Average home range sizes for males and females based on the 95% contour of the harmonic mean method were 483 ha and 181 ha, respectively, while home range estimates for males and females using the MCP method were 636 ha and 289 ha, respectively. The average home range size for all deer was 259 ha (harmonic mean) and 379 ha (MCP). Forty-eight percent of home ranges were elongated, with the remaining 52% exhibiting circular patterns.

The mean home range size for females did not differ significantly between the prefawning and fawning period ($t = 0.45$, $P = 0.66$). Home ranges during the fawning period averaged 37.7 ha, whereas pre-fawning ranges averaged 34.2

Table 1. Mean, standard error, and range of home range sizes of male and female whitetailed deer determined by two techniques on Fort Chaffee, Arkansas.

Sex	N	Harmonic Mean (95% contour)			Minimum Convex Polygon		
		Mean	S. E.	Range	Mean	S. E.	Range
Males	7	482.7 ha	88.2 ha	158-811 ha	636.4	233.4	178-1432 ha
Females	20	180.7 ha	22.5 ha	40-404 ha	288.7	100.8	55-963 ha

ha. However, we did find that two pregnant females made long moves (~ 14.0 km each) from their normal core areas to private land bordering Fort Chaffee near the time of parturition. Each deer remained in these new areas for several weeks, but then returned to their normal ranges.

Females extended their home ranges during the breeding period (t = 2. 1, $P = 0.05$). The mean size of home ranges during the 6-week breeding period was 53.2 ha, whereas home ranges averaged 21.9 ha during the 6-week pre-breeding period. Our data suggest that this extension occurred regardless of whether the females occupied home ranges in refuges or in hunted sections of the study area.

Originally, we intended to compare the movements of males during the breeding season with those during the remainder of the year. However, of the 7 males that were radio-collared at the beginning of the study only 3 survived through the breeding season. Therefore, the sample size was too small to make a reasonable comparison.

Limited movement of deer occurred between the refuges and the hunted sections of Fort Chaffee. One male immigrated 7.5 km into a refuge and 1 female emigrated 3.5 km from a refuge into a hunted area, just prior to the deer season. Four females inhabited home ranges on the edges of refuges and moved periodically between the refuge and hunted portions of their range; however, we noticed no obvious movements by these individuals into the refuge portion of their ranges during the hunting season.

Discussion

In northern regions, cold temperatures and snow result in seasonal migrations by deer and larger home ranges (Verme, 1968; Ozoga and Gysel, 1972; Drolet, 1976; Nixon et al., 1991). In the south, snowfall is seldom deep enough or persists long enough to impede travel, so seasonal ranges are not necessary. Winter mast supplies are rarely covered by snow and some browse species remain green, so deer do not have to move far to acquire food. We saw no seasonal movements among deer on Fort Chaffee; these deer exhibit fidelity to year-round home ranges as described by Progulske and Baskett (1958) and Marchington and Jeter (1967).

The size of home ranges of adult deer can vary from 45 to 2500 ha depending on sex, age, and habitat quality (Demarais et al., 2000). Annual home ranges of adult females is typically about 50% that of adult males. In the mixed pine/hardwood forests of the Arkansas Ozark Highlands, Cartwright (1975) calculated that annual home ranges averaged 520 ha using the MCP method. The mean size of males' ranges was 627 ha, whereas females averaged 453 ha. He speculated that these large ranges were a response to sparse food resources.

We anticipated that home ranges on our study area would be smaller than in the Ozarks because we thought that the interspersion of open fields and forests provided higher quality yearround habitat than Ozark forests. However, males on Fort Chaffee used home ranges that were very similar in size to those reported by Cartwright (1975) for males in the Ozarks; whereas, females on Fort Chaffee occupied home ranges that were 40% smaller than those in the Ozarks. These patterns may reflect the different factors that influence home range size for males and females. Male deer tend to expand their home ranges during the breeding season to increase breeding opportunities; this expansion is consistent across a wide range of population densities (Marchinton and Hirth, 1984; Beier and McCullough, 1990; Labisky and Fritzen, 1998). Therefore, home range size tends to be influenced most by the availability of mates. In contrast, the size of females' ranges may correlate closely with the density of resources (e.g. food and cover) required for their survival and that of their offspring. We speculate that males on Fort Chaffee cover as much area finding receptive females as males in the Ozarks, but females use smaller ranges because resources are more abundant on the base and they can meet their needs in a smaller area.

Approximately half of the home ranges on Fort Chaffee were elongated in shape and half were circular. Previous studies have shown that the configuration of deer ranges are usually elongated when calculated using the MCP method, but circular and irregular ranges have been reported (Marchington and Jeter, 1967). Linear home ranges provide maximum access to available resources and minimize movement and energy expenditure when food, cover, and water are distributed among diverse habitats (Stumpf and Mohr, 1962; Marchinton and Hirth, 1984). However, in more uniform habitat with an interspersion of resources, deer tend to move out in all directions from a central point resulting in circular patterns (Hood, 1971).

Smaller female ranges during the fawning season, when detected, have usually been attributed to the limited mobility of fawns. Ozoga et al. (1982) reported that does in Michigan greatly reduced the size of their home ranges for the first month postpartum and vigorously defended the area surrounding their fawn(s). They postulated that females actively defend an unchanging, well-defined area around her fawn. The females that they studied were in a fenced enclosure which prohibited movements. In contrast, Schwede et al. (1994) argued that females defended only a constantly changing space immediately around each fawn. We did not find reductions in home ranges during the 4-week perinatal period and speculated that this may relate to the patchy distribution of suitable cover for bedding fawns. Large meadows dominate much of the study area and during spring and summer these frequently burn due to accidental or prescribed fires resulting in short grasses that provide little cover. Consequently, females may be forced to

move fawns over relatively large areas to find suitable bedding sites resulting in relatively large home ranges during the fawning season.

Previous studies have shown that females may either restrict or expand their home ranges during the breeding season depending on the availability of mates (Holzenbein and Schwede, 1989; Labisky and Fritzen, 1998). When breeding males are abundant, females may limit their activities to core areas within their home range. This "sit-and-wait" strategy may be adaptive if it increases successful mating by providing predictable access to receptive females by mobile males searching for mates. However, females may be expected to increase their movements and shift to an "active search" strategy to facilitate mating when males are sparse. Holzenbein and Schwede (1989) proposed that the extent of female movements during the breeding season could be used as an index of the availability of males; increased movements by a large proportion of adult females would indicate a scarcity of breeding males in the population.

Labisky and Fritzen (1998) reported that females on a Florida study area with sparse males increased their movements during the breeding season in an apparent attempt to find mates. However, they acknowledged that because the breeding season and hunting seasons coincided, increased movements may have been due to disturbance by hunters. On Fort Chaffee, the mean home range size of females inhabiting hunted areas expanded during this period as might be expected if hunter disturbance caused increased movements. However, the home ranges of all 10 females inhabiting unhunted, refuge areas also increased during the breeding season suggesting that hunter disturbance was not the cause. We do not believe that range expansion during this period is caused by searches for food because forage, mast, and supplemental food plots were available throughout the study area through December. Rather, we speculate that the long history of bucks only hunting on Fort Chaffee combined with high mortality rates among adult males caused by poaching (Humphreys, 1996) may have reduced the proportion of breeding males in the population to a density which forced females to adopt an active search strategy for males during the breeding season and that this accounted for the home range expansion during the breeding season. Adult males comprised only 15% of the deer legally harvested on Fort Chaffee from 1991-95 (Nelson and Phillips 1998).

We also speculate that deer might actively move to the protection of the nonhunted refuge areas during the hunting seasons. Hunting on these areas has been prohibited for many years due to the danger posed by military activities. However, we detected no systematic movement of deer into refuge areas. Two deer made long movements during the hunt; one into a refuge and another out of a refuge. Females

with home ranges encompassing both hunted and refuge sections were as likely to found in either section during the hunting season.

Based on our results, habitat improvements for deer should be conducted at a spatial scale that provides an interspersion of life requisites (winter forage, cover, water) every 180 ha. Providing resources (or improving those already present) within the average female's home range size will ensure that individuals of both sexes have access to these resources and aid in improving the condition of Fort Chaffee deer.

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Mortality of Adult White-tailed Deer on Fort Chaffee, Arkansas

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Abstract

We conducted a telemetry study on Fort Chaffee, Arkansas, to estimate the extent, timing, and causes of mortality among resident adult white-tailed deer (*Odocoileus virginianus*). Twenty-seven deer were captured, radio-collared and monitored for 1 yr to assess seasonal mortality. Annual mortality rates differed considerably between sexes, with males exhibiting a much higher rate (86.1%) than females (5.3%). The primary causes of death among males were poaching, predation by coyotes, and legal harvest. Legal harvest by a gun-hunter accounted for the only female mortality. No mortalities were attributed to military exercises, which occurred frequently on the study area. Our results suggest that the male segment of the population would benefit from increased enforcement efforts to reduce illegal harvests and that continued liberal harvest of the female segment is advisable to maintain a balanced population sex ratio.

Introduction

The white-tailed deer (*Odocoileus virginianus*) is North America's most numerous and widespread large mammal (Halls, 1984). The high ecological and economic values of this species have long been recognized (Kellert and Smith, 2000). Because of these values, the public demands that deer populations be managed in a competent and professional manner (Woolf and Roseberry, 1998). Population management usually involves manipulating harvest strategies to adjust density and sex-age composition of the herd to meet specified management objectives. Biologically sound management requires reasonable estimates of age-specific natality and mortality rates (Demarais et al., 2000).

Fort Chaffee is the largest of three military installations in Arkansas where deer hunting is permitted, and it is one of the top deer-producing public areas in the state (unpubl. data, Arkansas Game and Fish Comm.). Data collected from hunter check stations, annual spotlight surveys, and periodic assessments of reproduction and physical condition are used to make management decisions regarding the resident deer population. However, these sources provide no information about the extent of nonhunting-related mortality. Halls (1984) stated "Nonhunting mortality may be the most significant unknown parameter in population modeling and monitoring. When unaccounted for, it can seriously inhibit the setting of hunting regulations to optimize a legal whitetail harvest."

Here, we report on the extent, causes, and timing of mortality in a sample of adult deer that were radio-collared and monitored from January 1995 until January 1996. We hypothesized that nonhunting mortality rates might be higher on Fort Chaffee than in other regional herds because of accidental deaths attributable to military exercises (artillery and small arms fire) and/or high frequencies of poaching.

Methods

Fort Chaffee is a 29,000-ha military base located in west-central Arkansas. The area consists primarily of second-growth oak-hickory (*Quercus* spp.-*Carya* spp.), oak-shortleaf pine (*Pinus echinata*), and bottomland hardwood forests interspersed with early-successional fields of various sizes. Excellent deer habitat is provided by extensive forest-meadow ecotones, which are maintained by frequent fires ignited accidentally during training activities. This habitat supported a deer population that was approximately three times higher than those on nearby public forests at the time of this study (G. Wilks, AGFC, pers. comm.).

Deer were captured using either net guns fired from a helicopter or rocket nets (Hawkins et al., 1968; Barrett et al., 1982). We attempted to capture equal numbers of each sex to compare mortality rates between sexes. Captured deer were immobilized with a mixture of 2.5mg/kg of ketamine hydrochloride and 0.5 mg/kg of xylazine hydrochloride. Each deer was aged based on tooth replacement and wear (Severinghaus, 1949), weighed on a spring scale accurate to 1 kg, and fitted with a radio-collar (Advanced Telemetry

Systems Inc., Isanti, MN) equipped with a mortality sensor that doubled the pulse rate if the collar remained motionless for 8 hr. All captured deer were monitored until they recovered from the anesthetics, then released at their capture site.

Deer were radio-tracked daily to monitor survival using a 3-element yagi antenna and receiver beginning one day after capture. A minimum of three assessments of survival was made weekly from the time of capture until death or the end of the study (31 January 1996). Mortality was detected by a change in the transmitter pulse rate. Dead deer were located immediately, and the carcass and site were evaluated for clues to the cause of death. Carcasses were returned to the laboratory and systematically necropsied (Woolf, 1978).

The color and consistency of femur marrow were used to evaluate the physical condition of deer at the time of death. Deer were considered to be in good condition if they had pink, fatty marrow indicative of normal fat reserves (Cheatum, 1949; Bischoff, 1954). Deer exhibiting red, gelatinous marrow were considered to be in poor physical condition. Signs of human presence near the carcass (e.g., boot tracks, collars that had been cleanly cut) provided evidence that deer were poached. Predation was evidenced by hemorrhage associated with bite or claw marks. Deer that were killed by hunters but not retrieved ("crippling losses") exhibited gunshot or arrow wounds. When scavenged, these carcasses lacked hemorrhage where chewed.

Mortality estimates were calculated using the microcomputer program MICROMORT (Heisley and Fuller 1985). MICROMORT allows the user to specify the time intervals, sources of mortality, and sex-age classes of interest for comparisons of mortality rates. We compared mortality rates during three intervals: spring-summer (1 March to 30 September 1995), gun season (25 November to 7 December and 28 December 1995 to 9 January 1996), and bowhunting season (1 October 1995 to 28 February 1996 excluding gun deer seasons). The sources of mortality were classified as legal hunting, poaching, crippling loss or predation. We calculated mortality rates separately for each sex.

Results

Twenty-seven deer (7 males:20 females) were monitored during this study. Of these, 7 (6 males:1 female;

25.9%) deer died from various causes during this period (Table 1). Deer ranged in age from 1.5 to 7.5 yr old when captured; deer > 3.5 yr. old comprised 62% of the sample.

Mortality rates varied considerably between the sexes with males exhibiting much higher rates (Table 1). Six of the seven (85.7%) males died during the 13-month monitoring period. All died during the bowhunting season, but only one of these males was legally harvested by a bowhunter. Three bucks (two from areas of Fort Chaffee that were closed to hunting) were poached. The bloody radio-collars from these animals had been cleanly cut from the deer. One of these individuals appeared to have been shot from a road, as the collar was found hanging in a tree near the road. A second male's collar was found on the ground next to the entrails of the field dressed deer which were located in an isolated area approximately 1 km from the nearest road. Fresh boot tracks were observed at both sites. A third buck was killed illegally during the 3-day period when gun permit holders were allowed to scout prior to the hunts. The carcass was scavenged and we categorized this animal as poached because hunters scouting near the carcass reported gunshots at this location on the day this deer died.

One mortality was caused by coyote predation and another was caused by either coyote predation or crippling by a bowhunter. A large portion of this carcass was consumed prior to recovery, so precisely categorizing the causes of death was not possible. The carcass of a yearling male was found approximately 1 km outside the deer's normal home range. The marrow in this carcass suggested that this deer was in poor physical condition prior to death. The individual had been killed on a ledge with a steep bluff on one side and a sheer rock wall on the other. Coyote tracks and feces were present at the site and some evidence of hemorrhage was present. The evidence suggests that this deer had been chased, cornered, and killed by coyotes. The carcass of another yearling male, with marrow typical of a deer in poor condition, was found in a greenbriar thicket along a creek. We could not determine whether this deer was a victim of predation or was a crippling loss, which had subsequently been scavenged by coyotes. However, the deer exhibited normal daily movements immediately prior to death suggesting that disease was not the likely cause of death.

Table 1. Annual mortality rates of 27 radio-collared white-tailed deer on Fort Chaffee AR, during 1995.

Sex	N	Causes of Mortality (%)				
		Legal harvest	Poaching	Predation	Unknown	Total
Male	7	14.3	43.1	14.3	14.3	86.1
Female	20	5.3	0.0	0.0	0.0	5.3

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The surviving 2.5 year old male was captured and collared in a section of Fort Chaffee that is open to hunting and located approximately 4 km from the nearest closed area. Throughout the year he made temporary excursions into the closed area and by the time the gun hunts began he was found exclusively in this refuge area.

The mortality rate among males during the bowhunting season was 86.1%, with 43.1% due to poaching, 14.3% due to bowhunting, 14.3% due to predation and 14.3% due to unknown causes, likely crippling and/or predation. Because no mortalities occurred during the other two intervals, the annual mortality estimate for Fort Chaffee males was 86.1%.

Only one mortality occurred among the 20 adult females monitored during this study (Table 1). A collared doe was harvested on the first day of the gun season. Consequently, the seasonal mortality rate for the gun season and the annual mortality rate for females was 5.3%.

It is noteworthy that we observed no mortalities during the spring or summer; all 7 deaths occurred after the opening day of bow season on 1 October. No mortalities occurred due to military activities or deer-vehicle collisions.

In addition to the radio-collared deer carcasses that were recovered and necropsied during this study, we also investigated the cause of death of 8 deer that were discovered on separate occasions while conducting field work. Four of these (all antlered males) had been poached on the Fort Chaffee golf course. The cause of death could not be determined for the other 4 deer; however, all were found between 26 September and 24 November on areas open to hunting. Two of these were fawns and 2 were older deer.

Discussion

Few adult deer mortality studies have been conducted in the southern United States and none in western Arkansas. Dinkines et al. (1992) conducted an adult mortality study at Fort Sill, Oklahoma, and reported that 50% of these deaths were directly attributable to military training. Other causes of death at Fort Sill included collisions with vehicles (16%), crippling loss (11%), and poaching (6%). These researchers noted that their study "strongly suggests that the consequences of military training activities should be considered in the management of white-tailed deer herds on military installations." In contrast, we found no evidence of military-related deaths or injuries on Fort Chaffee. However, the timing of mortalities was similar on Fort Sill and Fort Chaffee. Dinkines et al. (1992) reported that 75% of adult mortalities occurred between September and February on Fort Sill; all 7 deaths among deer on Fort Chaffee occurred during this period.

Previous studies have concluded that mortality rates tend to be higher among male than female deer. In Minnesota, the annual mortality rate for adult males was 53%, but only 21% for adult females. Predation by gray wolves (Canis lupus) and legal hunting were the primary mortality factors for both sexes (Nelson and Mech 1986). DeYoung (1989) reported the annual mortality rate for adult male deer in south Texas was 29%, with predation, legal hunting, and poaching accounting for most of the deaths.

Dusek et al. (1992) reported annual mortality rates from 17 to 57% for females in Montana. Hunting, which included legal harvest, crippling loss, and poaching comprised 74% of all mortalities in that study; whereas, only 8% of deaths were attributed to natural causes such as predation, disease, and malnutrition.

We recognize that adult males in the Fort Chaffee population could not sustain annual mortality rates of 86%. We caution readers that this high estimate likely reflects sample bias associated with the small number of males monitored during this study. In fact, harvest data collected at biological check stations on Fort Chaffee during the 1990's suggest a reasonably normal distribution of the age-classes among males. For example, 2.5 year old males comprised 25%, and older males 21%, of the male harvest in 1995 (unpubl. data, Arkansas Game and Fish Comm.). Nevertheless, it is interesting to note that only two of 27 deer in our sample were legally harvested, whereas three males were poached. Additional enforcement efforts to reduce poaching of antlered males, particularly between September and February, appears to be warranted on Fort Chaffee.

Harvest data collected at check stations on Fort Chaffee since 1991 have consistently shown that adult females comprise the largest proportion of the legal harvest (34-39%). This has caused some hunters to speculate that this segment of the population has been over-harvested. However, the observation that only 1 of 20 females in our sample was harvested suggests that these concerns may not be justified and regulations which encourage a more liberal harvest of females than males is warranted to maintain a balanced population sex ratio.

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Physicochemical Characteristics and Macroinvertebrate Assemblages of Riffles Upstream and Downstream of a Streambank Impacted by Unrestricted Cattle Access

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Abstract

Riparian zones are important contributors to stream ecosystem health. Alteration of such areas can change stream structure and function, resulting in modified productivity and hydrologic patterns. We studied two riffle sites on the South Fork of the Spring River in Fulton County, AR upstream and downstream of a streambank ostensibly degraded by unrestricted cattle access. The two sites were measured for differences in physical habitat (including bank width, stream velocity, depth, substrate composition, and embeddedness), chemical characteristics (including dissolved oxygen, pH, conductivity, turbidity and total suspended solids) and biological characteristics (including benthic macroinvertebrate community composition, similarity, and standing crop). Measurements were conducted quarterly for one year. We found embeddedness, total suspended solids and turbidity to be significantly higher downstream of the cattle access area. Community metrics were similar for both sites; however, macroinvertebrate standing crop was lower downstream. These results suggest moderate differences in stream productivity downstream of the cattle access site. Future work will evaluate whether reduced cattle access and streambank stabilization efforts result in improvements in water quality and density of macroinvertebrates.

Introduction

Riparian zones are highly integrative with stream ecosystems (Tang and Montgomery, 1995). They regulate the exchange of nutrients and organic material between forested areas and streams (Cummins, 1974), contribute large woody debris to streams (Cummins, 1974), contribute root strength which stabilizes streambanks (Gregory and Ashkenas, 1990), and contribute to cooler summer water temperatures (Hetrick et al., 1998). The riparian zone also regulates the composition of macroinvertebrate functional feeding groups by controlling the amounts and types of nutrients which enter the stream (Cummins, 1974).

Macroinvertebrates are particularly useful as biotic assays of water quality (Resh and Unzicker, 1975). In addition to being dependent upon the physical environment in which they live, macroinvertebrates are relatively long-lived, show a wide range of water quality tolerances, are relatively easily sampled, and are normally abundant and diverse in most streams. Environmental variables such as temperature, flow, and total suspended solids (TSS) can be seasonally highly variable in stream systems, influencing community structure.

The effects of livestock on stream ecosystems have been widely studied in the western U.S., but relatively few studies have been conducted in the eastern U.S. (for review, see Platts and Wagstaff, 1984). The South Fork of the Spring River is a third order Ozark stream which originates in Howell County, Missouri. The river flows southeast to its confluence with the Spring River in Sharp County, Arkansas.

The 520 farms along the South Fork support over 10,000 cattle. Forty-seven km of streambank of its 100 km total length are considered impaired (Arkansas Soil and Water Conservation Commission, 1996). Most farmers in this region allow free access of cattle into the river (T. Gentry, pers. comm.). Cattle spend a great amount of time in riparian areas, often causing severe erosion and riparian degradation; this results in increased siltation and declining water quality in stream ecosystems (Wohl and Carline, 1996). Further, the removal of vegetation in riparian areas leads to channel widening, channel aggradation, and lowering of the water table. These changes may adversely affect the biodiversity of a stream (Armour et al., 1991). Elevated levels of suspended sediments due to increased runoff often result in a decline or disappearance of many sensitive aquatic macroinvertebrate species and a rise in numbers of tolerant species (Vuori and Joensuu, 1996).

One such area occurs in Fulton County, AR. Loss of soil from erosion along a cattle pasture at this site has been measured by comparing aerial photographs over the past two decades (Grippo, unpublished data). The river channel has migrated an average of 9.1 m annually with a maximum migration of 32.3 m. The greatest amounts of migration and erosion are occurring in areas where there is little or no riparian zone.

The purpose of this study was to compare water quality, streambank erosion, hydrologic profiles and aquatic

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macroinvertebrate composition within riffles upstream and downstream of a riparian area ostensibly altered by unrestricted cattle access. It was hypothesized that certain water quality measures that reflect erosion (e.g., TSS, turbidity, altered substrate composition, embeddedness) would be higher in the downstream relative to the upstream site. This reduction in water quality should be reflected in faunal differences (e.g., reductions in diversity, increases in silt-tolerant species) within the lower site. This study is part of an ongoing project evaluating the efficacy of cattle fencing and streambank stabilization projects in the Ozark Highlands region of Arkansas.

Materials and Methods

Study Sites.--Two sites were chosen approximately 1.5 km apart on the South Fork which include an upper reference riffle (N 36° 22.103" W 91° 43.276") and a lower riffle (N 36° 22.522 W 91° 43.114), agriculturally-impacted by cattle ranching. Aquatic macroinvertebrates, physicochemical variables of water and physical habitat were sampled quarterly over a one-year period from July 1998 to May 1999. Cattle were not using the access site during times of sampling. Sampling was performed during periods of baseline water conditions for each season.

Physicochemical variables of water measured at each site were pH, conductivity, temperature and dissolved oxygen. Water samples were collected and taken back to the laboratory for analysis. Turbidity (NTU) was measured with a LaMotte turbidometer. Total suspended solids (TSS) were determined in mg/L according to the APHA (1995).

Physical Habitat.--Each riffle site was divided into five equidistant transects across the stream to establish a mean for each variable studied. Bankfull and wetted stream width were measured in meters at each transect. Percent canopy cover was measured four times along each transect (at each bank and at midstream, facing upstream and downstream) with a concave forest densiometer. Stream velocity was measured along each transect at five equidistant points with a General Oceanics flow meter (0.6 that of depth). Two measurements were made (0.2 and 0.8 of the depth) in areas with depths greater than 76.2 cm and averaged. Water depth was measured at five equidistant sites at each transect in addition to the thalweg. Total percent substrate composition of bedrock, boulders, cobble, gravel, sand and/or fines was determined visually following a modified Wentworth scale (Platts et al., 1983). A seasonal and between-site comparison of substrate composition was performed using chi-square analysis. Embeddedness was measured on a scale of 1-5 with a score of 5 indicating no embeddedness (Platts et al., 1983). Bankslope at transect was measured with a clinometer. A paired student t-test was performed to statistically compare stream habitat and physicochemical variables of the downstream site to the upstream site over the course

of a year. Significance levels for all statistical tests performed were established at $\alpha = 0.05$.

Aquatic Macroinvertebrates.--Five replicates of aquatic macroinvertebrates were sampled with a kick seine for five minutes each at each riffle. Organisms were collected, preserved in 10% formalin and identified to the lowest possible taxa. Functional feeding groups were assigned according to Merritt and Cummins (1996). A seasonal and between-site comparison of functional feeding groups was performed using chi-square analysis. Representative specimens from this study are maintained in the Arkansas State University Museum of Zoology (ASUMZ).

Richness was measured as total number of taxa, percent change in taxa richness, percent dominant taxon, number of Ephemeroptera/ Plecoptera/Trichoptera (EPT) taxa, and the ratio of EPT/EPT + Chironomidae. Composition measurements consisted of community loss index (Courtemanch and Davies, 1987), Jaccard similarity index (Jaccard, 1912), percent similarity (Brock, 1977), and Shannon-Weiner index (Washington, 1984). To directly compare our data with those previously obtained by the Arkansas DEQ (1996a) utilizing the EPA Rapid Bioassessment Protocol (Plafkin et al., 1989), a subsample of 100 individuals was randomly chosen from the summer sample.

Results

Aquatic Macroinvertebrates.--Collections of aquatic macroinvertebrates were seasonally quite variable, ranging from 145 to 1,488 specimens from the upper riffle (range of 19-22 taxa), and 107 to 448 specimens from the lower riffle (15-28 taxa) {Appendix 1}. There were more individuals collected within the upper than the lower site (a total of 2,782 versus 1,132). We identified a total of 40 genera in addition to Nematomorpha, Annelids, Chironomids, and dipteran larvae which were not identified to genus. The percent dominant taxon ranged from 0.20 to 0.62 for the upper riffle to 0.20 to 0.45 for the lower riffle. Ephemeroptera represented the most abundant order found in both riffles for all seasons except the winter sample of the upper riffle. The number of EPT taxa were quite similar with no significant differences ($P = 0.25$) between the two sites with the exception of the winter sample (9 EPT taxa for the upper riffle versus 12 EPT taxa for the lower riffle){Table 1}. The total percentages of individuals within the EPT taxa were 80 and 76 percents, respectively. The EPT/(EPT + Chironomidae) ratios were lowest during the fall and winter samples.

The dominant functional feeding group for both sites was collector-gatherers (55%), although the proportions declined dramatically during the fall sample (37% and 41% for the upper and lower riffles, respectively){Table 2}. Numbers of scrapers were greatly elevated during this period. The representation of functional feeding groups was not

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Table 1. Aquatic macroinvertebrate bioassessment indices within the upper and lower riffles on the South Fork, AR.

Index	Summer, 1998 UR	LR	Fall, 1998 UR	LR	Winter, 1999 UR	LR	Spring, 1999 UR	LR
Taxa richness	19	15	22	28	22	24	21	20
no. of EPT taxa	7	7	12	12	9	12	10	11
Diversity (H')	2.468	2.774	2.986	3.618	2.412	3.498	3.863	3.548
Jaccard similarity	*	0.360	*	0.581	*	0.586	*	0.850
Community Loss	*	0.667	*	0.211	*	0.208	*	0.06
Percent Similarity	*	26.92%	*	60.94%	*	51.14%	*	69.89%

Table 2. Percent functional feeding groups of aquatic macroinvertebrates sampled within the upper (UR) and lower riffles (LR) on the South Fork, AR. Number of individuals within feeding groups in parentheses.

Feeding Group	Summer, 1998 UR	LR	Fall, 1998 UR	LR	Winter, 1999 UR	LR	Spring, 1999 UR	LR
Scrapers	6(8)	10(11)	38(511)	37(161)	13(99)	24(76)	25(91)	23(60)
Filterers	3(4)	7(7)	0(4)	3(12)	1(8)	2(5)	3(9)	2(5)
Miners	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Predators	10(26)	22(24)	25(342)	20(86)	5(38)	8(26)	10(36)	9(24)
Collectors	72(100)	60(64)	37(501)	41(180)	81(637)	65(205)	62(223)	65(168)
Shredders	0(0)	1(1)	0(0)	0(0)	0(1)	0(1)	0(0)	0(0)
Piercers	(1)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Totals	138	107	1358	435	783	313	359	257

significantly different between sites ($\chi^2 = 1.82$, df $= 6$; $P = 0.93$).

The Shannon-Wiener diversity values were consistently lower within the upper riffle versus the lower riffle (mean values of 2.932 and 3.360, respectively). The two riffles showed highly variable Jaccard and percent similarity scores with the greatest faunal similarity occurring within the spring sample (0.85 and 69.9%, respectively) and the greatest differences occurring within the summer sample (0.360 and 26.92%, respectively). Likewise, the community loss values were 0.06 and 0.67, respectively (Table 1).

Physicochemical Variables of Water.--Water temperature ranged from a high of 28.7°C during the summer sample to a low of 5.6°C during the winter sample (Table 3). pH was slightly alkaline, with ranges of 7.67 in the fall sample to 8.14

in the summer sample. Dissolved oxygen concentrations were at or near saturation and ranged from a high of 9.8 ppm during the winter sample to a low of 8.1 ppm during the summer sample. Conductivity values were moderate in all sample periods (range of 384-423 µs/cm). Turbidity and TSS were also moderate in all sample periods (range of 5.1 - 22.6 NTU, 11.9 - 24.1 mg/l). Both turbidity and TSS were significantly lower ($P = 0.007$ and $P = 0.002$, respectively) for the upper versus the lower sites. No statistically significant differences were found between the upper and lower riffle sites for the other physicochemical variables studied.

Physical Habitat.--Mean bankfull width changed only slightly during the course of the study with the lower riffle significantly wider ($P < 0.001$) than the upper riffle site (Table 4). The upper riffle wetted width changed dramati-

Table 3. Means of physiochemical variables of water collected during 1998 and 1999 for the upper riffle (UR) and lower riffle (LR) of the South Fork, AR. An asterisk indicates a significant difference between sites ($P < 0.05$).

Variable	Summer, 1998		Fall, 1998		Winter, 1999		Spring, 1999	
	UR	LR	UR	LR	UR	LR	UR	LR
Water Temp. (°C)	28.3	28.7	10.6	10.5	5.7	5.6	22.7	22.8
Dissolved O_2 (ppm)	8.6	8.5	9.9	9.5	9.8	9.5	8.9	8.7
Conductivity (μs/cm)	385	385	419	422	421	423	387	387
pH	8.01	8.14	7.67	7.72	7.79	7.81	7.96	7.97
Turbidity (NTU)*	5.8	10.1	5.1	11.6	13.9	18.1	14.1	21.7
Total Suspended Solids*	13.8	21.2	11.9	17.3	19.2	24.1	14.3	19.2

cally between sample periods, but was not significantly different from the lower riffle. Mean depth, volume and velocity were highest during the winter sample at both stations with the lower riffle significantly deeper ($P = 0.003$) and possessing a greater volume ($P = 0.01$) than the upper riffle. There was no significant difference between stream velocity at both riffles. Both riffles consisted mostly of gravel, followed by cobble, and sand, yet the sites were significantly different for substrate composition for all seasons studied ($P < 0.01$). A within-site seasonal comparison demonstrated a significant difference ($P < 0.05$) within the summer sample for both sites, with a reduction of fines (< 0.062 mm). For ensuing seasons there was a progressive deposition of fines with a maximum during the spring sample. There were no significant differences in substrate composition within either site between the fall-winter and winter-spring samples. Embeddedness was highest in the spring at all stations; there was a significantly greater embeddedness for the winter and spring samples of the downstream versus the upstream site ($P < 0.001$ and $P < 0.05$, respectively).

Percent canopy cover was highest in all samples during the spring and lowest during the fall. The upper riffle showed a significantly greater ($P < 0.05$) amount of canopy cover than the lower riffle, largely due to the greater bankfull width of the lower riffle.

Discussion

Physicochemical variables measured for both riffle sites in the South Fork were well within those ranges identified in previous studies of the South Fork and from other extensive studies of Ozark streams (Arkansas DEQ, 1996b; Davis and Bell, 1998; Petersen, 1998). TSS levels were at the high end compared to other Ozark streams surveyed.

Although our study was not designed to establish a cause/effect relationship between stream characteristics and impacts of riparian grazing by cattle, several variables differed between upstream and downstream sampling sites that would be consistent with such a relationship. For example, sediment load, as measured by embeddedness, turbidity and TSS, was significantly greater in the downstream riffle. Additionally, there were dramatic declines (~60%) in numbers of individuals in the downstream site, perhaps reflecting decreased productivity in this system.

However, several biological measures, including diversity, community similarity, EPT ratios and composition of functional feeding groups were inconsistent with a decline in water quality due to riparian grazing. Diversity indices such as taxa richness and the Shannon-Wiener diversity index generally decrease with increasing perturbation (Washington, 1984); however, no significant differences in diversity existed between our two sites. Coefficient of community loss was highly variable seasonally, yet all values were lower than values reported by Courtemanch and Davies (1975) for environmentally stressed waters.

A comparison of our summer data with those of an Arkansas DEQ study on the South Fork (1996a) demonstrates that taxa richness, diversity indices, and EPT ratios of our sites are consistent with stream reach (Table 5). Only downstream sites, identified by the DEQ as being slightly to

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Table 4. Means of physical characteristics of the upstream (UR) and downstream (LR) riffle sites, 1998-1999, South Fork, AR. Standard deviations are in parentheses.

Variable	Summer, 1998		Fall, 1998		Winter, 1999		Spring, 1999	
	UR	LR	UR	LR	UR	LR	UR	LR
Bankfull Width (m)	32.6	79.8	32.7	79.4	32.8	79.8	32.5	81.7
	(3.6)	(4.9)	(3.6)	(3.3)	(3.4)	(4.5)	(3.8)	(3.7)
Wetted Width (m)	16.8	10.8	9.2	10.8	18.8	11.6	16.9	10.9
	(6.0)	(2.2)	(2.6)	(2.2)	(2.0)	(1.7)	(3.3)	(1.3)
Depth (m)	0.18	0.37	0.17	0.45	0.28	0.55	0.28	0.47
	(0.17)	(0.23)	(0.10)	(0.26)	(0.13)	(0.36)	(0.12)	(0.34)
Volume (m^3)	12.4	24.3	6.1	29.4	21.3	38.3	19.2	30.9
Velocity (cm/sec)	19.3	19.5	16.8	31.0	55.8	40.7	46.7	40.7
	(26.7)	(22.6)	(21.8)	(43.1)	(43.2)	(43.8)	(35.2)	(38.6)
Thalweg (m)	0.45	0.63	0.34	0.72	0.49	0.92	0.45	0.47
% Substrate								
Bedrock	0	0	0	0	0	0	0	0
Boulder	0	2	0	2	0	1	0	2
Cobble	12	34	36	30	38	30	36	24
Gravel	44	50	40	47	36	42	32	45
Sand	44	14	20	12	19	14	18	14
Fines	0	0	4	9	7	13	14	15
Embeddedness	5.0	5.0	5.0	4.6	4.6	2.4	3.0	1.6
	(0.0)	(0.0)	(0.0)	(0.6)	(0.6)	(0.6)	(1.0)	(0.9)
% Canopy Cover	26	19	22	17	N/A	N/A	28	20
	(44)	(39)	(39)	(44)			(45)	(42)

moderately impacted, were lower in taxa richness and diversity than in the present study. EPT ratios are commonly utilized as bioindicators of water quality despite the variation of pollution tolerances within families (e.g., *Hydropsyche* of the Trichoptera). Numbers of EPT taxa are typically reduced proportional to the degree of agricultural usage (Lenat, 1984).

Scrapers and filterers tend to be found in higher numbers in mid-reach areas of high quality streams (Vannote et al., 1980). However, collector-gatherers, which tend to feed on allochthonous fine particulate organic matter (Fisher and Likens, 1973), were dominant within both sites. Silt suspended in the water column reduces light penetration, and therefore periphyton (Wiley et al., 1990). The lack of significant feeding group differences was not consistent with the physical differences observed between the two sites. However, significant differences ($P < 0.01$) were identified when comparing our site functional feeding groups to other sites studied by the DEQ (1996a).

Evidence of increased levels of sediment were observed within the riffle site downstream of a heavily used cattle-access on the South Fork. Other than lower abundance in the downstream macroinvertebrate community, no significant biological differences were observed between sites. Both sites, however, show physical and biological characteristics consistent with slight impairment relative to other sites on the South Fork. Future work is planned to determine if reduction of cattle access and bank stabilization result in improvements in suspended solids levels and greater benthic macroinvertebrate productivity at the downstream site.

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Table 5. A comparison of aquatic macroinvertebrate indices resulting from sampling of the South Fork, Arkansas, in the summers of 1996 (DEQ, 1996b) and 1998 (UR, LR). Sites presented with an asterisk were DEQ sites. Relative stream location for each site begins with the furthest upstream site listed first, with site SF1 serving as the reference site. Miners and pierces were not represented as functional feeding groups.

Site				Functional Feeding Groups (%)					
	Richness	% Similarity	EPT Taxa	Scrapers	Filterers	Predators	Collectors	Shredders	Diversity
TR1*	15	29.0	9	30	8	4	55	4	3.355
Sf1*	19	-	9	39	16	11	31	2	3.588
PH1*	12	43.4	9	23	7	5	65	1	2.717
T1*	22	32.2	8	19	9	17	53	2	3.355
UR	16	10.2	7	3	2	19	75	0	2.295
LR	15	18.69	7	12	7	22	59	1	2.774
C1*	9	38.5	6	43	16	4	38	0	2.568
MP1*	14	28.5	5	7	38	15	39	2	3.285

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Appendix 1. Aquatic macroinvertebrate taxa list and combined number captured for all five samples for the upper (UR) and lower (LR) riffles of the South Fork.

Taxa	Summer, 1998 UR	Summer, 1998 LR	Fall, 1998 UR	Fall, 1998 LR	Winter, 1999 UR	Winter, 1999 LR	Spring, 1999 UR	Spring, 1999 LR
Phylum Nematomorpha			1					
Phylum Annelida								
Class Oligochaeta		5	2	2		19	4	14
Class Hirudinea						1		
Phylum Mollusca								
Class Gastropoda								
Family Physidae								
Physa	2	2	14	10	11	3	8	2
Class Pelecypoda								
Family Corbiculidae								
Corbicula	4	7	28	12	8	5	9	5
Phylum Arthropoda								
Class Crustacea								
Order Isopoda								
Family Asellidae								
Lirceus					1			
Order Amphidoa								
Family Gammaridae								
Gammarus		1						

Physicochemical Characteristics and Macroinvertebrate Assemblages of Riffles Upstream and Downstream of a Streambank Impacted by Unrestricted Cattle Access

Appendix 1. Continued.

Taxa	Summer, 1998 UR	Summer, 1998 LR	Fall, 1998 UR	Fall, 1998 LR	Winter, 1999 UR	Winter, 1999 LR	Spring, 1999 UR	Spring, 1999 LR
Class Insecta								
Order Ephemeroptera								
Family Ameletidae								
Ameletus	1							
Family Baetidae								
Baetis			1					
Family Baetiscidae								
Baetisca				1		3		
Family Caenidae								
Caenis			1				1	
Family Ephemerellidae								
Ephemerella					28	63	38	65
Family Ephemeridae								
Ephemera			13	29		3	3	9
Family Heptageniidae								
Cinygmula			5					
Stenonema	5	9	211	122	31	30	25	22
Family Isonychiidae								
Isonychia	183	5	3	20	12	4	33	14
Family Tricorythidae								
Tricorythodes			266	57	3	1	9	4
Family Polymitarcyidae								
Ephoron		49						
Order Odonata								
Suborder Zygoptera								
Family Coenagrionidae								
Argia			14	6	4		7	2
Suborder Anisoptera								
Family Gomphidae								
Erpetogomphys			3	1				
Stylogomphus		1		1				
Family Corduliidae								
Macromia		1						
Order Plecoptera								
Family Perlidae								
Acroneuria	1			3		1	1	2
Hansonoperla			16	7		1		1
Neoperla	17	10	300	59	15	22	17	19
Family Taeniopterygidae								
Oemopteryx					9	6	4	3
Order Megaloptera								
Family Corydalidae								
Corydalus	1	11	9	9	19	2	11	
Family Sialidae								
Sialis		1						

Appendix 1. Continued.

Taxa	Summer, 1998		Fall, 1998		Winter, 1999		Spring, 1999	
	UR	LR	UR	LR	UR	LR	UR	LR
Order Trichoptera								
Family Hydropsychidae								
Cheumatopsyche	4	4	80	38	28	6	22	3
Hydropsyche		4		1	1			
Family Hydropsychoidea								
Chimarra	2	1	82	12	24	6	37	7
Family Leptoceridae				2				
Order Lepidoptera								
Family Pyralidae								
Petrophila				3				
Order Coleoptera	1							
Family Elmidae	3							
Dubiraphia	9	1	49	5	14	5	17	4
Stenelmis (larvae)	1		381	19	46	37	54	33
Family Gyrinidae								
Dineutus	7							
Family Hydrophilidae	3							
Berosus	1							
Loccobius	1							
Family Psephenidae	3							
Ectopria (larvae)				5	2			
Psephenus (larvae)				2				
Order Diptera								
(larvae)			2	1	2	3	2	2
(pupa)	1							
Family Ephydridae								
Ephydra						1		
Family Chironomidae				15	39	32	28	23
Family Simulidae								
Simulium			1		486	63	34	25
Family Tabanidae								
Haematopota	1		4	5	3			
Family Tanyderidae								
Protoplasa						1		
Total	145	107	1488	448	788	318	361	259

Feeding Relationship Between Two Syntopic, Morphologically Similar Fishes, the Western Mosquitofish (*Gambusia affinis*) and the Blackspotted Topminnow (*Fundulus olivaceus*)

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Abstract

We sampled fish during the summer of 1999, in Caney Bayou on the campus of the University of Arkansas at Pine Bluff, Jefferson County, in order to study the feeding relationship between the western mosquitofish (*Gambusia affinis*) and the blackspotted topminnow (*Fundulus olivaceus*). We identified and enumerated the diet items of 56 blackspotted topminnows and 28 mosquitofish that were captured using electroshocking, seining, and dipnetting. Pooled diet items for each species were analyzed using a variety of approaches: percent of diet composition, frequency of occurrence, Levins' measure of diet breadth, and Morisita's measure of diet overlap. Twenty-one percent of mosquitofish and 8.9% of the blackspotted topminnow had empty stomachs. The mean number of individual prey items in mosquitofish stomachs was 2.5 (SD = 2.1), while the mean number of items for blackspotted topininnows was 72.5 (SD = 118.68). Detritus (37%), terrestrial insects (34%) and chironomids (16%) were the three major components of the western mosquitofish diet. Cladocerans comprised 96% of the blackspotted topminnow diets. The diet breadth for the western mosquitofish (0.51) was relatively broad compared to the blackspotted topminnow (0.01). Diet overlap between these species was low (0.01).

Introduction

The western mosquitofish (*Gambusia affinis*) and blackspotted topminnow, *Fundulus olivaceus* are small surface-oriented fishes with relatively large eyes and terminally superior mouths. Both species are commonly found throughout Arkansas and co-occur in the same habitats in many of the same bodies of water (i.e. syntopic). Given these similarities, one might expect similar feeding relations between these species. Alternatively, similar species frequently partition available food resources (Begon et al. 1990). Although information exists on the diets of these species, we know of no studies directly comparing the diets of these morphologically similar species. In this paper, we address the issue of diet overlap between blackspotted topminnows and mosquitofish.

The mosquitofish is the only livebearing fish species in Arkansas. Females reach a maximum length of 7.1 cm and males grow up to 3.1 cm (Miller and Robison, 1973). Mosquitofish are found throughout Arkansas in swamps, ponds, ditches, streams, rivers, and lakes, but they are most abundant in shallow, vegetated pools with little current. Mosquitofish remain at the surface in groups or schools. Although mosquitofish are native to Arkansas, they have

been introduced worldwide for controlling mosquito populations. Mosquitofish are surface feeders and eat a variety of terrestrial and aquatic insects, crustaceans, and other invertebrates (Robison and Buchanan, 1988). Mosquitofish are unique when compared to other Arkansas fishes because they store sperm, fertilize internally, and bear live young.

The blackspotted topminnow commonly grows to 5.1 to 8.9 cm long and to a maximum of about 9.7 cm (Miller and Robison, 1973). Blackspotted topininnows are found in creeks, large rivers, impoundments, and oxbow lakes throughout Arkansas. However, they are most abundant in clear upland waters, pools, and along margins near emergent vegetation (Robison and Buchanan, 1988). They are surface feeders and about half of their diet consists of terrestrial insects and crustaceans (Thomerson and Woolridge, 1970). Females deposit eggs singly on algae or other submerged vegetation.

Although mosquitofish and blackspotted topminnows are similar in many ways, differences also exist. Both species prefer low-current areas and have wide ecological tolerances. However, unlike the blackspotted topminnow, mosquitofish consume plant material (Robison and Buchanan, 1988). Additionally, the blackspotted topininnow is more common in quiet backwaters and clear upland streams than

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turbid lowland waters, which it is reported to avoid (Robison and Buchanan, 1988). By contrast, mosquitofish prefer turbid waters (Robison and Buchanan, 1988).

The objective of this study is to understand the feeding relationships between the blackspotted topminnow and the mosquitofish. In this study we characterized and compared the diets of mosquitofish and blackspotted topminnows using the number of diet items.

Materials and Methods

We sampled fish in Caney Bayou, an Arkansas River tributary, on the campus of the University of Arkansas at Pine Bluff (UAPB) in Jefferson County, Arkansas. The stream is located near the north end of the UAPB campus and Arkansas State Highway 79. It is a low gradient stream with modest to high turbidity. Fishes were sampled at two locations about a 0.8 km apart and composed mostly of pool habitat. Site one was located near the fish hatchery; whereas, site two was located near the new UAPB football stadium, which is about 0.2 km upstream from Highway 79. At the time of sampling, water at both locations was very turbid with low stream discharge.

We sampled fish on four separate days during the summer of 1999, two days at site one and two days at site two, and each episode lasted approximately two hours. Site one was sampled on July 8th and July 13th, and site two was sampled on August 4th and August 5th. Sampling commenced between 09:00 and 10:00 AM for all sampling episodes. Stream discharge was at base flow on all days except July 8th when discharge was slightly elevated due to rain the previous day.

We captured fish using electroshocking, seining, and dipnetting. Most fish were captured by seining because it was the most effective technique. After capture, the specimens were placed in a bucket of water containing MS-222 to prevent the fish from regurgitating their stomach contents. Fish were fixed in 10% formalin for two days. The fish were then rinsed and soaked in water repeatedly to remove the formalin, then placed in 70% ethyl alcohol for preservation.

Each fish was measured for total length (TL). Stomachs (i.e. foreguts) were dissected and opened so that each diet item could be removed and identified. The diet items were placed under a dissecting microscope, identified, enumerated, and stored in labeled vials. Diet items were categorized to what we considered to be a biologically meaningful level. Diet categories were algae, aquatic coleopteran, arachnid, larval and adult chironomid, cladoceran, larval and adult culicid, detritus, adult dipteran (other than chironomids and culicids), gastropod (snails), ostracod, and terrestrial insect. Nonidentifiable items were separated into terrestrial-based and completely unidentifiable.

Diet Analysis

We characterized diet composition of pooled diet items using the percent number of diet items, diet breadth, and diet overlap. We measured diet breadth with Levin's measure, calculated as

$$B = \frac{1}{\Sigma p^2_j}$$

where B = Levins' measure of niche breadth
p_j = Proportion of items in the diet that are of diet category j

Values generated from this equation ranged from one to the total number of diet categories for a species. To make diet breadths comparable between species diet breadth was standardized to express on a scale from zero to one by using the following equation (Krebs, 1989):

$$B = \frac{B-1}{n-1}$$

B = Levin's measure of niche breadth
n = number of possible diet categories

We used the Simplified Morisita's overlap index (Krebs, 1989) as a measure of diet overlap.

$$C_H = \frac{2\sum_{i=1}^{n}(p_{ij}p_{ik})}{\sum_{i=1}p^2_{ij} + \sum p^2_{ik}}$$

C_H = Simplified Morisita index of overlap (Krebs, 1989) between species *j* and species *k*.

p_{ij} = Proportion of diet category *i* is of the total number of diet items used by species j.

p_{ik} = Proportion of diet category *i* is of the total number of diet items used by species k.

n = total number of diet categories

Frequency of occurrence was used to measure the proportion of individuals containing at least one prey item in a given diet category. Detritus was enumerated by assigning a number from 1-4 for each fish. A "1" was assigned to stomachs with trace amounts of detritus present and a stomach full of detritus was given a value of "4". Values of "2" and "3" were assigned to stomachs about 1/2 and 3/4 full of detritus, respectively. Although this scheme was somewhat arbitrary, we chose it to make the amount of detritus as close as possible to the volume of large terrestrial insects found in these fishes stomach. This strategy allowed us to avoid making detritus more important than the largest potential prey items.

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Results

Twenty-eight mosquitofish (mean TL 35 mm, SD 6.8 mm) and 56 blackspotted topminnows (mean TL 40 mm, SD 6.3 mm) were collected and used for analyses. Twenty-one percent of mosquitofish and 8.9% of the blackspotted topminnow had empty stomachs. The mean number of individual diet items in mosquitofish stomachs was 2.5 (SD = 2.1), and 72.5 (SD = 118.68) for blackspotted topininnows. Diet composition of these two species differed (Fig. 1). Detritus (37%), terrestrial insects (34%), and chironomids (16%) were the three major components of mosquitofish diets (Fig. 1A). Cladocerans made up 96% of blackspotted topminnow diets (Fig. 1B).

Diet breadth of mosquitofish was 0.51, but only 0.01 for blackspotted topininnows. The overlap value between the mosquitofish and blackspotted topminnows was 0.01, indicating dissimilar diets. According to frequency of occur-rence analysis (Table 1), 44% of mosquitofish contained ter-restrial insects and 40% contained detritus. The frequency of occurrence analysis indicated that terrestrial insects and cladocera were the most important diet items for blackspot-ted topminnows with 45% of blackspotted topminnows con-taining cladocera and 43% containing terrestrial insects. A small percentage of both species' stomachs contained algae, coleopterans, chironomids, adult dipterans, adult culicids, and arachnids.

Table 1. Percent frequency of occurrence of diet items for blackspotted topininnows (B. S. Topminnow) and mosqui-tofish collected in July and August, 1999 in Caney Bayou, Jefferson County, Arkansas. (A) refers to adult and (L) refers to larvae.

Diet Category	B.S. Topininnow	Mosquitofish
Algae	5	0
Coleopteran	7	2
Chironomidae	29	16
Cladoceran	45	0
Detritus	11	40
Dipteran (A)	0	4
Culicid (A)	2	4
Culicid (L)	0	21
Ostracod	9	0
Gastropod	2	0
Arachnid	5	4
Terrestrial insect	43	44
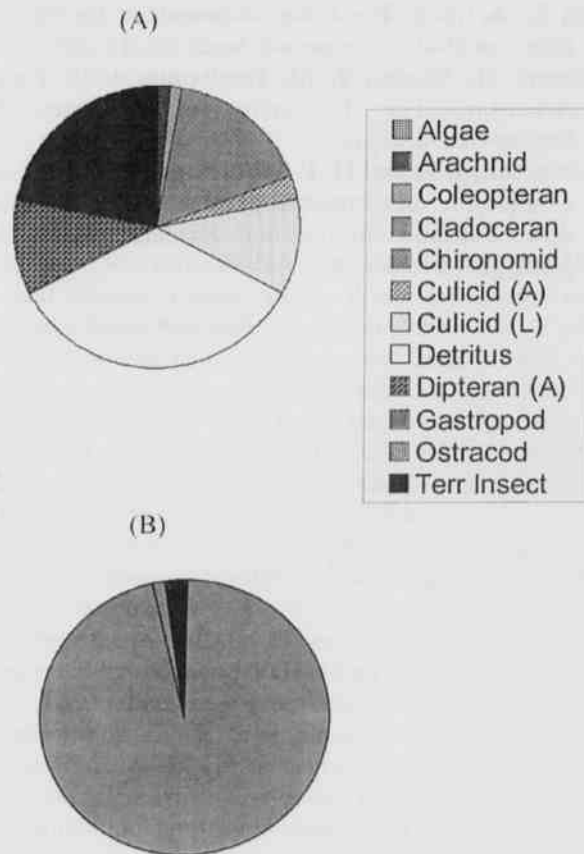
Fig. 1. Diet Composition of mosquitofish (A) and blackspot-ted topminnow (B) collected in July and August, 1999 in Caney Bayou, Jefferson County, Arkansas. In the legend (A) refers to adult and (L) refers to larvae.

Discussion

We found that blackspotted topininnows and mosqui-tofish had dissimilar diets, and therefore were partitioning much of the food resources in Caney Bayou. There was a large difference in frequency of occurrence of various prey items between these two species. Blackspotted topminnows had a narrower diet breadth than mosquitofish and diet overlap between these species was low.

Etnier and Starnes (1993) indicated that mosquitofish ingest a wide range of terrestrial and aquatic insects, crus-taceans, and other invertebrates. We also found that mos-quitofish consume a wide range of similar prey items.

In general, diet items that we found in the blackspotted topininnow were similar to those found by Thomerson and Wooldrige (1970) and Rice (1942), who found that terrestri-al insects were important prey items. Although terrestrial insects did not make up a large percent (by number) of their diet due to numerous cladocerans, terrestrial insects proba-bly were important in terms of caloric content because they were much larger than cladocerans. Additionally, the impor-

tance of terrestrial insects is reflected in the 43% frequency of occurrence in blackspotted topminnows.

Many factors could have influenced the amount and type of food found in the stomachs of mosquitofish and the blackspotted topminnow. For example, we only sampled fish during late morning and early afternoon of July and August. These fish may feed differently at different times of the day and year. A more thorough diet analysis should include sampling throughout the year at different times of the day. Also, consideration of diet item weight and volume would affect our results. The diet items in this study were enumerated. The importance of cladocerans would decline if we evaluated diets by volume or weight because cladocerans were very small relative to most of the other diet items. Despite these factors, it is striking that cladocerans comprised a large portion of the diets of blackspotted topminnows while no cladocerans were observed in mosquitofish stomachs.

It is possible that our sampling methodology may have affected the results. We electroshocked and seined fish. Seining was the most effective method for capturing fish. If seining selected for a specific type of individual fish that had different diet characteristics than fish captured by electroshocking or other means of capture, then our results may be somewhat biased. However, we do not believe that this had serious effects on our results because we sampled a variety of habitat types.

There are some possible reasons why these morphologically similar species have dissimilar diets. These species may participate in interactive segregation. We casually observed that blackspotted topminnows were found more commonly in the middle of the stream and mosquitofish were found near the stream bank. These species may have been consuming the most abundant available prey in those habitats. There may have been mostly Cladocera available in the mid-channel because cladocerans were found primarily in blackspotted topminnows. By the same token, there may have been a wider variety of potential food items in the areas where the mosquitofish were captured because that is what we found in their diet. Alternatively, these fishes may target different types of prey when living syntopically in order to reduce competition for food.

It is interesting that we found that the blackspotted topminnow and mosquitofish, which are so morphologically similar, had such different food habits. Many reasons may contribute to these findings and further study will be needed to clarify the reasons for the observed differences in food habits.

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Optical Transmittance of a Rice Leaf via Ray Tracing

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Abstract

Optical reflectance from a plant leaf increases in response to stress and disease. Previous studies at the University of Arkansas at Little Rock found that, while the reflectance from a rice leaf increased with increased salinity, reflectance changes could not be used to differentiate one stress or disease from another. The objective of this study is to characterize the angular distribution of optical transmittance for a healthy rice leaf using a ray tracing technique and assuming a three-media optical model. The ultimate goal is to relate this distribution to specific plant pathologies. Three rays are traced through the cross section of a healthy rice leaf by applying laws of geometric optics and considering air, cell wall, and chloroplast as media. The angular distribution of transmittance is calculated for each ray trace. L_{ei} is defined as the length of irradiated upper epidermal surface leading to a continuous transmittance $T_{bi}(\theta)$ at the bottom surface. The total transmittance is defined as the sum over i of $T_{bi}(\theta)$. $\Delta\theta_i$ is defined as the angle over which $T_{bi}(\theta)$ extends and $(\theta_j - \theta_i)$ is defined as the angular difference between the bisector of $\Delta\theta_i$ and the bisector of $\Delta\theta_j$. The probability density functions $pdf(\Delta\theta)$ and $pdf(\theta_j - \theta_i)$ are defined and shown to have diagnostic potential.

Introduction

Increased leaf reflectance is a generic response to plant stress and disease (Carter, 1991). While reflectance techniques have been successful in gauging the state of plant health, determining chlorophyll content (Inada, 1985), and estimating crop nitrogen status (Takebe et al., 1990), no reflectance techniques have been developed to diagnose specific stress or disease. Nilsson (1995) has reviewed leaf and canopy reflectance and transmittance measurements from the 19th century to the present. What is typically measured is either the total intensity, with an integrating sphere, or the relative intensity at different wavelengths using a photometer or spectrometer. Little or no attention has been given to how the overall spread and the angular distribution of transmitted light depend on leaf internal structure. In fact, analysis of leaf reflectance often seems designed to minimize the confounding effects of (internal) mesophyll structure (Penuelas et al., 1995). However, ray tracing makes it clear that the internal structure determines both the direction into which a single incident ray is transmitted and how parallel rays incident along a short length L_{ei} of epidermal surface are ultimately diffused.

Sinclair et al. (1971) have proposed that cell walls are oriented at right angles to each other and slowly diffuse light. This model predicts that any two parallel rays incident at different points on the epidermal surface are ultimately transmitted or diffusely reflected in unrelated directions. However, there was no distinction made between parallel rays incident relatively close together from parallel rays incident farther apart, and the possibility of anything less than total diffusion was not considered.

Kumar and Silva (1974) traced a light ray through the cross section of a healthy soy leaf. They found that a ray trace based on a model of four isotropic optical media (cell wall refractive index $n=1.52$, cell sap $n=1.36$, chloroplast $n=1.42$, air $n=1.00$) predicted to within 2% the experimentally determined values of total reflectance and transmittance. They found that the cell wall-air interface causes more deviation of the incident ray than any other single interface. They also pointed out that an earlier ray trace using only cell wall and air predicted total reflectance and transmittance to within 15% the experimentally determined values. They did not investigate how their four-media optical model would diffuse or distribute the transmitted light.

The objective of this study is to characterize the angular distribution of transmittance for a healthy rice leaf using geometric optics and assuming three isotropic optical media: cell-wall, chloroplast and air. This model will be used to determine a transmittance $T_{bi}(\theta)$, a continuous function characterizing the transmitted beam over an angle $\Delta\theta_i$ and which results from a parallel beam of light incident along a length L_{ei} of upper epidermal surface. The total transmittance $T_t(\theta)$ is defined as the sum over i of $\Sigma(T_{bi}(\theta))$. A ray

Optical Transmittance of a Rice Leaf via Ray Tracing

trace path will be analyzed to estimate reasonable values for L_{ei} and for $\Delta\theta_i$. The long-term goal of this research is to identify optical parameters of leaf internal structure that can be used to diagnose specific plant pathologies.

Materials and Methods

Rice Leaf Cross Section.–The rice leaf to be studied is the low-light-adapted *Lemont* species from Southern California. This is a well-researched variety used in high yield rice breeding experiments (Black et al., 1995). A two-dimensional (1.6 mm long and 0.78 mm wide) flag leaf cross section was fixed in a FAA solution, cut with a Base Sledge microtome and stained with hematoxylin (Tu et al., 1989). A 35-mm slide of the cross section was loaned to the authors by Dr. Paul Counce of the Rice Research and Extension Center in Stuttgart, Arkansas. A digital image of the Microtome cross section was processed into light regions (air) and dark regions (chloroplast) separated by a thin edge (cell-wall). A 0.6 mm section bordering a vascular bundle was magnified and used for the ray trace experiment.

Three Media Model.–The model for the *Lemont* internal leaf structure on which the ray traces are based is a three-isotropic-media model, one chloroplast, one air and each separated by a thin cell wall. Differentiation between mesophyll and palisade cells is assumed to add negligible deviation to light rays compared to that caused by the air-cell wall boundaries (Kumar and Silva, 1974). Woolley (1971) presented experimental results on the total reflectance from a soy leaf in air and vacuum infiltrated by oil. He found that the total reflectance dropped by 300% from the air to the oil infiltrated case. Since the air-cell well interface is eliminated in the oil infiltrated case and since scatter effects are unchanged after oil infiltration, Mie and Rayleigh scattering are considered insignificant compared to the effects of refractive index boundary changes (Kumar and Silva, 1974). Plant cells are typically too large to scatter light; however, mitochondria, ribosomes, nuclei and other plastids may cause some scatter (Gates et al., 1965). Given the difficulty of accounting for scatter and considering the results of Woolley, we follow Kumar and Silva and do not include it in our optical model.

Refractive Indices.–The refractive index of air was taken as 1.00 and the refractive index of chloroplast was taken as 1.42 (Kumar and Silva, 1974). Kumar and Silva took the refractive index of the soy leaf cell wall to be the same as the potato cell wall, arguing that both are composed mainly of cellulose and water (Kumar and Silva, 1974). Since the cell walls of plants are mostly cellulose and water (Clowes and Juniper, 1968), the refractive index of the rice leaf cell wall is taken as 1.52. These refractive indices are valid assuming that the ray trace is carried out using light in the near infrared since the leaf does not absorb in this

region. An absorbing medium makes the index of refraction a complex number and complicates the ray trace.

Geometric Optics.–Fresnel's equations (Hecht, 1998) are used to determine the relative amounts of energy transmitted for both parallel (p-polarized) and perpendicular (s-polarized) polarization states. Snell's law is used to determine the angle of refraction. The following relations are used to carry out the ray trace:

$$n_1 \sin \theta_1, = n_2 \sin \theta_r$$

$$Rp = \left\{ \frac{(n_1 / n_2)^2 \cos\theta_1 - ((n_1 / n_2)^2 - \sin^2 \theta_1)^{1/2}}{(n_1 / n_2)^2 \cos\theta_1 + ((n_1 / n_2)^2 - \sin^2 \theta_1)^{1/2}} \right\}^2$$

$$Rs = \left\{ \frac{\cos\theta_1 - ((n_1 / n_2)^2 - \sin^2 \theta_1)^{1/2}}{\cos\theta_1 + ((n_1 / n_2)^2 - \sin^2 \theta_1)^{1/2}} \right\}^2$$

In the expressions above, n_1 is the refractive index of the first medium, n_2 is the refractive index of the second medium, θ_1 is the angle of incidence, θ_r is the angle of refraction, Rp is the reflectance of light polarized parallel to the plane of incidence and Rs is the reflectance of light polarized perpendicular to the plane of incidence. Also important in the ray trace are Rt, the total reflectance $(=(Rp + Rs)/2)$, Tp, the transmittance of light polarized parallel to the plane of incidence $(=(1 - Rp))$, Ts, the transmittance of light polarized perpendicular to the plane of incidence $(=(1 - Rs))$ and Tt, the total transmittance $(=(Tp + Ts)/2)$.

Ray Trace.–Three rays spaced approximately 0.2 mm apart are incident at the leaf surface, going from air to cell wall. Initially, the rays are a 50/50 mix of parallel and perpendicular polarization:

$$Io = (Ipo + Iso), Ipo/Iso = 1$$

where Ipo is the initial intensity for the light polarized parallel to the plane of incidence and Iso is the initial intensity for the light polarized perpendicular to the plane of incidence.

A portion of a ray trace is shown in Fig. 1. Fresnel equations were applied at point A, which is a chloroplast-cell wall boundary, to find Rp, Rs, Tp and Ts. Snell's law is used to find θ_r. Since the cell wall at point A is taken as very thin, the angle at which the ray refracts from chloroplast into the cell wall is taken as the angle of incidence at the subsequent cell wall-air boundary. Again, the ray splits into Rp, Rs, Tp and Ts and θ_r is calculated; the reflected and transmitted rays continue to the next interfaces at points B and C. The portion transmitted at point C propagates to point D. This process is continued until all the rays are either transmitted, diffusely reflected or become insignificant. At interface points like A, B, C, D, a tangent is drawn at the point where
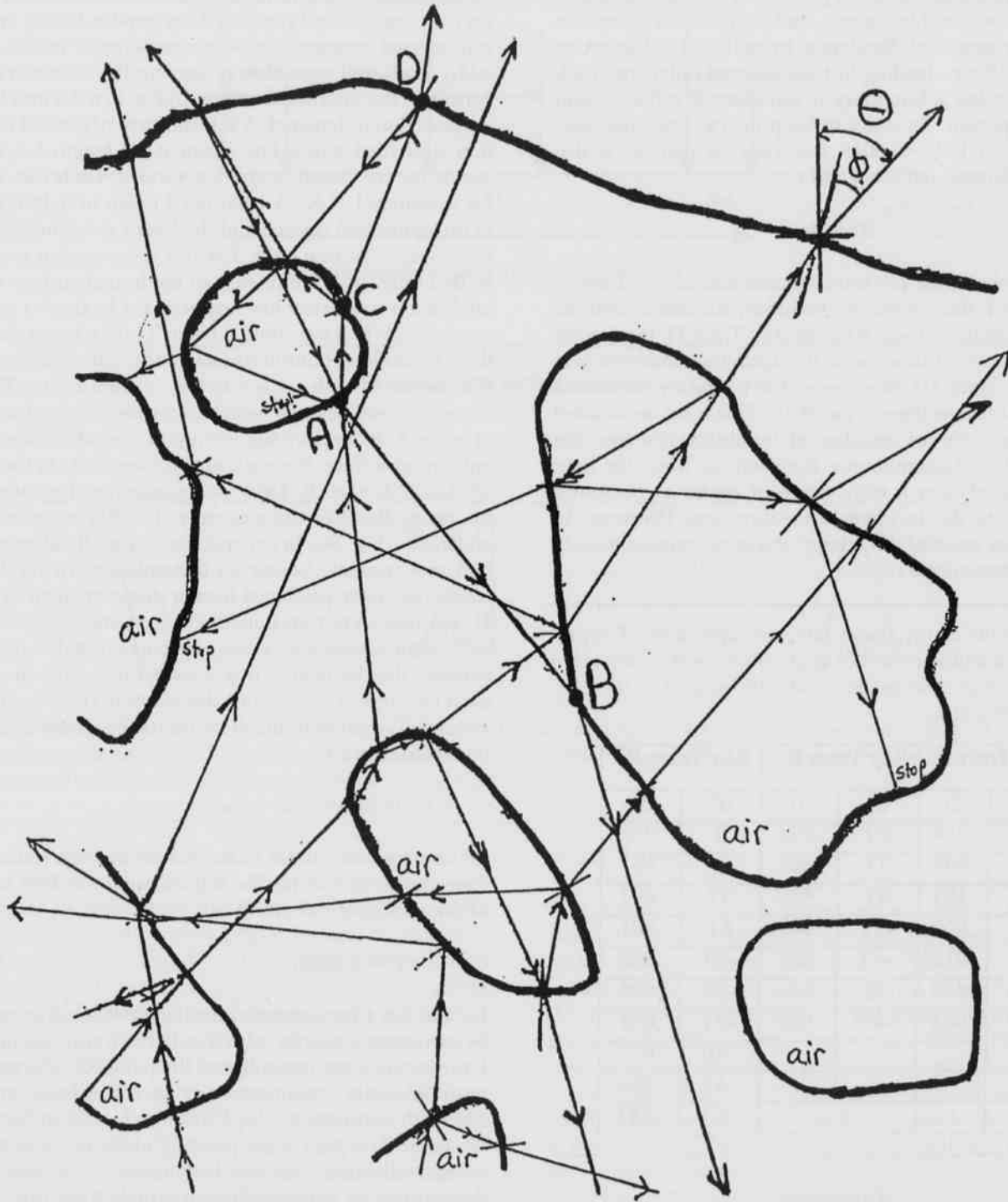
Fig. 1. A ray intersects the chloroplast – cell wall boundary at point A and is transmitted and reflected according to Fresnel Equations. The reflected ray propagates to point B where it is totally internally reflected. The transmitted ray refracts according to Snell's Law and propagates, through the cell wall – air boundary, to point C. The ray is again partially reflected and partially transmitted at point C. θ is measured with respect to the incident beam direction and φ is measured with respect to the leaf surface.

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the ray intersects the boundary between the two media. A normal is drawn to this tangent, and a protractor is used to measure the angle of incidence to within $1°$. Except at angles of incidence leading to total internal reflection, each time a ray strikes a boundary it splits into a reflected and transmitted portion. In order to keep the ray trace manageable, whenever $I_t/I_0 < .0018$, the trace for that ray is discontinued (Kumar and Silva, 1974).

Results

The results of the ray trace are summarized in Table 1. In Ray Trace I, there were 147 boundary transitions and the total transmittance T_t was 0.62; in Ray Trace II, there were 232 boundary transitions and the total transmittance was 0.59; in Ray Trace III, there were 326 boundary transitions and the total transmittance was 0.55. This is an anticipated result: the greater the number of boundary changes, the smaller the total transmittance. For each ray trace, the light was transmitted over a wide range of angles as measured with respect to the incident beam direction. However, in each ray trace most of the energy was concentrated in only one of the transmitted rays.

Table 1. Results of ray traces one, two and three. T represents the transmittance at the angle θ where θ is measured far from the leaf cross section and with respect to the incident beam direction.

Ray Trace I		Ray Trace II		Ray Trace III	
$\theta°$	T_t	$\theta°$	T_t	$\theta°$	T_t
48	.014	29	.008	0	.065
54	.005	37	.067	2	.167
62	.105	43	.459	37	.002
87	.009	-11	.003	61	.001
-23	.013	-13	.008	-63	.006
-30	.459	-32	.044	-69	.006
-50	.003	-43	.003	-21	.003
				-40	.013
				-47	.003
				-63	.287

Discussion

Data Analysis.—One consequence of modeling leaf internal structure as a number of discrete isotropic media separated by a thin cell wall is that as two parallel rays are incident ever closer at the initial epidermal surface, they deviate from each other by a smaller and smaller angle upon

transmission. As the limit of coincidence is reached, the two rays are transmitted parallel. This applies to any model of leaf internal structure that assumes isotropic media separated by a cell wall regardless of the number of media taken to constitute the internal structure. In Fig. 2, a 0.6 mm long leaf cross section is depicted. A 0.1 mm strip of the leaf cross section is divided into n line segments of length L_{ei}, where e stands for the initial epidermal surface. Each line segment L_{ei} is centered at X_i. A collimated beam of light is incident at the epidermal surface and the beam is segmented identically over a 0.1 mm strip. The leaf cross section is arranged so that only the 0.1 mm strip of epidermal surface is irradiated. Each irradiated line segment L_{ei} in the 0.1 mm strip corresponds to a transmitted beam $T_{bi}(\theta)$ where b stands for the 0.6 mm long bottom surface of the leaf cross section and θ is measured with respect to the incident beam. $T_{bi}(\theta)$ is a dimensionless quantity which gives the energy transmitted at angle θ divided by the energy of the ray incident at the epidermal surface. For each ray incident at X_i in the domain $(X_i-L_{ei}/2, X_i+L_{ei}/2)$, $T_{bi}(\theta)$ is a continuous function of θ in the range $(\theta_{ai}, \theta_{bi})$. Consequently, $T_{bi}(\theta)$ is extended into an angle $\Delta\theta_i = \theta_{bi} - \theta_{ai}$. In general, each beam incident along L_{ei} becomes multiple beams on transmission. In RT I and II, seven rays were produced from a single incident ray; in RT III ten rays were transmitted. For each trace, however, over 50% of the transmitted energy is concentrated in one ray. To simplify the discussion, it is assumed that corresponding to each L_{ei} there is exactly one distribution $T_{bi}(\theta)$ such that the average T_{avi} of $T_{bi}(\theta)$ for θ in $(\theta_{ai}, \theta_{bi})$ is greater than some threshold value T_o:

$$(\int T_{bi}(\theta)d\theta)/(\theta_{bi}-\theta_{ai}) \geq T_o$$

We consider only those beams whose average transmittance exceeds this threshold. The total distribution $T_t(\theta)$ is defined as the sum over i of the $T_{bi}(\theta)$:

$$T_t = \Sigma T_{bi}(\theta)$$

L_{ei} and $\Delta\theta_i$ were estimated for the *Lemont* leaf cross section by analyzing a specific path that led to transmission. For RT I, the incident ray is incident at the point X_1. The path of the most intensely transmitted ray in RT I leads to $T_{b1}(\theta_1)$ where θ_1 is measured with respect to the incident beam direction. The path corresponding to $T_{b1}(\theta_1)$ was highlighted and all other paths were ignored. A second ray was drawn incident at the epidermal surface 2 μm from and parallel to the incident ray drawn at X_1. This new ray was traced along the same direction as the path corresponding to $T_{b1}(\theta_1)$. It became the transmitted ray $T_{b1}(\theta_2)$ where θ_2 is measured with respect to the incident beam direction. This process was continued for a third and fourth ray drawn 4 μm and 6 μm from the ray drawn at X_1. The third ray fol-
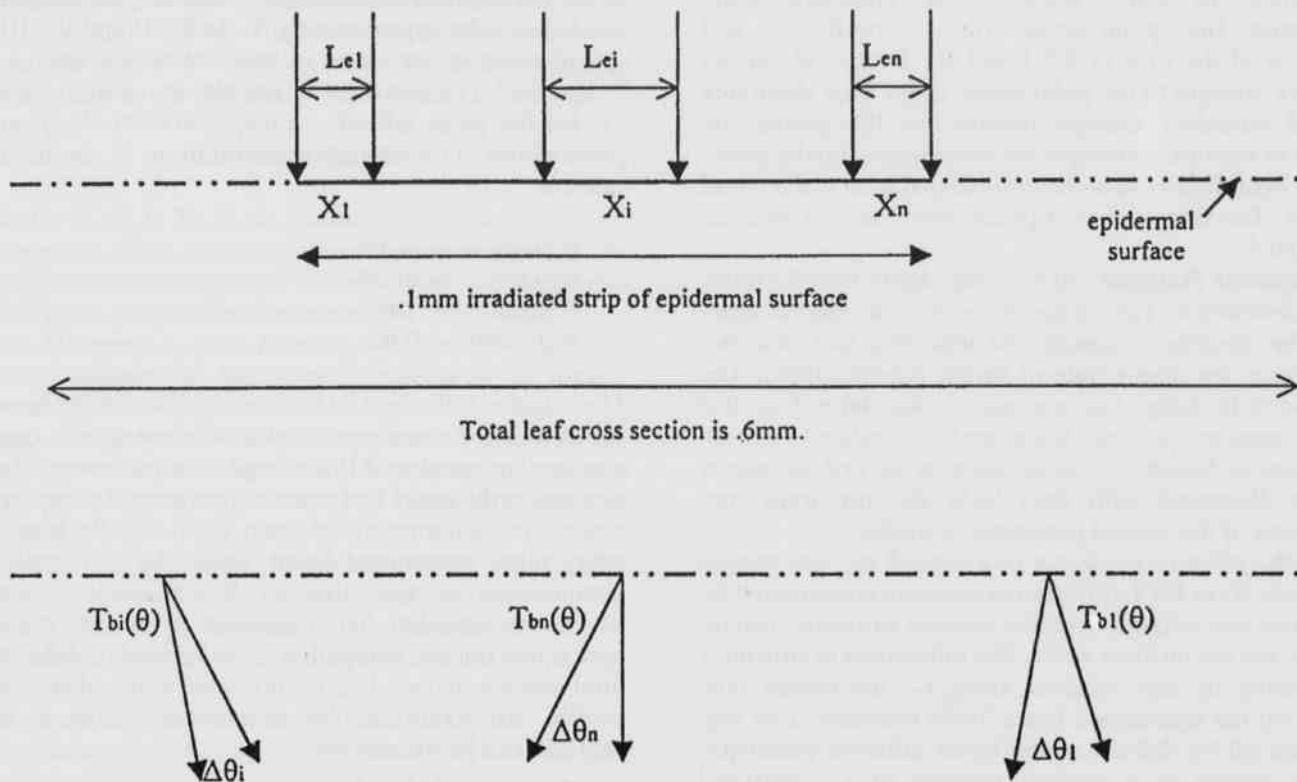
Fig. 2. Total length of leaf cross section is 0.6 mm. A beam of collimated light is incident along a 0.1 mm strip of the leaf cross section at the epidermis. The 0.1 mm strip is segmented into n lengths of L_{ei}. Each L_{ei} corresponds to a distribution of transmitted energy $T_{bi}(\theta)$. Each $T_{bi}(\theta)$ is spread over an angle $\Delta\theta_i$.

lows a path similar to that followed by the first and second ray and is transmitted as $T_{b1}(\theta_3)$ where θ_3 is measured with respect to the incident beam direction. The fourth ray at $X_1 + 6$ μm encounters a different topography than the rays incident at X_1, $X_1 + 2$ μm and $X_1 + 4$ μm and is transmitted in an unrelated direction, that is, in a direction corresponding to a different L_{ei}. From RT I, we found that $\theta_1 = 42°$, $\theta_2 = 42°$ and $\theta_3 = 39.5°$. Therefore, just below 39.5°, as measured with respect to the incident beam direction, the transmittance drops discontinuously to zero. For these first three rays, $\Delta\theta = d\theta_1 + d\theta_2 \sim 2.5°$ where $d\theta_1$ is the angle between $T_{b1}(\theta_1)$ and $T_{b1}(\theta_2)$ and $d\theta_2$ is the angle between $T_{b1}(\theta_2)$ and $T_{b1}(\theta_3)$. Since $\Delta T_{b1}(\theta_2)$ is small, the Fresnel relations guarantee that $T_{b1}(\theta_2)$ and $T_{b1}(\theta_3)$ are both close to $T_{b1}(\theta_1)$, and so $dT_{b1}(\theta_2)/d\theta$ shows a large negative spike near 39.5°. Assuming symmetry around X_1, L_{ei} is estimated at five to ten micrometers and the scale of $\Delta\theta_i$ is degrees. This means that a 0.6 mm long cross section of leaf irradiated along a 0.1 mm strip of epidermal surface could produce a total transmittance $T_t(\theta)$ consisting of as few as ten distinct distributions and each distribution spread into an angle $\Delta\theta$ as small as five degrees.

The micro-fibril structure of the initial epidermal surface causes scattering (Gates et al., 1965). This would decrease the typical length L_{ei} and therefore increase the total number of transmitted beams $T_t(\theta)$. A more realistic model needs to include scatter at the epidermal surface. Another source of scatter is the chlorophyll containing grana in the chloroplast (Gates et al., 1965). However the volume of grana is on the order of one million times smaller then the volume of chloroplast (Clowes and Juniper, 1968). Therefore, if the grana density inside the chloroplast is small enough, the corresponding extinction of transmitted light should be small.

The analyzed 0.6 mm length of leaf cross section was located only as edging a vascular bundle. Variability in the leaf internal structure is large (Gates et al., 1965). However, this variability notwithstanding, our choice of three closely spaced rays yielded results consistent with empirical data and validates our assertion that ray tracing has diagnostic potential.

The polarization of light transmitted from the leaf

changes from a 50/50 mix of parallel and perpendicular polarization to some preferentially polarized state. Comparing the polarization ratios ($PR = R_p/R_s$ and $PT = T_p/T_s$) of the rays in RT I and RT II after about ten boundary changes to the polarization ratios after about one hundred boundary changes implies that the greater the number of boundary changes the more preferentially polarized the light. Polarization therefore depends on leaf internal structure. The distribution of polarization ratio PT was not investigated.

Diagnostic Potential.--Ray tracing shows that the transmitted distribution $T_t(\theta)$ depends on the leaf internal structure. The literature supports the idea that leaf structure depends on the plants state of health (Carter, 1992). The objective is to define two parameters that depend on leaf internal structure and can therefore be correlated with the plants state of health. The application of the first parameter will be illustrated with data from the ray trace; the application of the second parameter is similar.

As the point of incidence of a second ray was moved away from X_1 in RT I, the internal structure encountered by the second ray differed from the internal structure encountered by the ray incident at X_1. The differences in structures encountered by rays incident along L_{ei} determines how spread out the transmitted beam $T_{bi}(\theta)$ becomes. This suggests that $\Delta\theta$ be defined as the beam diffusion parameter and be treated as a random variable of a normalized Gaussian probability density function $pdf(\Delta\theta)$ (Montgomery, 1996):

$$pdf(\Delta\theta) = (1/\sqrt{(2\pi)}\sigma)\exp\{-(\Delta\theta - \mu)^2/2\,\sigma^2\},$$

where μ is the mean and σ is the standard deviation of a set of n beam diffusion values corresponding to the n $T_{bi}(\theta)$ transmitted beams. Therefore $P(\Delta\theta_a, \Delta\theta_b) = \int pdf(\Delta\theta)d\Delta\theta$ integrated over $(\Delta\theta_a, \Delta\theta_b)$ gives the probability of finding a transmitted beam diffused in the range $(\Delta\theta_a, \Delta\theta_b)$.

A second parameter is the angular difference (AD) between two beams. If θ_i bisects angle $\Delta\theta_i$ and θ_j bisects angle $\Delta\theta_j$, then $(\theta_j - \theta_i)$ defines the angular difference parameter, which is the angle between the bisector of $T_{bi}(\theta)$ and the bisector of $T_{bj}(\theta)$. Since the transmitted beam directions are structure dependent, $(\theta_j - \theta_i)$ is also structure dependent. This suggests that $AD = (\theta_j - \theta_i)$ be treated as a random variable of the function $pdf(AD)$:

$$pdf(AD) = (1/\sqrt{(2\pi)}\sigma)\exp\{-(AD - \mu)^2/2\,\sigma^2\}$$

where μ is the mean and σ is the standard deviation of a set of $\Sigma(n - m)$ beam displacement values where the sum runs from m = 1 to m = n, and n is the number of transmitted beams. $P(AD_1, AD_2) = \int pdf(AD)dAD$ integrated over (AD_1, AD_2) gives the probability of measuring an angular difference between two beams in that range.

The beam diffusion parameter, θ, is used as an example. In RT I, the spread about the most intensely transmitted ray was found to be approximately 5°. In RT II and RT III, the spread about the two most intense beams was estimated at 7° and 8.5°. The mean is 6.8° and the standard deviation is 1.6. For this plant, $pdf(\Delta\theta) = .25\exp(-(\Delta\theta-6.8°)^2/5.1)$ and the probabilities of measuring beam diffusions in specific intervals are:

P (0,5)   = 17.4%
P (5,10)   = 81.3%
P (10,15) = 1.4%
P (15,180) ~ 0.0%

The angular difference (AD) is treated similarly; however, AD is a discrete random variable whereas $\Delta\theta$ is a continuous random variable. AD is a large scale parameter of structure across the entire leaf cross section since it compares the bisector of each transmitted beam $T_{bi}(\theta)$ with the bisector of every other transmitted beam $T_{bj}(\theta)$. $\Delta\theta$ is a small-scale parameter of structures that are close to specific paths that lead to transmission. The diagnostic hypothesis suggested here is that $pdf(\Delta\theta)$ and $pdf(AD)$ can be used to define structural indexes that are highly correlated to the plants state of health. For example, the differential structural index $DSI(\Delta\theta)$ can be defined as

$$DSI(\Delta\theta) = \{[\int pdf(\Delta\theta)\,d\Delta\theta]_{max} - \{[\int pdf(\Delta\theta)d\Delta\theta]_{min}\}/\{[\int pdf(\Delta\theta)d\Delta\theta]_{max} + \{[\int pdf(\Delta\theta)d\Delta\theta]_{min}\}.$$

Here $[]_{max}$ means the interval $(\Delta\theta_a, \Delta\theta_b)$ of highest probability, and $[]_{min}$ means the interval $(\Delta\theta_a, \Delta\theta_b)$ of smallest, non zero probability. $DSI(\Delta\theta)$ characterizes the normalized difference in beam diffusion for the leaf under study. A $DSI(\Delta\theta)$ close to zero indicates structural uniformity while a $DSI(A\Delta\theta)$ close to one indicates no uniformity of structure. It may be possible to characterize each state of plant health with a unique $DSI(\Delta\theta)$.

Conclusions

The internal structure of a leaf cross section has been modeled as three isotropic media separated by a thin cell wall, and the total transmittance $T_t(\theta)$ has been written as the superposition of the angular distributions $T_{bi}(\theta)$. Each distribution $T_{bi}(\theta)$ corresponds to a length L_{ei} of irradiated epidermal surface and is spread into an angle $\Delta\theta_i$. L_{ei} was estimated as five to ten micrometers, and the scale of $\Delta\theta_i$ was estimated in degrees. Two measurable parameters of leaf internal structure were defined, and a corresponding differential structural index $DSI(\Delta\theta)$ was proposed as a diagnostic tool making use of the angular difference and diffusion of transmittance.

The authors would like to acknowledge Dr. Paul A.

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Floristic Status of Log Ferns *(Dryopteris)* in Arkansas

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Abstract

The fern flora of Arkansas consists of 96 taxa, including five species and three hybrids of the Log Fern genus *Dryopteris*. This report summarizes a twenty year floristic and ecologic study of their distribution and abundance in Arkansas. Historical data are presented to review the slow accumulation of taxa reported in floras of Arkansas from early collectors to 1980 and the rapid accumulation of taxa since 1980 employing modern field techniques. Chorological data and floristic data are presented based on field, herbarium, and literature studies to correct the record and document the known localities of the eight Arkansas taxa: *Dryopteris carthusiana* at three localities in three counties; *Dryopteris celsa* at 23 localities in five counties; *Dryopteris goldiana* at one locality in one county; *Dryopteris ludoviciana* at one locality in one county; *Dryopteris marginalis* at numerous localities in 38 counties; *Dryopteris* X*australis* at nine localities in four counties; *Dryopteris* X*leedsii* at two localities in two counties; *Dryopteris celsa* X*goldiana* at one locality in one county. Floristic data are presented to exclude from the state flora two species and two hybrids of the genus *Dryopteris*: *D. cristata, D. intermedia, D.* X*neo-wherryi,* and *D.* X*separabilis.* Arkansas has more localities and county occurrences of *Dryopteris* X*australis* than any state in the hybrid's range. One locality in Baxter Co. supports a genus community of *Dryopteris* comprised of three species and three hybrids.

Introduction

The fern genus *Dryopteris* includes the Shield Ferns, Wood Ferns, and Log Ferns, comprising 13 temperate species in North America north of Mexico (Carlson and Wagner, 1982; Montgomery and Paulton, 1981, Montgomery and Wagner, 1993; Wagner, 1971). The species were problematic historically, but are reasonably well known now as a result of the application of modern systematic approaches. Hybridization and polyploidy among these species has produced 27 of a possible 78 interspecific hybrids (Montgomery, 1982; Wagner, 1971; Wagner and Musselman, 1979). The identification of hybrid plants in Arkansas and elsewhere previously contributed to considerable confusion in *Dryopteris* nomenclature and floristics.

The first modern summary of Log Ferns in Arkansas was by Taylor (1976), who reviewed herbarium specimens, conducted field studies to relocate old collection sites, produced a modern fern flora for Arkansas (Taylor and Demaree, 1979), and published a useful field guide (Taylor, 1984). Taylor (1984) reported three species and one hybrid *Dryopteris* as part of the fern flora of Arkansas; this information was restated by Smith (1988). Within weeks of the publication of Taylor's Manual, another *Dryopteris* species and one extremely rare hybrid were discovered in Arkansas (Peck et al., 1985, 1987). Subsequent field surveys were conducted to describe the status of these recently discovered populations and their reproductive biology in Arkansas

(Peck and Peck, 1988). Contract surveys supported by state, federal, and private organizations to inventory these and other plants of biological concern on federal lands in the Ouachita Mountain region of Arkansas (Bates, 1988-1992) revealed additional localities, but these were reported without herbarium specimen vouchers. Ten years after Taylor's Manual, a new summary of county-level floristic records of Arkansas ferns (Peck and Taylor, 1995) reported four species and two hybrid *Dryopteris* in the Arkansas flora, with five of the six showing increased distributional data. Since then, additional field work has added another *Dryopteris* species and an extremely rare hybrid to the Arkansas fern flora (Peck et al., 2000). Additional field study added new localities and county records through intensive field search of appropriate microhabitats in promising regions of the state.

At present, the fern flora of Arkansas consists of 96 taxa, including five species and three hybrids of the Log Fern genus *Dryopteris*. Since the last summation (Peck and Peck, 1988), much new locality-level information has accumulated from field, herbarium, and literature study. Thus, it was deemed appropriate to prepare a new summary with interpretation and to provide a key to species plus hybrids. Detailed discussions of the importance of specimen records to validate present and past literature are presented to point out the critical role Arkansas' *Dryopteris* have played in a regional and national understanding of hybridization in Log Ferns.

Methods

Since 1981, efforts were made to re-locate, re-collect, and re-voucher the Log Fern flora of Arkansas to provide a better evidentiary basis to the extent of their state occurrence. Herbarium searches at national herbaria, including MO, US, NY, PHIL, along with specimen review of in-state and out-of-state folders at UARK, were conducted to augment earlier searches of the ten Arkansas herbaria [UARK, LRU, UCAC, STAR, UAM, HSU, HDX, APCR, Harding, Lyons]. Literature at national, regional, and state levels was searched for passages referring to Arkansas Dryopteris floristics. New records and new locality reports were noted and followed by a search for and examination of herbarium vouchers to validate those published findings. Published findings, unsupported with specimen records, required duplicative work to provide vouchers. Field work targeted appropriate regions of 10 counties (Baxter, Bradley, Garland, Lawrence, Logan, Montgomery, Polk, Stone, Van Buren, and Yell counties) to locate additional populations of rare Dryopteris. This field work was combined with supplemental general collecting across the northwestern one-half of the state to obtain recent vouchers for Dryopteris marginalis. Lastly, a review of national electronic distribution maps on the Arkansas flora [such as that of Smith (1988) maintained by the Bioinformatics Project at Texas A&M and national distribution maps of FONAP, the Flora of North America Project, and BONAP, the Biota of North America Project, with the latter now available as a CD (Kartesz and Meacham, 1999)] was undertaken to assess their accuracy. County dot maps, a key to species and hybrids, and a summary of localities were prepared to document and summarize Log Fern floristic data.

Results and Discussion

General Floristics.--The accumulation of taxonomic and floristic information on the genus Dryopteris in Arkansas is summarized in Table 1. The general trend shows a slow increase in taxa, reflecting past difficulty in the survey and inventory of a biodiverse, topographically rugged state, by relatively and proportionately few botanists with limited means of transportation. Yet, from 1860 until 1943 each major collector wrote a fern flora for Arkansas, providing a rich literature trail to the floristic data and herbarium specimen vouchers. This floristic documentation difficulty was compounded by the slow realization by fern experts of the hidden diversity within southern representatives of Dryopteris and a painfully slow process to separate southern species from forms, varieties, and hybrids within a genus with reticulate species formation that incorporated interspecific hybridization, polypoidy, and backcrossing to form a

Table 1. Incremental increase in floristic knowledge about pteridophytes in general and taxa of the genus Dryopteris in particular in the Arkansas vascular plant flora: floras cited by their author and year of publication, # pteridophyte taxa (species plus hybrids), # Dryopteris taxa (species plus hybrids) reported, and scored for eight known plus one excluded Arkansas taxa [D. cristata]. Floras cited in bibliography. Taxon key: ca = D carthusiana, ce = D. celsa, cr = D. cristata, go = D. goldiana, lu = D. ludoviciana, ma = D. marginalis, Xau = D. Xaustralis, Xle = D. Xleedsii, Xcg = D. celsa X goldiana.

Flora: Author (Year)	# ferns and fern allies	# Log Fern	species						hybrids		
			ca	ce	cr	go	lu	ma	Xau	Xle	Xcg
1. Nuttall (1835)	23	1						ma			
2. Lesquereux (1860)	35	3	ca		cr			ma			
3. Harvey (1881)	39	3	ca		cr			ma			
4. Branner and Coville (1891)	47	3	ca		cr			ma			
5. Buchholz (1924)	49	2			cr			ma			
6. Buchholz and Palmer (1926)	51	3	ca		cr			ma			
7. Moore (1940)	67	4	ca		cr			ma		Xle	
8. Demaree (1943)	70	4	ca		cr			ma		Xle	
9. Taylor (1976)	70	4	ca	ce				ma		Xle	
10. Smith (1978)	70	4	ca	ce				ma		Xle	
11. Taylor and Demaree (1979)	73	4	ca	ce				ma		Xle	
12. Taylor (1984)	72	4	ca	ce				ma		Xle	
13. Peck, Peck and Taylor (1987)	87	6	ca	ce			lu	ma	Xau	Xle	
14. Smith (1988)	78	6	ca	ce			lu	ma	Xau	Xle	
15. Peck and Taylor (1995)	92	6	ca	ce			lu	ma	Xau	Xle	
16. Peck, Hendrix, and Witsell (2000)	96	8	ca	ce		go	lu	ma	Xau	Xle	Xcg

Table 2. Correct name, cytomorphotype, range, Arkansas distribution, synonymy [S=] for Arkansas *Dryopteris*, and misapplied names [M=] used in literature or on herbarium specimens.

1. *Dryopteris carthusiana* (Villars) H. P. Fuchs
   Tetraploid, North America and Europe
   Arkansas: Two localities in two counties
      S=*Polypodium carthusianum* Villars
      S=*Polypodium spinulosum* O. F. Muell.
      S=*Polystichum spinulosum* (O. F. Muell.) Lam.
      S=*Aspidium spinulosum* (O. F. Muell.) Sw.
      S=*Nephrodium spinulosum* (O. F. Muell.) Strempel
      S=*Lastrea spinulosa* (O. F. Muell.) Presl
      S=*Thelypteris spinulosa* (O. F. Muell.) Nieuwl.
      S=*Dryopteris austriaca* var. *spinulosa* (O. F. Muell.) Fiore
      S=*Dryopteris spinulosa* (O. F. Muell.) Watt

2. *Dryopteris celsa* (Palmer) Palmer, Knowlton & Pollard
   Tetraploid, North American endemic
   Arkansas: Twenty-three localities in five counties
      S=*Dryopteris goldiana* subsp. *celsa* Palmer
      S=*Aspidium goldianum* f. *celsum* (Palmer) Clute
      S=*Nephrodium goldianum* var. *celsum* (Palmer) Waters
      S=*Aspidium goldianum* var. *celsum* (Palmer) Robinson
      S=*Dryopteris goldiana* f. *celsa* (Palmer) Clute
      M=*Dryopteris atropalustris* Small
      M=*Dryopteris clintoniana* X *goldiana* [sensu Shaver]
      S=*Dryopteris goldiana* X *ludoviciana* [sensu Small]
      M=*Dryopteris ludoviciana* X *marginalis* [sensu Klekowski]
      S=*Dryopteris xcelsa* [sensu Small]

3. *Dryopteris cristata* (L.) A. Gray
   Tetraploid, Northern North America and Europe
   Excluded from Arkansas flora
      S=*Polypodium cristatum* L.
      S=*Polystichum cristatum* (L.) Roth.
      S=*Aspidium cristatum* (L.) Sw.
      S=*Nephrodium cristatum* (L.) Michx.
      S=*Lastrea cristata* (L.) C. Presl
      S=*Thelypteris cristata* (L.) Nieuwl.
      S=*ludoviciana* X "*semicristata*" [sensu Wagner]
      M=*Dryopteris goldiana* X *ludoviciana* [sensu Klekowski]

4. *Dryopteris goldiana* (Hook.) A. Gray
   Diploid, North American endemic
   Arkansas: One locality in one county
      S=*Aspidium goldianum* Hook. ex Goldie
      S=*Nephrodium goldianum* (Hook.) Hook. & Grev.
      S=*Lastrea goldianana* (Hook.) Presl
      S=*Polystichum goldianum* (Hook.) Keyserl.
      S=*Aspidium filix-mas* var. *goldiana* (Hook.) Christ
      S=*Filix goldiana* (Hook.) Farw.
      S=*Filix-mas goldiana* (Hook.) Farw.
      S=*Thelypteris goldiana* (Hook.) Nieuwl.

5. *Dryopteris intermedia* (Muhl. ex Willd.) A. Gray
   Tetraploid, North American Endemic
   Excluded from Arkansas flora
      S=*Aspidium intermedium* Muhlenberg ex Willd.
      S=*Dryopteris austriaca* var. *intermedia* (Muhl. ex Willd.) Morton
      S=*Dryopteris spinulosa* var. *intermedia* (Muhl. ex Willd.) Underw.

6. *Dryopteris ludoviciana* (Kunze) Small
   Diploid, North American endemic
   Arkansas: One locality in one county, possibly extripated

      S=*Aspidium ludovicianum* Kunze
      S=*Nephrodium floridanum* Hook.
      S=*Aspidium floridanum* (Hook.) D. C. Eat. ex Chapm.
      S=*Aspidium cristatum* var. *floridanum* (Hook.) D. C. Eaton ex Mann
      S=*Lastrea floridana* (Hook.) Kunze
      S=*Dryopteris floridana* (Hook.) Farw.

7. *Dryopteris marginalis* (L.) A. Gray
   Diploid, North American endemic
   Arkansas: many localities in 38 counties
      S=*Polypodium marginale* L.
      S=*Aspidium marginale* (L.) Sw.
      S=*Nephrodium marginale* (L.) Michx.
      S=*Lastrea marginalis* (L.) C. Presl
      S=*Polystichum marginale* (L.) Keyserl.
      S=*Thelypteris marginalis* (L.) Nieuwl.
      S=*Filix marginalis* (L.) Farw.
      S=*Filix-mas marginalis* (L.) Farw.

8. *Dryopteris Xaustralis* Small
   Triploid, "sterile", North American endemic
   Arkansas: Nine localities in four counties
      M=*Aspidium cristatum* var. *clintonianum* D. C. Eaton in A. Gray
      M=*Dryopteris cristata* var. *clintoniana* (D. C. Eat.) Underw.
      M=*Thelypteris cristata* var. *clintoniana* (D. C. Eat.) Weath.
      M=*Thelypteris clintoniana* (D. C. Eat.) House
      M=*Dryopteris clintoniana* (D. C. Eat.) Dowell
      S=*Dryopteris cristata* var. *australis* (Wherry) Bloomquist & Correll
      S=*Dryopteris clintoniana* var. *australis* Wherry
      S=*Dryopteris australis* (Wherry) Small

9. *Dryopteris Xleedsii* Wherry
   Triploid, "sterile", North American endemic
   Arkansas: Two localities in two counties
      M=*Dryopteris cristata* (L.) A. Gray
      M=*Dryopteris celsa* (Palmer) Palmer, Knowlton & Pollard
      M=*Dryopteris celsa* X *D. spinulosa* [sensu Morton]
      M=*Dryopteris marginalis* (L.) A. Gray
      M=*Dryopteris celsa* X ? [by Crane]
      M=*Dryopteris separabilis* Small
      M=*Dryopteris goldiana* f. *arkansana* [annotation by Wherry but never published]
      M=*Dryopteris clintoniana* var. *australis* Wherry
      M=*Dryopteris australis* (Whery) Small
      M=*Dryopteris wherryi* Crane
      M=*Dryopteris goldiana* X *marginalis* [sensu Wherry]
      M=*Dryopteris Xneo-wherryi* Wagner [sensu Montgomery]
      S=*Dryopteris celsa* X *marginalis*

10. *Dryopteris celsa* X *goldiana*
    Triploid, sterile, North American endemic
    Arkansas: One locality in one county

11. *Dryopteris Xneo-wherryi* Wagner
    Diploid, sterile, North American endemic,
    Excluded from Arkansas flora
       S=*D. goldiana* X *marginalis*

12. *Dryopteris Xseparabilis* Small
    Triploid, sterile, North American endemic,
    Excluded from Arkansas flora
       S=*D. intermedia* X *marginalis*

genus of 13 compilospecies with 27 hybrids in North America (Table 2). This process of taxon recognition lasted into the 1970s. For example, although *Dryopteris celsa* was collected from Arkansas in 1924 and the herbarium specimen voucher was annotated correctly by 1935, it was not reported from Arkansas until Taylor (1976). Although only three *Dryopteris* taxa were reported correctly from Arkansas until 1976, since then five more taxa were added in less than one-fourth the time based primarily on the ability to check herbarium specimen vouchers.

County dot maps prepared for each species and hybrid (Figs.1 - 8) show that Log Ferns generally occur in the northwestern one-half of Arkansas. Only *Dryopteris marginalis* is common and widely distributed. All other species and hybrids are rare in Arkansas. Maps useful for the national distribution of Arkansas's fern flora were provided by the Flora of North America Project (FONAP) including species maps [www.fna.org] that accurately reported the distribution of Arkansas' four species. The convenience of using these data must be tempered with a high amount of caution. County dot maps for Arkansas ferns based on data provided by Smith (1988) were placed on the Internet by the Bioinformatics Center at Texas A&M [www.tamu.edu]. National state distribution maps were posted by the Biota of North America Project (BONAP) [www.bonap.org]. These maps provide state-wide and national coverage for *Dryopteris* in Arkansas, but two maps are incorrect. The map for *Dryopteris* X*leedsii* has six states incorrectly mapped. The map for *Dryopteris* X*neo-wherryii* includes Arkansas where the hybrid has not been found. In addition, electronic flora compilers only recognize hybrids reported with a collective binomial, thus under-reporting the biodiversity of a genus and the flora of Arkansas by one taxa.

A key to Arkansas Log Ferns, species and hybrids, was included in this report. Keys to ferns generally do not include keys to hybrids (Lellinger, 1984; Smith, 1994), but such plants are relatively easy to detect with use of a compound microscope to discern whether the plant has the uniform, viable spores of a species or the irregular size and shape of non-viable spore products produced by primary hybrids (Montgomery, 1982).

Species Distribution and Chorology

***Dryopteris carthusiana* in Arkansas.**--The Spinulose Woodfern *Dryopteris carthusiana* (Villars) H. P. Fuchs is a circumboreal, fertile, allotetraploid species ($4n = 164$), denoted by the genome code IISS (Table 2). The species is generally thought to be the result of hybridization between two diploids, *Dryopteris intermedia* (II) and an unknown species "semicristata" (SS), followed by polyploidy, chromosome doubling, to produce the fertile alloteraploid species *Dryopteris carthusiana*. This species occurs in Arkansas at the

extreme southwestern edge of its range (Fig. 1). *Dryopteris carthusiana* is known from two special microhabitats and one common microhabitat. it occurs around the entrance to a cool, blowing-air cave, near the top of the tallest mountain in the state, and along a shaded stream bank.

Lesquereux (1860) provided the first report of *Dryopteris carthusiana* from the "woods" of Arkansas. According to Harvey (1881), *D. carthusiana* was "said to grow in rich woods by the Botanist [Lesquereux] of the Ark. [Geological] Surv. I have not found any specimens." Branner and Coville (1891) included this species without comment. Buchholz (1924) indicated that 1) his field searches failed to find this species where it should occur, 2) that he found no specimen in Arkansas herbaria, and 3) that he found no specimen in the five largest national herbaria located in Boston, Chicago, St. Louis, New York, and Washington, DC. Buchholz (1924) concluded that it was "very doubtful" that this species is found as far south as Arkansas. Surprisingly, Buchholz and Palmer (1926) reported *D. carthusiana* as present in the Arkansas flora based on a collection in 1924 by Dwight Moore near the summit on the north slope of Magazine Mountain in Logan County. Moore (1940) reported *Dryopteris carthusiana* in Arkansas as known only from that location. However, when Taylor (1976) sought out that voucher, it could not be located. Taylor (1976) and Taylor and Demaree (1979 reported this species from Arkansas based only on a specimen Moore collected in 1960 from Stone Co. at Rowland Cave. Peck (1986) reported the rediscovery of 4 plants of this species on Magazine Mountain, probably having relocated the Moore location. The *D. carthusiana* specimens cited in Buchholz and Palmer (1926) and Moore (1940) remain missing. Perhaps the specimens were included in exchanges with other herbaria, a practice noted by Buchholz and Palmer (1926) or they were discarded when Herbarium UARK was moved in the early 1970s from Old Main Building to the Botany-Engineering Building.

The species is known from three localities in three counties in Arkansas (Fig. 1):

1) Logan Co.: below Brown Springs, Magazine Mountain, Rd 308, below summit on north facing side, T6N R25W S22, Blue Mountain Quad., 4 plants. Specimens: Peck 85105 (LRU) on 5 Oct 1985; Young A-1 (LRU) on 10 Nov 1990; observed by Peck in 1993.

2) Stone Co.: Rowland Cave, 1 mi N Fifty Six, T15N R12W S1, Fifty Six Quad., organic humus, moist, cool, at cave entrance and on limestone outcrops above and adjacent to entrance. Taylor (1976) reported 10 plants; Peck (1986) reported two dozen plants. Hyatt in 1990 observed 20 plants. Now under increased protective management; Peck observed over 100 plants in 1999. Specimens: D. Moore 60-54, 2 sheets, (UARK) on 7 Aug 1960; Taylor 2894 (SIU, UARK) on 28 Sep 1975; Peck 81089 (LRU) on 18 June 1981; Hyatt 352.69 (UARK) on 23 Aug 1990; Crank 92022 (HSU) on Sep 10 1992; Peck 99401 (LRU) on 20 July 1999.

3) Yell Co.: Danville Mt., along Ark 27, 0.5 mi down from power station, T5N R22W S6, Danville Mountain Quad., a few plants. Specimens: T. Kelly 14 (LRU) on 18 Nov 1990.
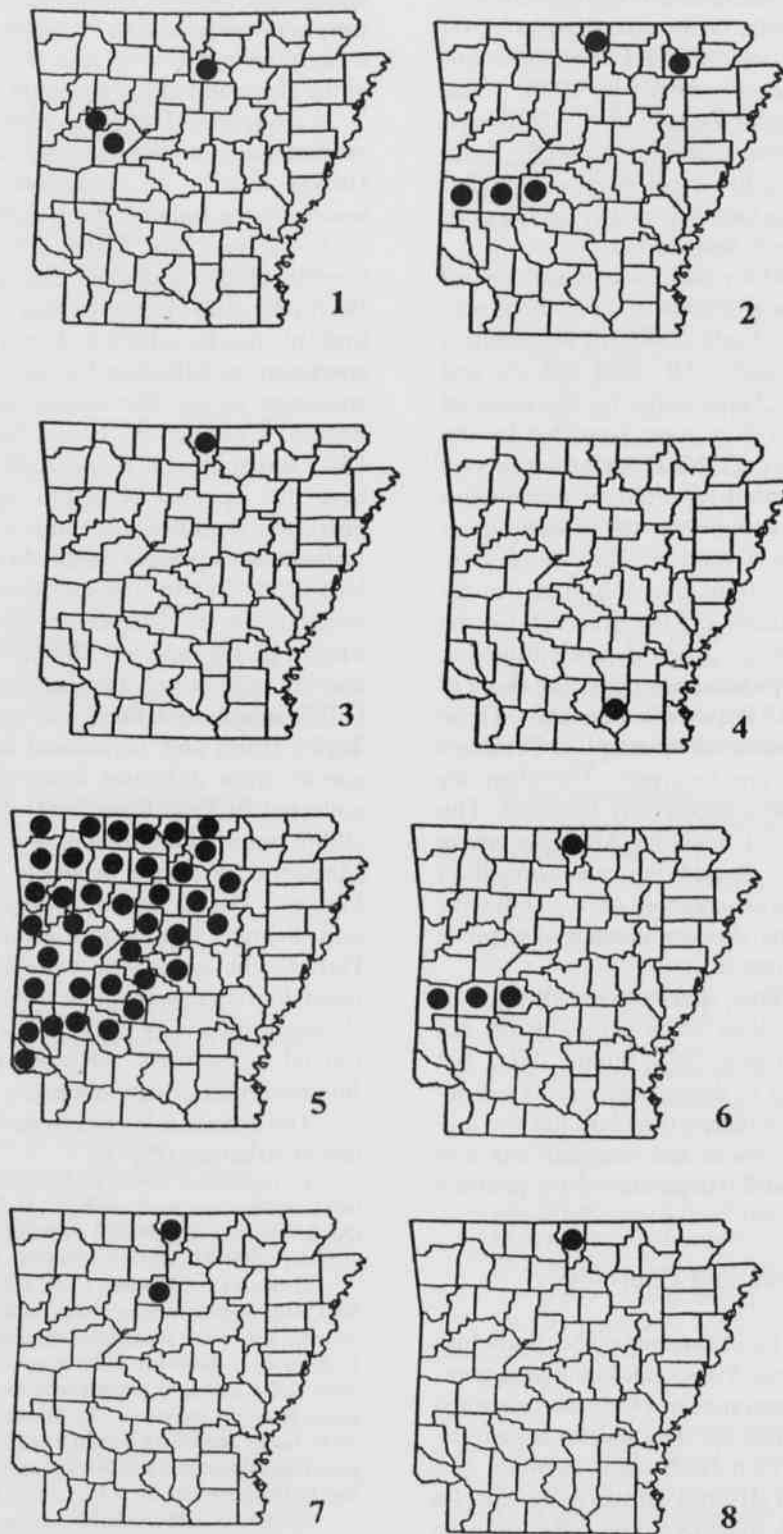
Figs. 1-8. Map 1. *Dryopteris carthusiana.* Map 2. *Dryopteris celsa.* Map 3. *Dryopteris goldiana.* Map 4. *Dryopteris ludoviciana.* Map 5. *Dryopteris marginalis.* Map 6. *Dryopteris X australis.* Map 7. *Dryopteris X leedsii.* Map 8. *Dryopteris celsa X goldiana.*

***Dryopteris celsa* in Arkansas.**--The Log Fern *Dryopteris celsa* (Palmer) Palmer, Knowlton & Pollard is a North American endemic, fertile, allotetraploid species (4n = 164) denoted by the genome code GGLL (Table 2). This species was formed as the result of multiple events of two diploid species hybridizing: *Dryopteris goldiana* (GG) and *Dryopteris ludoviciana* (LL) to form sterile GL which became fertile through polyploidy, chromosome doubling, to become the allotetraploid GGLL (Werth, 1991). This is a much misunderstood taxon. It was one of the last *Dryopteris* species to be recognized in North America. Recognition and separation of this species from other winter-green species required the efforts of many pteridologists, who concluded (Wagner, 1972) "that the main reason for the confusion is the continuum of cytomorphotypes in *Dryopteris* that renders cluster analysis moot". For many years and for many fern experts, *D. celsa* was erroneously considered to be *D. clintoniana* X *goldiana*, an incorrect position that held sway into the 1960s (Shaver, 1954; Walker, 1962a; Wagner, 1971).

Compounding the systematic problem, the geographic range of *D. celsa* was underestimated as well. Small (1938) reported that *D. celsa* was restricted to the Coastal Plain and Piedmont adjacent to the Great Dismal Swamp of North Carolina and Virginia north to Delaware to Maryland. Small (1938) explicitly stated "this log fern seems not to have spread into the Mississippi Valley", but noted that "there is a somewhat closely related fern on the other side of the Mississippi River in Arkansas" (a reference to the Palmer fern at Shirley now called *D.* X*leedsii*). Mysteriously, Small (1938) did not mention the voucher specimen of *D. celsa* collected in 1924 from Imboden, Lawrence Co., Arkansas, and housed at the Smithsonian Institution Herbarium in Washington, DC, where it was correctly named by Maxon; it is important to note that 16 years later, Moore (1940) did not list *Dryopteris celsa* as occuring in Arkansas.

Wagner (1972) summarized the status of *Dryopteris* in the Southern Appalachians and Southeastern United States, commenting extensively on *D. celsa* and its relatives. Based on specimens collected from Arkansas in the early 1950s by Jewel Moore, Aileen McWilliams, and later by Dwight Moore and Hugh Iltis, and determined to be *Dryopteris celsa* by W. H. Wagner, Wherry (1972) noted that the range of *D. celsa* was now much wider than previously suspected. The range was now "South Carolina to North Carolina in Coastal Plain swamps, in uplands from Georgia to North Carolina, in the Gulf Coastal Plain and Mid-south Interior Highlands of Illinois and Missouri, recently known from New Jersey to New York, westward to Michigan, and in the south, across the Gulf States to Texas and Arkansas". Plants in Michigan, New York, Louisiana, Texas, Missouri, and Illinois were old collections, originally mis-identified and mis-reported as *D. cristata*. These voucher specimens were

slowly being recognized and annotated as southern plants of *D. celsa* (Wagner and Wagner 1965; Wagner et al., 1969; Thomas et al., 1973; Peck and Peck, 1988).

Taylor (1976) was the first to report *D. celsa* in Arkansas, although its state occurrence was vouchered in 1924. Localities continued to be found; Peck and Peck (1988) reported eight localities in four counties: one in Lawrence Co., one in Garland Co., two in Montgomery Co., and four in Polk Co. Bates (1988-1992) surveyed the Ouachita National Forest under contract and reported without vouchers the occurrence of *D. celsa* at seeps and springs in Garland, Montgomery, and Polk counties, but failed to note all cytomorphotypes present. Hyatt located a population of *D. celsa* in the north-central region of Arkansas in Baxter Co., but too late to be included in the published county flora (Hyatt, 1993). Extensive efforts were made to re-locate and collect voucher specimens of this species.

Twenty-three localities of *D. celsa* are known to occur in five Arkansas counties (Fig. 2):

1) Baxter Co.: Merrill Ridge Blowing Cave, For. Serv. Rd. 1127, Merrill Ridge Road, 17N R12W S30, Norfolk SE Quad., in a spring on south side of main creek feeding into Stewart Fork, a collapsed blowing cave with spring and large breakdown rocks at entrance covering 10 x 20 m, approximately 100 plants. Hyatt voucher incorrectly locates the site at R13W; relocated by Earl Hendrix USFS-ONF in 1999. Specimens: Hyatt 4947.03 (UARK) collected on 1 July 1992; Peck 99404 (LRU) on 20 July 1999.

2) Baxter Co.: Caroline Gap sink, For. Serv. Rd. 73, Push Mt. Rd, T17N R12W S19, Norfolk SE Quad., organic humus in sink hole, drying out, population greatly reduced, now 6 adults and 2 juvenile plants, discovered by Earl Hendrix USFS-ONF. Specimens: Peck 99403 (LRU) on 20 July 1999.

3) Garland Co.: Meyer Creek, along For. Serv. Rd. 386; seepage bog and stream bank along road, with D. ¯australis, T3SR22W S16/17, Pearcy Quad., Over 100 plants mainly to the east of the creek. Specimens: Peck 84690 (LRU) on 27 Oct 1984; Peck 91150 (LRU) on 3 June 1991; Peck 99187 (LRU) on 15 Jun 1999.

4) Garland Co.: Walnut Fork Creek, N of Charleton Campground by trail or W of Crystal Springs on For. Serv. Rd. 47 to ford of creek to seepage, with D. X*australis*, T2S R22W S29, Crystal Springs Quad. Two dozen plants. Specimens: Peck 88433 (LRU) on 16 Aug 1988; Peck 91150 (LRU) on 8 June 1991; Crank 92003 (HSU) on Nov 2, 1992; Peck 95452 (LRU) on 20 Nov 1995; Peck 99242 (LRU) on 4 July 1999.

5) Lawrence Co.: York Springs, on old York estate, 3.5 mi S of Imboden, T18N R2W S35, Imboden Quad. Spring now a concrete box marked with name "York Spring' above stock pond in cleared and overgrazed pasture, no longer supports fern population; fern extirpation and spring location verified by Steve Orzell, Arkansas Dept. Natural Heritage, in November 1984. Specimen: B. C. Marshall #9 (US) on 24 May 1925. Specimen sent to W. Maxon at US for identification. Annotated as Lawrence Co. by Morton. Named *D. celsa* by E. T. Wherry in 1935. Identification confirmed by F. W. Crane in 1956. Identification confirmed by W. H. Wagner in 1974. No other specimen of this fern from this locality exists.

6) Montgomery Co.: Wehunt Creek seep, W of Norman on AR 8, S on For. Serv. Rd. 43 to wooded seep on W side of gravel road in stand of Equisetum with D. X*australis*. T3S R27W S33, Big Fork Quad. Population declining, stressed from road development and canopy loss; approximately 200 plants in 1981; 50 plants in 1999. Specimens: Taylor 2845 (SIU, UARK) and Taylor 2846 (UARK) on 21 Aug 1975; Peck 81128 (LRU) on 7 June 1981; Peck 84715 (UARK) and Peck 84717 (LRU) on 3 Nov 1984;

Peck 99125 (LRU) on 4 July 1999.

7) Montgomery Co.: Montgomery Creek, W of Collier Springs, For. Ser. Rd. 117, alder thicket and springs, T3S R24W S18, Caddo Gap Quad., 11-30 plants present. Specimens: Peck 92186 (LRU) on 21 Aug 1992; Peck 99454 (LRU) on 11 Sep 1999.

8) Montgomery Co.: Buttermilk Springs, T4S R24W S6, Caddo Gap Quad., about 25 plants according to Bates (1988). Witsell noted 200 plants in 1999, including 100 fertile adults and 100 smaller juvenile plants. Peck estimated population size was similar to Witsell's description. Specimens: Bouffard, Bates & Wood 25523 (MO) on 10 May 1991; Peck 92180 (LRU) on 21 Aug 1992; Witsell 99083 (LRU) on 11 Aug 1999; Peck 99450 (LRU) on 11 Sep 1999.

9) Montgomery Co.: Bates Spring, T4S R25W S5, Norman Quad., SW Norman on For. Serv. Rd., S Mine Creek Rd. on C65A. Four plants found. Specimens: Peck 99451 (LRU) on 11 Sep 1999.

10). Montgomery Co.: Little Missouri River tributary creek seep, NW of Little Missouri Falls along Mine Creek Rd., creek and spring. T4S R27W S6, Big Fork Quad., Sixteen plants found. Specimens: Peck 92204 (LRU) on 21 Aug 1992; Peck 99463 (LRU) on 11 Sep 1999.

11) Montgomery Co: Singing Springs, E Norman on For. Serv. Rd. 208, N of road along trail to seepage coming out of box canyon and along stream below with *D. Xaustralis*. T3S R24W S22, Caddo Gap Quad. Less than two dozen plants observed. Specimens: Peck 95097 (LRU) on 27 Apr 1995.

12) Montgomery Co: Box Springs, W of Norman on AR 8, S on For. Serv. Rd. 73, spring and creek flowage on E side of road, with numerous plants of *D. Xaustralis*. T4S R26W S33, Polk Creek Mtn. Quad. Fewer than 10 plants observed. Specimens: Peck 95125 (LRU) on 18 Aug 1995; Peck 99121 (LRU) on 4 July 1999; Witsell 99041 (LRU) on 3 Aug 1999.

13) Montgomery Co.: Lick Creek Seep, T4S R26W S22, Polk Creek Mtn. Quad. Twenty-two plants counted. Specimens: Peck 92195 (LRU) on 21 Aug 1992; Peck 99458 (LRU) on 11 Sep 1999.

14) Montgomery Co.: Collier Springs wooded seep and bog, along For. Serv. Rd. 177, W side of road, N and above springs. T3S R24W S17 NW1/4, Caddo Gap Quad. Six plants counted. Specimens: Peck 99142 (LRU) on 4 July 1999.

15) Montgomery Co.: Collier Springs Creek, along For. Serv. 177, E side of road, S of Collier Springs with *D. Xaustralis*. T3S R24W S17, se 1/4, Caddo Gap Quad. Fewer than one dozen plants observed. Specimens: Peck 99140 (LRU) on 4 July 1999.

16) Montgomery Co.: Albert Pike area, swamp woods, T4S R27W S27, Athens/Langley Quads. Specimens: Jewel Moore & Aileen McWilliams 3149 (UCAC) on 1 Aug 1951. Originally determined as D. goldiana; corrected to *Dryopteris celsa* by W. H. Wagner. This specimen was anonymously and erroneously annotated as "Polk Co.", but the area is in Montgomery County. Furthermore, this specimen complements the J. Moore 3142 (UCAC) specimen of *Dryopteris marginalis* from "Albert Pike Area near camp" collected on 28 July 1951, and correctly located in Montgomery Co. on Moore's original specimen label. Specimens not relocated nor re-collected by Peck.

17) Polk Co.: SE Big Fork, swamp, Big Fork Quad. Specimens: McWilliams sn (UCAC) collected on 1 June 1951. First determined as *D. goldiana* by collector. Annotated by J. Moore in 1983 as *D. celsa*. Locality is uncertain; warrants relocation efforts. Not re-collected by Peck.

18) Polk Co.: Big Fork St. Sci. Area, valley of Big Fork Creek, N side of Missouri Mountain, NNW Big Fork, spring over gravel outwash. T3S R2W S10 SE 1/4, Big Fork Quad. Specimens: D. Moore 520840 (MO, UARK) collected with A. McWilliams and H. H. Iltis on 12 Oct 1952.; E. B. Smith 739 (UARK) on 6 May 1978; Peck 84700, 84702 (LRU) on 3 Nov 1984; Peck 99484 (LRU) on 12 Aug 1992. Peck noted six plants in 1984. Bates noted three plants in 1988. Peck noted same six plants in 1999. Original determination as *D. australis*; annotated by F. W. Crane in 1956 as D. celsa; annotated by E. B. Smith as *D. clintoniana*; determined as *D. Xaustralis* by W.C.Taylor in 1973; determined as D. celsa by W.C. Taylor in

1974; determined *D. celsa* by E. B. Smith in 1978; determined *D. celsa* by J. H. Peck in 1985.

19) Polk Co.: Kates Creek, T3S R7W S18, Big Fork Quad, alder thicket, weedy site overgrown and brushy. Bates observed numerous plants on 20 Feb 1990; Peck noted 30 plants in 1992. Specimens: Peck 92234 (LRU) on 21 Aug 1992; Peck 99468 (LRU) on 12 Sep 1999.

20) Polk Co.: Polk Co. Rd. 38, SW of Abernathy Springs. T3S R28W S26, Big Fork Quad. Eight plants seen. Specimens: Peck 92268 (LRU) on 22 Aug 1992; Peck 99488 (LRU) on 12 Sep 1999.

21. Polk Co.: Polk Co. Rd 38, SW Abernathy Springs on Athen Road, Big Fork Creek Seep, T3S R28W S34, Big Fork Quad. Twelve plants found. Specimens: Peck 99512 (LRU) on 24 Sep 1999.

22) Polk Co.: Heath Valley Rd, W Big Fork on Polk Co. 61, hillside seep, T3S R28W S15, Big Fork Quad. Fourteen plants observed. Specimens: Peck 92244 (LRU) on 22 Aug 1992; Peck 99475 (LRU) on 12 Sep 1999.

23) Polk Co.: Highway 8 seep, NW of Big Fork, rocky bluff with hillside seep into alder-willow thicket, T3S R28W S10, Big Fork Quad. Four plants seen. Specimens: Peck 92258 (LRU) on 12 Aug 1992; Peck 99479 (LRU) on 12 Sep 1999.

***Dryopteris cristata*-excluded from Arkansas Flora.--** The Crested Woodfern *Dryopteris cristata* (L.) A. Gray is a fertile, circumboreal, allotetraploid species (4n = 164) denoted with the genome code of LLSS (Table 2). It occurs most abundantly in the Pleistocene-glaciated Great Lakes Region of North America, westward part-way across Canada, and eastward into Europe. It was reported mistakenly from lowlands in the Southeastern United States, usually only later being recognized as a name being misapplied to plants of *D. celsa* or *D. ludoviciana* (Thomas et al., 1973; Peck and Peck, 1988). *Dryopteris cristata* is not known to occur in Arkansas, but it was reported continuously (Table 1) from Arkansas in the state literature from 1860 to 1943 and was first excluded by Taylor (1976). Indeed, no Arkansas specimen exists to support the original or subsequent claims.

In 1848, Asa Gray made the combination *Dryopteris cristata*. Lesquereux (1860) was the first to report *D. cristata* from Arkansas, reporting that it occurred in "swamps and woods" of southeastern Arkansas. Harvey (1881) and Branner and Coville (1891) continued to report this species from Arkansas. Interestingly, Harvey (1881) reported that there were specimens of this species. While no specimens were seen by subsequent workers, trades of Harvey herbarium materials were made with other institutions (Buchholz and Palmer, 1926) leaving few specimens at UARK.

The absence of the older voucher specimens is a common problem in interpreting the older Arkansas literature. It was originally reported as *Aspidium cristatum*, now an early an early synonym of *Dryopteris cristata*. Harvey (1881) reported the following: "occurs in S.E. Arkansas...We have specimens from near Pine Bluff found growing in swamps by Mr. G. E. Lytle.' This voucher has yet to be found to substantiate that this fern or any other *Dryopteris* grows "near Pine Bluff." Buchholz (1924) challenged the Arkansas presence of *D. carthusiana* in lists prior to his because he did not see a voucher, and yet, he did not challenge the voucherless

presence of *D. cristata* in Arkansas lists. Based on their present ranges, *Dryopteris cristata* is much less likely to be found as far south as Arkansas than *D. carthusiana*. Next, Moore (1940) reported that *D. cristata* occurred in the "swamps of southeastern Arkansas."

The confusion within the Arkansas state fern literature was then transferred and further distorted in the national fern literature. Clute (1901, 1938), in the most popular fern manual of the early 20th century, noted *D. cristata* as present in Arkansas, being the southwesternmost station. Broun (1938), in his index of all North American pteridophytes, reported "*D. cristata* from Newfoundland to Idaho, south to southeastern Virginia, and northern Arkansas; Europe." Small (1938) in his authoritative manual to the pteridophytes of the Southeastern United States reported *D. cristata* from "North Carolina to Arkansas and in Canada from Saskatchiwan to Ontario and Newfoundland." Shaver (1954) in his excellent manual to the ferns of Tennessee noted that *D. cristata* occurred in Tennessee only in the extreme northeastern corner of the state in a bog at high elevation; then Shaver cites Broun (1938), noting its occurrence in "northern Arkansas." The very popular illustrated flora of Illinois included a volume on ferns by Mohlenbrock (1967) that reported *D. cristata* as ranging from "Newfoundland south to Nebraska, Arkansas, and Virginia." Mickel (1969) in his "How-to-Know" manual provides a distribution map of *D. cristata* that includes the northeast corner of Arkansas. Wherry (1972, p. 144) reported *D. cristata* in the southern lowlands from "Rapides Parish, La., to SE Ark. and NE Tex., in swampy habitats." The Louisiana and Texas plants were misidentified specimens of *D. celsa*. Wherry (1972, p. 301), in reference to ferns of the southern uplands, also reported *D. cristata* "in the Mississippi River lowlands of La. and Ark." Wherry (1972) noted the Louisiana plants were based on fragmentary collections of *D. ludoviciana*; the Arkansas plants were "unattributed," with Wherry commenting that the Arkansas material "has apparently never been rediscovered here in recent times,"an apparent reference to the Palmer fern at Shirley, Arkansas, which is *D. X leedsii*. Thomas et al. (1973) in clarifying the situation in Louisiana stated that reports of *D. cristata* in "southeastern Arkansas," as well as Louisiana and Texas are "extremely dubious."

Therefore, Taylor (1976), Taylor and Demaree (1979), Taylor (1984), Peck, Taylor, and Peck (1987), Peck and Peck (1988), and Peck and Taylor (1995) excluded *D. cristata* from the Arkansas flora. These workers indicated that all reports unsupported by vouchers; no specimens exist now that suggest a misidentification was the basis, and no one has found the enigmatic specimens by Lytle who had found *D. cristata* "SE of Pine Bluff." These important vouchers were lost in herbarium specimen trades of specimens as noted by Buchholz and Palmer (1926). Alternatively, they were lost

as late as the early 1970s when Herbarium UARK was moved from Old Main Building to the Botany-Engineering Building, at which time many old specimens and duplicates were culled and destroyed. Enigmatically, three specimens of *Dryopteris cristata* from Lyman H. Hoysradt of Pine Plaines, NY, collected on 18 July 1878, given as a gift to F. Leroy Harvey, and deposited at UARK, still exist in UARK's out-of-state folders and have survived such trades and compaction efforts. Until valid specimens are located, *Dryopteris cristata* remains excluded from the pteridophtye flora of Arkansas.

Dryopteris goldiana in One County.--The Giant Logfern *Dryopteris goldiana* (Hook.) A. Gray is a diploid, fertile, North American endemic, denoted with the genome code GG (Table 2). This species was discovered as new to Arkansas in 1999. Relocating a *D. celsa* locality found by Phil Hyatt in Baxter Co., Earl Hendrix, staff botanist for the Ozark National Forest discovered that the original location on the Hyatt specimen was incorrect. After finding the correct locality, Hendrix noticed that the locality contained "more than just *D. celsa*." Peck joined Hendrix on 20 July 1999 to survey the locality and collect specimens. C. T. Witsell, now of Arkansas Dept. Natural Heritage, collected late fall specimens in September and November 1999 to confirm species-hybrid identities, which differ in their response to the approach of winter. Peck et al. (2000) reported five plants of *Dryopteris goldiana* (Hook.) A. Gray in the midst of a *Dryopteris* genus community containing *Dryopteris celsa*, *Dryopteris marginalis*, *D. X australis*, *D. X leedsii*, and *D. goldiana* X *celsa*. The locality is in a remote part of the Ozark National Forest in Baxter Co. (Map 3). The complexity of the populations at this locality warrants additional inventory and development of management plans to protect all of the rare taxa in this watershead. The locality is disjunct by 100 km from localities in southern Missouri, but no more so than are disjuncts in Minnesota and in western Missouri from their metropolis regions (Iffrig, 1979; Wagner, 1972; Werth, 1991).

One locality in one county:

1) Baxter Co.: Merrill Ridge Blowing Cave, For. Serv. Rd. 1127 or Merrill Ridge Rd., T17N R12W S30, Norfolk SE Quad., in the slope above and below the blowing cave and spring entering Stewart Fork Creek, 10 x 20 m area. Five plants counted. Specimens: Peck 99417 (LRU).

Dryopteris intermedia excluded from Arkansas Flora.--The Intermediate Log Fern *Dryopteris intermedia* (Muhl. ex Willd.) A. Gray is a North American endemic, fertile, diploid species denoted with the genome code II (Table 2). Smith (1994) included *Dryopteris intermedia* (Muell. ex Willd.) A. Gray in Smith's key to the species of *Dryopteris* in the vascular flora of Arkansas. He annotated the name with an asterisk, meaning that this and another 300 some species were added to his book as "possible addition" plants. This meant that they were not yet known in Arkansas, but that they might be found in Arkansas. Unfortunately, the dis-

claimer was not noticed by most biogeographers. Since 1994, I have received over a dozen inquiries regarding this species's occurrence in Arkansas. Therefore, it is important to explicitly exclude this species from the state flora. The species has never been reported from Arkansas nor has any herbarium specimen been collected. The species occurs to the north in Missouri and northeast in Illinois as very rare and local populations. Perhaps field efforts in northeastern Arkansas might locate it around seeps, springs, or north-facing slopes, particularly on sandy soils or sandstone cliff faces. *Dryopteris intermedia* is sometimes confused with *D. carthusiana* as they are similar in general morphology, but readily distinguished based on uniform pinnule symmetry and size, presence of glandular hairs, and smaller spores of the former and unequal pinnules, lack of glandular hairs, and larger spores of the latter.

D. ludoviciana in One County.--The Southern Log Fern *Dryopteris ludoviciana* (Kunze) Small is a North American endemic, fertile, diploid, species denoted with genome code LL (Table 2). This was the first of the ever-green *Dryopteris* species of the "cristata" group known from the lowland coastal plain of the Southeastern United States. It was known first from and named from very limited populations in Louisiana, but was later found to be more widespread and abundant in Florida. There are two reports from Texas. In 1931 it was discovered as far north as North Carolina. It was reported from one locality (Fig. 4) in Arkansas (Peck et al., 1985; Peck et al., 1985). The field status of this population was discussed in Peck and Peck (1988) who noted that there were many juvenile, non-sporiferous plants, suggesting a young population or one that is not reproducing itself. Werth (1991) analyzed allozymes of this species, including Arkansas material collected in 1985, and provided a distribution map that shows clearly that the Arkansas material is the most northwestern in the species range.

In 1982, *D. ludoviciana* was discovered for the first time in Arkansas at Warren Prairie State Scientific Area by Sundell and McIntyre who found plants in the central wooded area on the south side of the property. Others plants were located by Peck in 1984 to the east of that location. Peck and Peck (1988) reported 70 plants in two plots with only eight sporiferous adults in the eastern population at Warren Prairie.

According to a Trip File Report by Lance Peacock, dated 4 May 1988, on file at Arkansas Dept. Natural Heritage, the area of Warren Prairie was severely impacted by "an arson-fire" set on 7 November 1987 by deer hunters mad at Georgia-Pacific for leasing lands to some hunters and excluding other hunters. This fire may have contributed to the decline of this species at Warren Prairie. The eastern population may have been eliminated directly as a result of the fire, as plants have not been seen there since. In a Trip

File Report by Bob Steinauer to Lance Peacock and Nancy DeLamar, dated 23 Apr 1991, on file at Arkansas Dept. Natural Heritage, Steinauer reported the following: "I checked the *Dryopteris* population and it looked fine. There is a fair amount of low growing honeysuckle in the area that needs to be watched. It is currently not overtopping any of the ferns but a problem may develop in the future. The area to the east on which Jim Peck had previously found *Dryopteris* was also searched but no plants were found. It seems as if the wildfire of 1987 has eliminated this [Peck's eastern] population." The eastern area is now overgrown with *Rubus.* Since 1991, no one has seen the western plants. With both the eastern and western plants unfindable, the species is now considered extirpated at Warren Prairie. No additional Arkansas locations are known.

Specimens of one Arkansas locality in one county:

1) Bradley Co.: Warren Prairie St. Sci. Area, T13S R7W S13, Wilmar South Quad. In willow "pin" oak and sweetgum woods adjacent to cypress at edge of forest adjacent to salt-duripan prairie. Peck noted more than 100 plants in 1984. Possibly extirpated by fire in 1987. Specimens: Sundell & McIntyre 2864 (UAM) on 18 Sept 1982; Peck 84641 (LRU, MIL, MICH, UARK) on 14 Oct 1984; Peck 85014 (LRU) on 8 June 1985.

Dryopteris marginalis in 38 Counties.--The Marginal Shield Fern *Dryopteris marginalis* (L.) A. Gray is a North American endemic, fertile, diploid species (2n = 82) denoted with the genome code as MM (Table 2). *Dryopteris marginalis* was reported by Nuttall (1835-1836) and by all subsequent authors of Arkansas pteridophyte floras (Table 1). Harvey (1881) reported it as "quite common upon shaded moist cliffs in the mountains of Arkansas. Grows very large. Inland and along streams." Moore (1940) reported *D. marginalis* "as common, in rocky woods and on ledges." *Dryopteris marginalis* occurs in 38 of the 75 Arkansas counties (Fig. 5), being common across the northwestern one-half of the state with rock outcrops, present in localities too numerous to enumerate and in abundances too extensive to census.

Hybrid Distribution and Chorology

Dryopteris Xaustralis in Four Counties.--Wagner and Musselman (1982) reported the known national distribution of the extremely rare hybrid *Dryopteris Xaustralis* as being from eight localities in four states: including two localities in Alabama, two localities in Louisiana, three localities in North Carolina, and one in South Carolina. Of these eight localities, five were extirpated. Peck et al. (1985) reported one locality in Arkansas. Werth et al. (1988) reported five new localities in four new states: one locality in Virginia, two localities in Tennessee, one locality in Mississippi, and one locality in Georgia, with only the last considered extripated. Taylor (1984) added a second locality in Arkansas. Redman (1992, 1999) reported three localities from Maryland. Thus, this North American endemic hybrid was

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known from 18 localities in 17 counties in 10 states with six historical localities already extripated.

The issue of *Dryopteris Xaustralis* in the Arkansas flora is now settled. Moore (1940) reported this taxon in Arkansas for the first time using the name *Dryopteris clintoniana* var. *australis*, but applied it to the Palmer fern at Shirley Arkansas, which it is not. On this basis, Taylor and Demaree (1979) excluded from the Arkansas pteridophyte flora the name *Dryopteris clintoniana* var. *australis*. The first correct inclusion of this fern in the Arkansas flora came about in 1984 when Steve Orzell discovered it along Meyer Creek, Garland Co. (Orzell and Peck, 1985; Peck et al., 1985). Since then it was found at a second locality in Garland Co, five localities in Montgomery Co, and one locality each in Baxter and Polk counties. At present, *Dryopteris Xaustralis* is known from nine populations in four counties of Arkansas (Table 3).

This report adds seven new localities and the third and fourth Arkansas county records from Baxter and Polk counties. The national range of this hybrid consists now of 25 localities in 19 counties in 10 states. With six of 25 localities extirpated, leaving 19 extant, the importance of Arkansas' nine extant localities can be appreciated. Furthermore, Arkansas has four counties in which the hybrid is known (Fig. 6), whereas, Maryland and North Carolina each have three counties in which the hybrid is known. A few localities exist in seven other states. No county and no state other state has more localities than the five known from Montgomery Co., Arkansas.

The nine localities in four Arkansas counties:

1). Baxter Co.: Stewart Fork Creek collapsed blowing cave and permanent seepage spring, Merrill Ridge Road, T17N R12W S31, Norfolk SE Quad., wooded oak forest at toe-slope of steep hillside, a dozen plants with *Dryopteris celsa, D. goldiana, D. marginalis, D. Xleedsii*, and *D. goldiana X D. celsa*. Specimens: Peck 99701 (LRU) on 20 July 1999.

2) Garland Co.: Meyer Creek wooded seep, along For. Ser. Rd. 386, T3S R22W Sec 16, Pearcy Quad., wooded acid seep over firm mineral soil with D. celsa. Several hundred plants. Specimens: Orzell 1392, 1394 (MIL) on 26 July 1984; Orzell 1492 (MIL) on 20 Sep 1984; Orzell 1566 (MIL) on 27 Oct 1984; Peck 84680 (LRU) and Peck 84682 (UARK) on 27 Oct 1984; Peck 91150 (LRU) on 3 June 1991; Crank 92004 (HSU) on 25 June 1992; Crank s.n. (MO) on 27 Sep 1993; Peck 95462 (LRU) on 20 Nov 1995; Peck 99186 (LRU) on 15 June 1999; Witsell 99074 (LRU) on 11 Aug 1999.

3) Garland Co.: Walnut Creek, W of Crystal Springs on For. Serv. Rd. 47, S along Walnut Creek to seep with *D. celsa*. T2S R22W S29, Crystal Springs Quad. Peck observed two hundred plants in 1981. Peck observed fewer than 24 in 1999. Specimens: Peck 88434 (LRU) on 16 Aug 1988; Pittman 9298811 (LRU) on 29 Sept 1988; Peck 91151 (LRU) on 3 June 1991; Crank 92004 (HSU) on 18 Aug 1992; Peck 95452 (LRU) on 20 Nov. 1995; Peck 99243 (LRU) on 4 July 1999.

4) Montgomery Co: Box Springs wooded seep, W of Norman, For. Serv. Rd. 73, S of AR 8, with *D. celsa*. T4S R26W S33, Polk Creek Mt. Quad. Sixty plants counted. Specimens: Peck 95126 (LRU) on 18 Aug 1995; Peck 99120 (LRU) on 4 July 1999; Witsell 99044 (LRU) on 3 Aug 1999.

5) Montgomery Co.: Collier Springs Creek, along For. Serv. Rd. 177, S of Spring in Collier Creek on E side of road, with *D. celsa*. T3S R24W S17,

Caddo Gap Quad. Ten plants seen. Specimens: Peck 99141 (LRU) on 4 July 1999.

6) Montgomery Co.: Singing Springs wooded seep and creek, E of Norman, N of For. Serv. Rd. 208, with *D. celsa*. T3S R24W S22, Caddo Gap Quad. Twelve plants observed. Specimens: Peck 95096 (LRU) on 27 Apr 1995.

7) Montgomery Co.: Buttermilk Springs, T4S R24W S6, Caddo Gap Quad.. Twenty-five plants reported in 1988 by Bates, but Witsell in 1999 observed 50 plants; Peck noted 38 plants in 1999. Specimens: Witsell 99091 (LRU) on 11 Aug 1999; Peck 99451 (LRU) on 11 Sep 1999.

8) Montgomery Co.: Wehunt Seep, W of Norman on AR 8, S on For. Serv. Rd. 43, T3S R27W S33, Big Fork Quad. Locality in decline from road building and removal of canopy trees. Three plants with *D. celsa*. Specimens: Peck 81129 (LRU) on 7 June 1981; Peck 84721 (LRU) on 3 Nov 1984; Peck 91237 (LRU) on 18 Jun 1991; Peck 99124 (LRU) on 4 July 1999.

9). Polk Co.: Big Fork Creek seep, SW of Abernathy Springs on Polk Co. 38, Athens Road, along Big Fork Creek, hillside acid seep over hard mineral soils, T3S R28W S34, Big Fork Quad. Seven plants observed. Specimens: Peck 99513 (LRU on 24 Sep 1999.

***Dryopteris Xleedsii* in Two Counties.**--This rare *Dryopteris* hybrid is a North American endemic known from only six localities in four states [Arkansas, Maryland, New York, and Pennsylvania], with the Arkansas locality some 1000 km disjunct from the other populations on the eastern coastal plain (Wagner and Taylor, 1976). The first locality to be discovered was in Arkansas. However, it was not recognized initially as that taxon at the time that Wherry (1942) named the hybrid using plants discovered by A. N. Leeds along the Susquehanna River in Harford Co., Maryland. This was reasonable, as the Arkansas Palmer fern was no longer locateable by botanists, having been seen last in 1935. The history of the Arkansas *Dryopteris* is central to an understanding of the confusion surrounding many other hybrid *Dryopteris* plants, and this confusion persisted into the 1970s among fern experts. Therefore, it is instructive to analyze the chorology of this hybrid to understand how a fern plant could be given 12 incorrect names by fern experts and for most of its known existence be "lost" to the same experts (Table 2).

On 30 March 1928, E. J. Palmer [Palmer 33216 (NY, US)] with Delzie Demaree collected and identified as *Dryopteris cristata* (L.) Gray a large and unusual *Dryopteris* from the base of sandstone bluffs near Shirley in Van Buren Co., Arkansas. The ragged, coarsely-lobed appearance of the specimens indicates that these fronds were late fronds formed in 1927 that overwintered and lodged before collection in spring of 1928. Later collections were of normal fronds, more regular and finely lobed. Interestingly, this was not the first time Palmer visited this locality; four years earlier on 28 May 1924, both Palmer and Delzie Demaree collected a specimen of *Dryopteris marginalis* [Palmer 25170 (UARK); Demaree 25170 (MO)] from the same partially shaded, sandstone north- facing bluff of the Little Red River near Shirley, Arkansas, Van Buren Co. It is not known whether they noticed this plant in 1924, and then returned specifically to collect it when they appreciated its impor-

tance. If it was overlooked and first noticed in the spring of 1928, it is not know why they returned to an old locality four years later when the fronds were at their worst. The specimens Palmer collected in 1928 were problematic, reflected by the series of conflicting annotations left on specimens by subsequent workers. They were annotated as *D. celsa* by E. T. Wherry in 1935 and as *D. celsa* X *spinulosa* by F. W. Crane in 1953. They were correctly determined as *D. X leedsii* in 1979 by W. H. Wagner, Jr.

Additional insight can be derived from inspection of correspondence kept with specimens in herbaria. In 1931, Palmer wrote about this fern to Dr. William Maxon at U.S. Maxon wrote back to Palmer asking if additional material could be sent to him. Palmer wrote to Delzie Demaree asking him to collect more material for Maxon. Demaree did so in 1932. Maxon deposited some specimens at US, sent additional material to E. T. Wherry (now at PH), and returned some to Demaree. Demaree wrote a letter to J. K. Small in 1933 explaining this sequence of events (letter of 22 June 1933 at NY). On 4 Nov 1932, Demaree collected 3 sheets with shoot apices and a living rhizome and sent them to Maxon at US; all were labeled as *Dryopteris* sp. to US [Demaree 10089, 3 sheets (US; SMU)]. The label data indicated: "Go up railroad from Shirley to railroad bridge across river, cross bridge, turn left, and go straight across a small field to bluff; fern common at base of bluff and part way up, region very rocky, but soil very fertile, well wooded; some fronds 3 feet long." In 1935, E. T. Wherry annotated Demaree's specimens as *D. celsa*. During the 1950s, F. W. Crane annotated them as "*D. celsa* X?" The specimen sent to SMU was originally determined as *D. marginalis*. It is important to note that there is no way one can fail to find these plants by following the simple directions on the specimen label. In hindsight, it is difficult to comprehend how this plant could be lost for 40 years.

On 10 Nov 1932, Palmer wrote to Demaree, that "I have just had a letter from Dr. Maxon asking about a *Dryopteris* collected [at Shirley]....He seems interested in it and thinks that it is an undescribed species." William Maxon planted and grew the Demaree rhizome of the Palmer fern at his home in Washington, DC(Wagner and Taylor, 1976). The following year Maxon corresponded with Demaree [in litt., 20 Sep 1933.... "Your Arkansas *Dryopteris* has done remarkably well....it is an exceptionally attractive fern in cultivation"]. No specimens exist at Herbarium US to support the letter.

On 3 Nov 1935, D. Moore collected specimens with E. T. Wherry and both collectors labeled the plants *D. goldiana* f. *arkansas*, coming from "Shirley, Arkansas, shady, moist, rocky woods," and they both called the specimens "Arkansas Goldi Fern." Specimens were distributed to several herbaria, including MO, UARK, UCA, NY, PHIL, US (2 sheets). At US, they were annotated by F. W. Crane as

"*D. celsa* X *marginalis*?"; at PHIL a specimen was annotated by J. K. Small as *D. separablis* (see this report below). W. H. Wagner, Jr. annotated Wherry 350441 (MO) as *D. X leedsii* in 1971; W. C. Taylor annotated the specimens at UCAC and UARK as *D. X leedsii* on 21 Aug 1974.

After this visit in November 1935, the Palmer Fern was not seen and the location became "lost" until 1974. In 1936, E. T. Wherry returned to Shirley, Arkansas, on 5 September 1936 and noted "Trip to Shirley, Ark., for *Dryopteris arkansana* was a flop. The cows had eaten what the drought had left." The note with this statement by E. T. Wherry, filed with the Demaree letter to Small of 22 June 1932, is preserved on a literature herbarium sheet at NY.

Wherry (1937) published a new species he called *D. clintoniana* var. *australis*, referring to a plant in Forney, Alabama (now known as *D. X australis*), but noted that a plant from Shirley, Arkansas, was very similar or also that species. Small (1938) renamed the Forney plant *D. australis* and referred to the Palmer fern as *D. australis* or "being very close to this." Small (1938) also named *D. separabilis* based on material from the Great Dismal Swamp; he also referred to the Palmer Fern as similar to if not that of *D. separabilis*.

Moore (1940) reported the discovery of the Palmer Fern incorrectly, leading to problems among the two leading botanists of the Arkansas flora. According to Moore (1940), "An unusual colony of *Dryopteris* was discovered in 1931, near Shirley, Van Buren County, by a party including E. J. Palmer, Delzie Demaree, and the writer [Dwight Moore]. It was growing in a moist rocky wood associated with *Dryopteris marginalis*. Its sori, however, instead of being marginal, were midway between the margin and the midveins of the pinnules. It showed resemblance to *D. clintoniana* and some to *D. celsa*. After considerable study it was designated by Dr. E. T. Wherry (1937) as *D. clintoniana* var. *australis*." Consequently, Moore (1940) referred to the Palmer Fern as *D. clintoniana* var. *australis* Wherry, the Southern Clinton''s Shield Fern, meaning *D. X australis* (Wherry) Small. Interestingly, Moore (1940) referred to D. celsa as not being present at Shirley and failed to report it from anywhere within Arkansas. Moore seemed to be unaware of its discovery in Arkansas in 1924.

Based on the plants discovered by A. N. Leeds in Maryland, Wherry (1942) named the hybrid *D. X leedsii*, noting it occurred in large populations with many size classes. At the time, *D. goldiana* was believed to be the other parent with *D. marginalis* although *D. goldiana* was not present at the Maryland locality. The other parent *D. celsa*, mentioned as being present at the Maryland locality, was not considered as a potential parent until much later. S. Walker (1962b) examined the cytology of *Dryopteris* plants at Leeds' locality in Maryland. He noted size classes, diploid and triploid plants with anomalous spores, along with fertile diploid and tetraploid plants in the mixed collections sent to him by E.

T. Wherry. Walker (1962b) postulated a hybrid origin for Leed's Fern from diploids *D. goldiana* and *D. marginalis*. Believing that Walker's report raised more questions than answers, Wagner and Wherry revisited the Susquehanna location in 1963 and noted the presence of the tetraploid *D. celsa*. This find acounted for a "diploid X tetraploid" origin of the sterile triploid hybrid, Leeds' Fern and a report was published (Wagner and Wagner, 1965). In 1964, Wagner, Demaree, and Redfearn attempted to rediscover the Palmer Fern in Arkansas, but without success, searching mainly around the Leslie area. In 1966, the sterile diploid at the Maryland locality was determined to be *D. goldiana* X *marginalis* and then was given a collective binomial (*D. X*neo-wherryi* Wagner (Wagner and Wagner, 1966) to honor E. T. Wherry.

While studying the Arkansas fern flora as his disseration research, W. C. Taylor traveled with Delzie Demaree on several trips to relocate the Palmer Fern, first again near Leslie and then near Shirley. On 18 Aug 1974, Taylor and Demaree drove through the town of Shirley, Arkansas, in Van Buren Co. Demaree knew instantly that this was the correct location. Taylor crossed the river and found the fern. The locality was soon visited by Warren Wagner, Jr., Florence Wagner, Paul Redfearn, Alice Redfearn, Carl Taylor, Jerry Taylor, and Jewel Moore. Wagner and Taylor prepared two reports of the discovery (Wagner and Taylor, 1976; Taylor, 1982).

After all of this trouble, it is indeed unfortunate that the range of this hybrid was mapped incorrectly by the Biota of North America Project [www.bonap.org], with the map showing the four states in which it does occur (Arkansas, Maryland, New York, and Pennsylvania) and five states where it does not (Michigan, New Jersey, Virginia, Georgia, and Tennessee).

A second Arkansas locality with five plants of *D. X*leedsii* was recently discovered in Baxter Co. (Fig. 7). The discovery of this locality was reported in Peck et al. (2000) and discussed in the section on *Dryopteris goldiana*.

There are two localities in two Arkansas counties (Fig. 7):

1). Baxter County: Stewart Fork Creek collapsed blowing cave and permanent seepage spring, Merrill Ridge Road, T17N R12W S31, Norfolk SE Quad. Five plants present along with *D. celsa, goldiana, marginalis*, X*australis*, and *D. celsa* X *goldiana*. Discovered by Earl Hendrix, botanist, Ozark National Forest. Specimens: Peck 99704 (LRU) on 20 July 1999.

2). Van Buren Co.: Palmer Fern, Shirley, Arkansas: Atoka sandstone rubble, on north- facing rocky slope, along Middle Fork of Little Red River, SW of Shirley, AR, T12N R13W S24, Shirley Quad. Discovered by E. J. Palmer in 1928; location lost after 1935; rediscovered by Demaree and Taylor on 18 Aug 1974; Twelve apices in 1981 through 1999, similar in appearance to photo taken in 1935. Specimens: E. J. Palmer 33216 (NY, US) on 30 March 1928; D. Demaree 10089 (NY, US-3 sheets, SMU) on 4 Nov 1932; D. Moore 350441 (MO, NY, PHIL, UARK, UCA, US-2 sheets) on 3 Nov 1935; Wherry 350441 (UCA, UARK) on 3 Nov 1935; W. C. Taylor 2597 (SIU) on 18 Aug 1974; F. S. Wagner & W. H. Wagner, Jr. 74164 (MICH) ; J. & W. C. Taylor 2597 (MICH); A. P. Redfearn 29403

(MICH); J. Moore sn (UCAC) on 13 Sep 1974; W. C. Taylor 24419 (UARK) on 11 Dec 1974; Peck 81116 (LRU) on 14 June 1981; Peck 88249 (LRU) on 18 June 1988; Crank 92019 (HSU) on 18 Aug 1992; Peck 92435 (LRU) on 18 Aug 1992; Peck 99130 (LRU) on 12 June 1999. At MO, the Moore specimen collected in 1935 is accompanied by MO #1102531, a B&W photograph of the plant next to a tree, still recognizable today, verifying the expanded plant of today as the plant from which material was collected in 1935.

***Dryopteris celsa* X *goldiana* in Arkansas.**--The Logfern-Giant Logfern Hybrid, *Dryopteris celsa* X *goldiana* is a sterile triploid, North American endemic, denoted with the genome code GGL (Table 2). Until recently, it was not known from Arkansas. It was discovered while attempting to relocate a locality in Baxter County discovered by Phil Hyatt that had *Dryopteris celsa*. Details are presented in the discussion of *Dryopteris goldiana* in this report.

One locality in one county (Fig. 8):

1) Baxter Co.: Merrill Ridge Blowing Cave, on For. Serv. Rd. 1127, Merrill Ridge Rd. T17N R12W S30, Norfolk SE Quad., Three plants were counted. Specimens: Peck 994254 (LRU) on 20 July 1999.

***D. X*neowherryi* Wagner-excluded from Arkansas Flora.**--The New-Wherry Hybrid Log Fern *Dryopteris X*neo-wherryi* Wagner is a North American endemic, sterile, diploid hybrid with the genome code GM, being the non-polyploid hybrid between *D. goldiana* and *D. marginalis* (Table 2). In 1908 Dowell located the *Dryopteris* hybrid *D. goldiana* X *marginalis* at a locality in Harford Co., Maryland. Wherry (1961a,b) commented on this hybrid and noted that as both parents are diploid, the hybrid should likewise be diploid, but sterile. A few plants at the Harford site had normal fertile spores and some were tetraploid, leading Crane in 1961 to naming them Wherry's Woodfern, *Dryopteris wherryi* Crane. Unfortunately, these plants were *Dryopteris celsa*, making this combination illegitimate. Walker (1962b) studied 12 plants from the type locality of *D. X*leedsii* in Harford Co., Maryland, and reported three cytological entities, a sterile diploid, and sterile triploid, and a tetraploid. Wherry had originally interpreted *D. X*leedsii* to be *D. goldiana* X *marginalis*. In the Southern Fern Guide, Wherry (1972) did not report the presence of *D. X*neowherryi* in the south, particularly Arkansas. Wagner (1971) reported that *Dryopteris X*leedsii* (*D. celsa* X *marginalis*) and *D. X*neo-wherryi* (*D. goldiana* X *marginalis*) are sufficiently similar to have caused considerable confusion, but their relationships are now fairly well understood.

However, in summaries of *Dryopteris* species and hybrids (Montgomery and Paulton, 1981; Montgomery, 1982), the range of hybrid *D. goldiana* X *marginalis* was described as "Ontario, Vermont, New York, New Jersey, south to West Virginia, and western North Carolina, west to Arkansas and Illinois." The reference to Arkansas is incorrect, reflecting a confusion at that time over the identify of the Palmer *Dryopteris* at Shirley, Arkansas, which is now known to be *D. X*leedsii*. The difference between the sterile triploid *D. X*leedsii* (GLM) and the sterile diploid *D.*

X*neowherryi* (GM) is the presence of the "L" genome of *D. ludoviciana* (Wagner and Wagner, 1965, 1966). This error was perpetuated in Montgomery and Fairbrothers (1992) who reported *D.* X*neo-wherryi* to range from Vermont, New York, and Ontario, south to West Virginia and western North Carolina, west to Arkansas [incorrectly] and Illinois. The Biota of North America Project (BONAP) electronic mapping project [www.bonap.org] reproduced this range and accordingly, *D.* X*neo-wherryi* was mapped for Arkansas where it does not grow. Literature errors were difficult to correct; now electronic mistakes perpetuate past errors.

Dryopteris Xseparabilis Small-excluded from Arkansas Flora.--The Separated Hybrid Log Fern *Dryopteris* X*separabilis* Small is a North American endemic, sterile triploid hybrid denoted with the genome code GIL (Table 2). Montgomery (1982) notes that the hybrid has a glandular indusium of *D. celsa* and the basal stipe scales of *D. intermedia*. The present known distribution is New York, Maryland, SE Virginia, NE and W. North Carolina, and Michigan.

Small (1938) named this taxon as a species based on a 22 Nov 1935 collection by A. N. Leeds from the Lake Drummond region of the Great Dismal Swamp in Virginia. Small noted affinities with *D. cristata, goldiana*, and *ludoviciana*. The range was reported from Virginia and North Carolina, Great Dismal Swamp, but "also moist rocky woods and bases of bluffs, Ouachita Co., AR." In the discussion, Small (1938, p. 284-286) states "In 1928 imperfect specimens of a large fern were collected in Arkansas. These were distributed to various herbaria. On November 3, 1935, better specimens were collected in the same region"...clearly a reference to the Palmer Fern located at Shirley, which is *D.* X*leedsii*. Small (1938) continued, "Then on November 22, 1935, the fern was found in the Great Dismal Swamp, Virginia," documented with the following voucher A. N. Leeds 3583 (PHIL). Small (1938) concluded, "If at one time, it flourished in the Atlantic seaboard and the Mississippi Valley, it now remains to us, as far as we know, in only two outposts, retreats as it were, one the Dismal Swamp, the other the hills of Arkansas." All literature references are in error, being comments on what is today known as *D.* X*leedsii*. There are no known localities of this hybrid in Arkansas.

Key to *Dryopteris* Species and Hybrids

1. Spores uniform in size and shape (using compound microscope)..2
1. Spore irregular in size and shape (using compound microsope) 6

2. Sori submarginal, near edges of pinnules; blade leathery.....
....*Dryopteris marginalis*

2. Sori medial, away from edges of pinnule; blade papery.....3

3. Fronds bipinnate-pinnatifid; pinnules toothed, basal pinnule 2-3x longer than upper counter pinnule of same basal pinna; pinnae triangular......................................*Dryopteris carthusiana*
3. Fronds pinnate to bipinnate; pinnules not toothed, uniform size and shape; pinnae elongate, lanceolate.........................4

4. Fertile pinnae narrower than sterile pinnae, occupying distal 1/2 blade; scales uniformly tan..............*Dryopteris ludoviciana*
4. Fertile pinnae same width as vegetative pinnae, occupying distal 1/2 to nearly entire blade; scales dark brown with black center..5

5. Frond gradually tapering at distal end; scales dull, 1/2 brown/black....................................*Dryopteris celsa*
5. Frond abruptly tapering at distal end; scales glossy, mostly black...*Dryopteris goldiana*

6. Sori about midway between midrib and margin or closer to margin; blade gradually narrowering to tip and to base, 3-6th pinnae longest; basal pinnae lanceolate, 2x as long as wide or less; scales dark glossy brown with pale border.......
Dryopteris X*leedsii*
6. Sori nearer midrib than margin; blade 2-3x longer than wide; scales dull usually dark brown to nearly black with pale margins 7

7. Fertile upper pinnae contracted, with pinnae narrower and more widely spaced than lower pinnae without sori; blade 3x longer or more than wide; scales dull dark brown...........
Dryopteris X*australis*
7. Fertile pinnae not contracted, blade 2x longer than wide, gradually narrowed to the tip; basal pinnae elongated, at least 3x longer than wide; scales nearly black with pale margins......................................*Dryopteris celsa* X *goldiana*

individuals and organizations, this unfunded project would have taken longer and could not have been as complete.

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Characteristics of Some Fruiting Plant Species in Northwest Arkansas, and the Avian Assemblages that Feed on Them

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Abstract

Fruits continue to be recognized as an important food source for birds in temperate areas, particularly during the fall migration period. More than 20 species of plants producing fleshy fruits are found in the Arkansas Ozarks. However, only a few of these appear to be important resources for birds during the fall migration period (August - October). Among those are sassafras (*Sassafras albidum*), gray-backed grape (*Vitis cinerea*), black cherry (*Prunus serotina*), hercules club (*Aralia spinosa*) and pokeweed (*Phytolacca americana*). Over the past 4 years, we have documented the physical and nutritional characteristics of those fruits and taken observational data on the assemblages of birds eating them. It appears that avian species assemblages feeding on fruits are partially determined by the physical and nutritional contents of those fruits. Sassafras is extremely lipid-rich and higher in caloric content than the other species of fruits. It appears to be eaten almost exclusively by larger birds, perhaps be due to the large size of its fruits, which may exceed gape width of many smaller bird species. *Prunus* and *Vitis* are also eaten by a large number of avian species. *Phytolacca* was eaten only by a small number of primarily resident bird species and often persisted into the winter. Reasons for this pattern are not clear, as it was relatively similar to the other fruits in most characteristics. *Aralia* was seen being eaten by only a few species of birds but is less common than the other species, and its small fruits may not be as attractive as those of the other species. Compared to other places in the east, there appear to be a relatively low number of migratory frugivorous birds in northwestern Arkansas. Overall, there were very few species noted at any fruiting plants, and a large proportion of the total assemblage of birds was comprised of resident species.

Introduction

Researchers are increasingly recognizing the importance of fruit as a food resource for migratory birds. While it has long been recognized that many avian taxa, even those that are primarily insectivorous, eat fruits during migration, the extent and magnitude of that change in diets has only recently become apparent (Parrish, 1998). Therefore, information about distribution, abundance, and characteristics of different fruit species is important, as those factors may affect resource availability to migratory, and perhaps also resident, bird species during the fall migration period (Parrish, 1998; Thompson & Willson, 1979; Johnson et al., 1979).

Many studies of frugivory by migratory birds have taken place during the fall migration period in the eastern United States (Stiles, 1980). Most of these studies have focused on species assemblages eating fruits (Malmborg & Willson, 1988; Parrish, 1998), interactions among fruiting species and their avian dispersers (Baird, 1980; Malmborg & Willson, 1988; Thompson & Willson, 1979), or nutritional content of fruits (Johnson et al., 1979). All of these factors may have important consequences both to birds eating fruits and to fruiting plants that rely on birds for seed dispersal.

Despite this, little has been published about fruiting plants and the birds that eat their fruits in Arkansas. It has been noted that, compared to other places in the eastern U.S., fall migrants are relatively scarce in northwestern Arkansas (Neal and Mlodinow, 1986; pers. obs.). In addition, Smith and Riley (1990), noted that a pokeweed (*Phytolacca americana*) on which they monitored fruit crop and avian visitation, was only visited by a few species of resident birds. It was not clear from their study whether this is a general pattern in northwestern Arkansas, or limited to pokeweed. We present here some additional observational and analytical data on *Phytolacca* and other fruiting plants in northwestern Arkansas, some tentative conclusions about bird-plant interactions in this region, and some suggestions for future research.

Methods

Species Assemblages.--Species assemblages of birds utilizing different fruiting plants were determined using field notes taken by Prather and Mlodinow during the period from August through October in each year from 1995 through 1999. Additional data were obtained from fecal samples of birds captured while mist-netting at Lake Fayetteville, Washington County, during those same time periods.

Phenology and Persistance of Fruits.--Phenology of *Vitis* and *Sassafras* were determined by weekly counts of ripe and

unripe fruits on fruiting plants taken by Smith and Riley between mid-August and late October 1984. Phenology and removal rates for fruits of *Prunus* were determined by weekly counts of ripe and unripe fruits taken by Prather between mid-August and late September 1997. Removal rates were also determined for *Sassafras* and *Vitus* using unpublished data taken by Smith and Riley every two days between mid-August and early November 1984. Removal rates for these three species were made with those of *Phytolacca* determined by Smith and Riley between mid-August and early November 1984 (Smith and Riley, 1990). No phenology was determined for *Aralia*. Persistence of fruits was determined from notes taken by Prather in the field during fall and winter of 1995 - 1999 and the phenological data taken above.

Nutritional Analysis.--Samples of each of the 4 species of fruits were collected and analyzed to determine nutritional content. Each sample was dried to constant weight in a vacuum oven at 100° C., and the following nutritional components were determined in the Nutritional Analysis Laboratory of the Department of Poultry Science at the University of Arkansas, Fayetteville: calories/gram dry weight, percent ash, percent crude protein, percent crude sugar and specific sugar content, percent crude fat and specific fatty-acid content, and percent indigestible fiber. Means and standard deviations were determined by running a minimum of 3 samples through each type of analysis. Unless otherwise noted, all analytical procedures are those found in the Center for Excellence in Poultry Science Laboratory Manual for Nutritional Analysis. Caloric content was determined using bomb calorimetry. Percent ash was determined by placing 500 mg samples in a muffle furnace at 500° C for 24 hours and reweighing the remaining material. Percent crude protein was determined by weighing 50 mg dry weight samples through a CE Elanotech elemental analyzer, in which the sample is fired at high temperature and the percent nitrogen in the resulting gas is measured. Percent protein was determined indirectly by multiplying percent nitrogen by a correction factor of 4.25 (Izhaki, 1990). Percent crude sugar was determined by hydrolyzing 500 mg dry weight samples in a 3/1 solution of 1% H_2PO_4 and methanol, removing the methanol under vacuum, and running the resultant solution through a High Pressure Liquid Chromatography (BPLC) reverse-phase column. Passage of specific sugars was detected using a Refractive Index Analyzer (RI). Percent crude fat was determined by running 500 mg dry weight samples through supercritical fluid extraction (SFE) with CO^2 as a solvent, washing the extract with benzene, and weighing the extract once the benzene evaporated. Specific fatty acids was determined by dissolving the extract in hexane, and running through a gas chromatograph (GC). Passage of specific fatty acids was detected with a Flame Ionization Detector (FID). Percent indigestible ("dietary") fiber (primarily cellulose) was determined by neutral detergent fiber (NDF) analysis

(Goering and Van Soest, 1987). Five-hundred mg dry weight samples were dissolved in boiling saline and acid solution for one hour and filtered to extract all undigested elements. Those elements were dried to constant weight and reweighed to determine percent content.

The mean size of each fruit was determined by measuring the diameter of 100 fruits of each species, with the exception of sassafras, which had oblong fruits. A length and width of 50 fruits were measured for this species.

Energetics of Fat Deposition.--Cost of fat deposition, and amount of fat that could be generated was determined for birds eating 100 g of each fruit type. For purposes of this analysis, it was assumed that there was no uptake or energetic cost due to passage of the indigestible fiber and mineral (ash) components of the fruits. Uptake of all other groups of ""energy-bearing" compounds (proteins, carbohydrates, and lipids) was assumed to be 100%. To allow for direct comparison, final values of the energy budget based on each fruit were converted to grams of fat/kcal energy spent.

Since fatty acids are taken up from the digestive tract essentially unchanged (Klasing, 1998), and the fatty acids stored by birds often parallel those in their diet (Blem, 1990; Caldwell, 1972, Klasing, 1998), all fatty acids were assumed to be stored in the forms and ratios found in the initial food source. Additionally, it was assumed that there was no metabolic cost associated with storage of fatty acids.

Proteins were broken down into their component amino acids for analysis. Since insufficient amounts of sample were available for amino-acid analysis, amino acid profiles for fruits were taken from published literature (Izhaki, 1993). Fruits in the same or closely related families as those analyzed in this study were used. Each amino-acid was assumed to be deaminated and converted to acetyl-CoA through a standard pathway. Ketogenic amino-acids were assumed to enter directly into lipogenesis as either acetyl-CoA or acetoacetyl-CoA after deamination. Glucogenic amino acids were assumed to be converted to either pyruvate or the citric-acid cycle intermediates alpha-ketoglutarate or succinyl-CoA after deamination. All digestible carbohydrates (starches and simple sugars) were assumed to be taken up as glucose and converted to acetyl-CoA through glycolysis.

Results

Species Assemblages.--A total of 24 species of birds were observed feeding on fruits of these five species of plants between August and October (Table 1). *Prunus, Vitis,* and *Sassafras* were all eaten by 10 or more species, while only 5 species were observed eating *Phytolacca* and *Aralia*. Only 20% (1 of 5) of the species seen eating pokeweed were long-distance migrants, while 50-75% of the bird species seen eating each of the other fruits were long-distance migrants (Table 1). Only one small-bodied species (Red-eyed Vireo)

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Table 1. Species assemblages of birds feeding on various fruits in northwestern Arkansas. Bold type indicates a long-distance migratory species.

Taxon	Aralia spinosa	Phytolacca americana	Prunus serotina	Sassafras albidum	Vitis cinerea
Downy Woodpecker (*Picoides pubescens*)			x		
Red-bellied Woodpecker (*Melanerpes carolinus*)			x		
Eastern Kingbird (***Tyrannus tyrannus***)			x	x	
Great-crested Flycatcher (***Myiarchus crinitus***)			x		x
Least Flycatcher (***Empidonax minimus***)	x			x	
Alder Flycatcher (***Empidonax alnorum***)	x				
Tufted Titmouse (*Baeolophus bicolor*)			x		
Northern Mockingbird (*Mimus polyglottus*)	x	x	x		
Brown Thrasher (*Toxostoma rufum*)	x	x			
Gray Catbird (***Dumatella carolinensis***)	x	x	x	x	x
American Robin (*Turdus migratorius*)		x	x	x	x
Wood Thrush (***Hylocichla mustelina***)				x	
European Starling (*Sternus vulgaris*)		x	x		
Red-eyed Vireo (***Vireo olivaceous***)			x	x	x
Warbling Vireo (***Vireo gilvus***)					x
Philadelphia Vireo (***Vireo philadelphicus***)					x
White-eyed Vireo (***Vireo griseus***)	x	x			
Orange-crowned Warbler (***Vermivora celata***)	x				
Baltimore Oriole (***Icturus galbula***)			x	x	
Common Grackle (*Ouiscalus quiscala*)			x		
Summer Tanager (***Piranga rubra***)			x	x	
Scarlet Tanager (***Piranga olivacca***)					x

was observed eating *Sassafras*, while several small-bodied species were observed eating *Prunus, Vitis,* and *Aralia*.

Phenology and Persistence of Fruits.--Availability of ripe fruits of both *Sassafras* and *Prunus* peaked in early-mid September and ripe fruits rarely persisted after the end of that month (Figs. 1 and 2)[1]. Availability of ripe fruits of *Vitis* peaked in late September and early October, primarily because removal did not occur until later in October (Fig. 3). Ripe grapes were noted uncommonly after the end of October. Pokeweed had a much more prolonged ripening period (Riley and Smith, 1990), and commonly persisted into winter months. No data were taken on the peak fruiting period of *Aralia*. However, it was noted mainly in September and early October, and rarely seen outside those months.
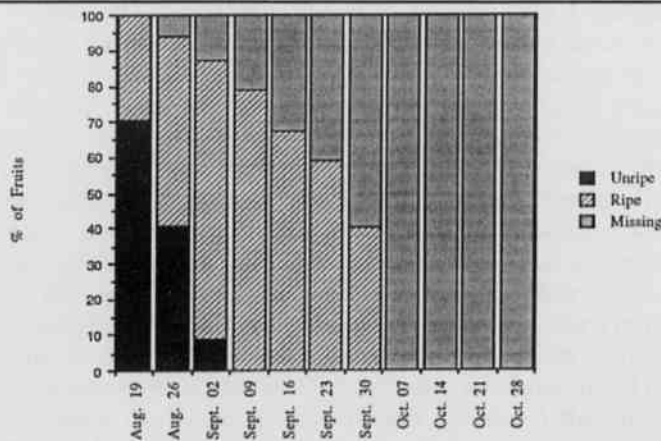
Fig. 1. Percent of ripe, unripe, and missing fruits of *Sassafras* over the study period. Data collected by Smith and Riley using weekly counts of fruits on marked branches during fall 1984.
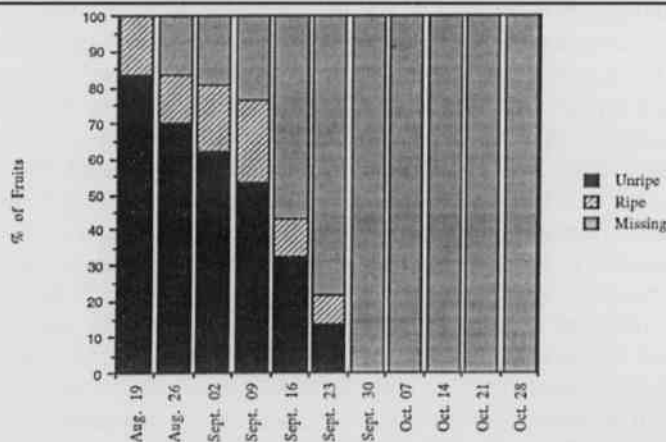
Fig. 2. Percent of ripe, unripe, and missing fruits of *Prunus* over the study period. Data collected by Prather using weekly counts of fruits on marked branches during fall 1997.

[1]Fruits of *Prunus* trees in other parts of Arkansas often ripen earlier in the summer. Thus, the phenology of the trees in this study appears to be atypical for this species.
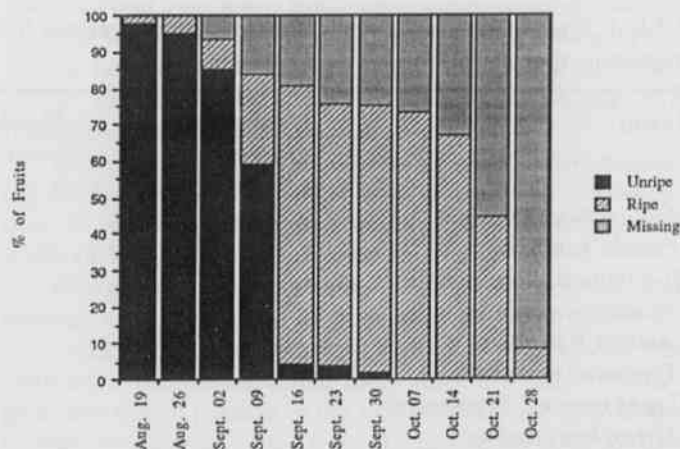
Fig. 3. Percent of ripe, unripe, and missing fruits of *Vitus* over the study period. Data collected by Smith and Riley using weekly counts of fruits on marked branches during fall 1984.

Physical and Nutritional Characteristics of Fruits.-- *Sassafras* was outstanding among the fruits analyzed as having comparatively high lipid content and comparatively low sugar content (Table 2). *Sassafras* also had much higher caloric content (Table 3) than the other fruit species and a larger fruit (Table 4). The other four types of fruit were essentially similar in nutritional content (Table 2), caloric value (Table 3), and color (Table 4), although *Aralia* had a much smaller fruit than did the other species (Table 4). Sagsafras yielded higher amounts of fat per grain, and had a lower cost/gram fat deposited than did the other species (Table 3). The amount of fat deposited and the cost/gram of fat deposited was similar for the other fruit species (Table 3).

Discussion

The avian species assemblage observed eating fruits in northwestern Arkansas is relatively small compared to that of other areas in the east, e.g. Illinois (Malmborg & Willson, 1988) and Rhode Island (Parrish, 1998). Notably lacking in our observations are *Catharus* thrushes and northern-breeding warblers, which make up a large part of the species assemblage in these locations. These species are rare in northwestern Arkansas during fall migration (Neal & Mlodinow, 1986). Indeed, although 60% (15 of 25) of the species we noted were long-distance migrants, only 2 of these, the Red-eyed Vireo and the Gray Catbird were observed eating fruits on many occasions, and both of these breed locally. Besides these two species, the most commonly noted species at fruiting trees were Northern Cardinal, Northern Mockingbird, and American Robin, all of which are resident in northwestern Arkansas. At least for American Robins, juveniles appear to eat more fruit than

Table 2. Nutritional characteristics[a] of taxa of fruits eaten by birds in northwestern Arkansas.

Nutritional Content Taxon	% Starch	% Sugar	% Protein	% Lipid	% Indigestible Fiber	% Ash
Aralia	30.93 ± 2.78	36.78 ± 2.40	7.23 ± 1.19	03.14 ± 0.16	12.37 ± 1.71	5.61 ± 0.66
Phytolacca	29.08 ± 1.12	39.36 ± 2.21	5.37 ± 0.33	01.75 ± 0.24	17.86 ± 1.15	6.26 ± 0.42
Prunus	32.44 ± 1.80	42.54 ± 3.20	2.31 ± 0.19	01.24 ± 0.02	17.55 ± 3.77	3.92 ± 0.24
Vitus	45.02 ± 0.74	27.18 ± 1.19	3.12 ± 0.08	02.21 ± 0.17	15.72 ± 0.99	6.57 ± 0.65
Sassafras	04.88 ± 2.47	07.77 ± 1.30	4.32 ± 0.22	30.68 ± 0.15	50.34 ± 3.39	2.02 ± 0.06

[a]   Mean ± standard deviation of % dry weight. All values based on 3 samples.

Table 3: Comparison of the efficiency of utilizing different food items eaten by migratory birds for building fat stores.

Taxon	Calories[a] / Gram	Digestible Components[b]	Energy Used (KJ)	Fat Produced	Cost / Gram (KJ)
Aralia	4748 ± 044	78.1%	80.6	25.9 g	3.11
Phytolacca	4476 ± 029	75.6%	78.3	24.3 g	3.23
Prunus	4324 ± 189	76.5%	80.0	25.1 g	3.19
Vitus	4252 ± 043	77.5%	78.5	25.4 g	3.09
Sassafras	7269 ± 166	47.6%	26.5	35.4 g	0.75

[a]   Mean ± standard deviation.
[b]   Percent dry weight of all protiens, lipids, sugars, and starches.

Table 4: Comparison of some characteristics of the fruits and fruit crops of plant species eaten by birds in northwest Arkansas.

Taxon	Fruit Size (mm) [a]	Ripe Fruit Color	Peak Fruit Availability	Persistance After Ripening
Aralia	5.21 ± 0.34	Purple-Black	September ?	Rare
Phytolacca	8.24 ± 0.43	Purple-Black	Aug. - Oct.	Common
Prunus	7.20 ± 0.51	Red-Black	August ?	Rare
Vitus	7.40 ± 0.94	Purple-Black	Sept. - Oct.	Uncommom
Sassafras	7.67 ± 0.63	Blue-Black	Aug. - Sept.	Rare
	X 9.94 ± 0.61			

[a]   Mean ± standard deviation.

adults (Smith, pers. obs). The preponderance of resident species as fruit-eaters in northwestern Arkansas would make this an interesting area to study frugivory and seed dispersal.

The data suggest that several of the fall-fruiting plant species in northwestern Arkansas are quite similar in nutritional content and physical characteristics. *Sassafras* was larger and higher in energetic content than the other species, characteristics that should make it very attractive to migratory birds. Large numbers of Eastern Kingbirds, Gray Catbirds, and Baltimore Orioles have been noted in fruiting *Sassafras* trees in late August and early September (pers. obs.). Such large groups of birds were also noted occasionally at cherry trees.

Sassafras crops appear to be removed very rapidly (Fig. 1, Smith, pers. obs.), as were those of *Prunus* (Fig. 2). *Prunus* appeared to be the most favored food of migrants and was seen being consumed by the most species. The smaller fruits may make this species more attractive to small birds than

Sassafras. Vitis was more persistent after ripening, although the plants examined for phenology were stripped of fruits in late October. *Phytolacca* fruits ripened over a longer period of time than did fruits of the other species (Smith & Riley, 1990), and were very persistent after the end of the ripening period.

Fruit size appears to be an important factor influencing the avian species assemblage eating the various fruit species examined in this study. Of the birds observed eating *Sassafras*, only Red-eyed Vireo can be said to be relatively small-bodied, whereas several small-bodied species (*Empidonax* flycatchers, Tufted Titmouse, warblers, vireos, and Indigo Bunting) were seen eating *Prunus, Vitis,* and *Aralia. Aralia* was exceptional in being attended by three of the smallest species observed eating fruits: Least Flycatcher, White-eyed Vireo, and Orange-crowned Warbler. Small species may be able to swallow the fruits of *Aralia* more easily than those of other species. However, small fruits may not be attractive to larger birds able to eat larger-fruited species. It has been shown in other systems that frugivore assemblages can be affected by fruit size, especially if fruits are large and exceed the gape width of many species that could potentially feed on them (Wheelwright, 1985).

Pokeweed remains enigmatic among the fruiting plants of northwestern Arkansas in being attended almost exclusively by common resident bird species despite having no exceptional physical or nutritional characteristics. This pattern does not appear to be related to lack of observations, since most of the species seen eating *Phytolacca* have been noted doing so many times. Pokeweed is also quite common, and should be available in areas with a wide variety of bird species, making the pattern even more difficult to explain. Some additional evidence that *Phytolacca* is less favored by birds than other fruit species is that ripe fruits commonly persist well after the end of the normal fruiting period, a trait seen rarely in the other species discussed here. Finally, in a study in Illinois, pokeweed was noted as being eaten by relatively few species (Malmborg & Willson, 1988). It seems likely that *Phytolacca* is being avoided by many species of birds due to some unknown factor, perhaps toxic secondary compounds that make the fruits less palatable (Izhaki & Safriel, 1989). More research on this species is certainly warranted.

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Wave Profile for Antiforce Class II Waves

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Abstract

Breakdown waves propagating in the opposite direction of the applied electric field force are referred to as antiforce waves. Breakdown waves moving into a pre-ionized medium are referred to as Class II waves. Using a one-dimensional, steadystate, three-fluid, hydrodynamical model and considering the electrons as the main element in propagation of ionizing waves, we have derived the proper boundary conditions for antiforce waves moving into a preionized medium. Using the new boundary conditions and for several current values ahead of the wave, the set of electron fluid dynamical equations (equations of conservation of mass, momentum, and energy coupled with Poison's equation) has been integrated through the dynamical transition region. The solutions meet the expected boundary conditions at the end of the wave. The electron velocity and electric field values conform to the physical conditions at the end of the dynamical transition region. For several current values ahead of the wave, the wave profile for electric field, electron velocity, electron temperature, and electron number density will be presented.

Introduction

All attempts of using Maxwell's equations to explain breakdown waves have failed; even though this phenomenon has been known for some time, it is wide open for explanation. The earliest person known to pay attention to these waves of luminous pulses in an evacuated chamber was Hauksbee (1706/7). During the last several decades, many experiments have been conducted, but the data recorded have been incomparable. The individual experiments were done with different procedures; there was not a standard procedure. For example, experimenters used different geometrical configurations for the gas chambers and used different gases in their chambers.

J. W. Beams (1930) did experiments on the electrical gas discharge in air and hydrogen. He recorded that breakdown waves travel from the electrode with the applied potential toward the other electrode that is grounded, disregarding the polarity of the potential applied. L. B. Loeb (1965) did studies of luminosity of the spark breakdown in which he suggested that potential waves are present during this phenomenon. Loeb first proposed a qualitative model for the propagation of a streamer, as a mechanism for electrical breakdown in a gas. The mechanism of the streamer process proposed by Loeb for a point-anode plane-cathode geometry is as follows: "Photons emitted by the excited gas molecules diffuse outward from the anode, ionizing and exciting new molecules. The photons emitted by the newly excited molecules diffuse further into the gas, and the cycle of diffusion, excitation, ionization and photon emission is repeated.

The net result of this process is the propagation of a photoionization wave from the anode to cathode."

Beams (1930) provided a qualitative explanation of the pulse. He said that the gas behind the wave is electrically conducting. This means that the wave is carrying the potential from the charged electrode and discharging it to the electrode that is grounded. A high electric field occurs at the front of the wave, and the motion of the wave front is due to the mass difference of the electrons and the positive ions. Larger diameters of the tube and a higher potential difference on electrodes increases the velocity of the wave front. Higher initial pressure also increases the velocity until a pressure of a few Torr, and then the velocity begins to decrease.

It is presumed that the ionization of a small amount of the gas occurs where the potential gradient is greatest. The electrons produced receive their kinetic energy from the electric field. The condensed, high-temperature electron gas expands, creating a shock wave, which propagates down the tube into the neutral or undisturbed gas partially ionizing the gas molecules. Energy given by the external electric field drives the shock wave. The shock wave is followed by another wave known as the rarefaction wave.

Electron driven shock waves moving into a non-ionized medium are called Class I waves. Shock waves moving into an ionized medium have a different structure than Class I waves. Waves that move in a medium of significant electron density are known as Class II waves. For example, this would occur when a Class I wave has already moved through the medium leaving a high electron concentration

behind. After an initial lightning discharge has occurred in the atmosphere, the medium left behind is composed of positive nitrogen ions and negative oxygen ions, with equal number densities.

Far ahead of the wave front, a weak electric field ($E\infty$) accelerates the positive and negative ions to a speed of v_o in opposite directions, which creates a current ahead of the wave front. The current ahead of the wave will alter the shock conditions for electron temperature as well as Poisson's equation.

The equations of conservation of mass, momentum, and energy for Class II Waves will remain the same as the ones for Class I waves (Hemmati et al., 1999). In dimensionless variables the equations respectively are

$$\frac{d}{d\xi}(\nu\psi) = \kappa\mu\nu, \tag{1}$$

$$\frac{d}{d\xi}[\nu\psi(\psi-1)+\alpha\nu\theta] = -\nu\eta - \kappa\nu(\psi-1). \tag{2}$$

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

The dimensionless variables are

$$\omega = \frac{2m}{M}, \quad k = (\frac{mV}{eE_0})K, \quad \mu = \frac{\beta}{K}, \quad \alpha = \frac{2e\phi_1}{mV^2}, \quad \eta = \frac{\epsilon_0 E_0^2}{2e\phi}\nu,$$

$$T_e = (\frac{2e\phi}{k})\theta, \quad E = \eta E_o, \quad x = -(\frac{mV^2}{eE_0})\xi, \quad v = V\Psi.$$

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

Solution of the Equations

Assuming that the wave is moving in the positive x direction with a velocity of V_0 referenced to the lab frame, in the wave frame the neutral particles will be swept into the wave front at a velocity of $-V_o$. Ahead of the wave the positive and negative ions in the electric field E_∞ will enter the wave front with velocities of $-(V_0 + v_o)$ and $-(V_0 - v_o)$ or vice versa. Therefore, the equation of conservation of cur-

rent at the wave front will become

$$env - eN_i V_o = en_0(V_0 - v_o) - en_0(V_o + v_o). \tag{5}$$

When the wave front propagates into the ionized medium, the ions go from being under the influence of a weak electric field E_∞ to a strong electric field E_o. The electric field in the wave front will strip loosely bound electrons from the negative ions and drive the loose electrons away from the wave front with a speed v. It is assumed that the electron temperature and the electron gas pressure are large enough to drive the wave.

To find the initial condition on electron temperature, the global momentum equation is integrated and the constant of integration is evaluated by the conditions ahead of the wave. The global momentum equation reduces to

$$n_1 m v_1^2 + N_{i1}(M-m)V_o^2 + MNV_o^2 + n_1 kT_{e1}) + (N+N_i)kT +$$
$$\frac{\epsilon_0}{2}(E_o^2 - E_o^2) - n_0 kT_{eo} - (N_0 + N_{io})kT_0 - n_0 m(V_0 - v_0)^2 -$$
$$MN_0 V_o^2 = 0. \tag{6}$$

The electron and neutral particle temperatures ahead of the wave are T_{eo} and T_o, respectively. Instead of $E\infty$, the electric field at the wave front is E_o. The particle densities $N = N_o$, and $N_i = N_{io} = n_i$ because the ionization occurs inside the sheath, not at the wave front. As a result, $(N+N_i)kT_o$ and $(N_0 + N_{io})kT_0$ cancel each other. The electron temperature ahead of the wave is at room temperature, which becomes negligible compared to the electron temperature inside the sheath. The wave velocity, V_o, is much larger than the neutral-ion velocity, v_o, ahead of the wave. Therefore, the terms containing v_o^2 are neglected. Taking all of these assumptions and employing the equation of conservation of heavy particles further reduces the equation. Introducing the dimensionless variables, the initial condition on electron temperature becomes

$$\theta_1 = \frac{\psi_1}{\alpha}(1-\psi_1) + \frac{2\psi_0 v_0}{\alpha v_1}(\frac{M}{m} - 1). \tag{7}$$

θ_1, ν_1, and ψ_1 are the electron temperature, density, and velocity at the wave front, respectively. Solving the equation of conservation of current for N_i and substituting it in Poisson's equation, and introducing dimensionless variables will reduce it to

$$\frac{d\eta}{d\xi} = \frac{\nu}{\alpha}(1-\psi) - \frac{2v_0\psi_0}{\alpha}, \tag{8}$$

where v_0 and ψ_0 are the dimensionless ion density and electron velocity ahead of the wave. $J_0 = \psi_0 v_0$ is the dimensionless current ahead of the wave.

Analysis

Using the singularity inherent in the equation set we were able to integrate the set of electron fluid dynamical equations by trial and error. The complete set of equations is composed of the equations of conservation of mass, momentum, and energy, eqs. (1) to (3) and Poisson's equation [eq. (8)]. The method of integration of the set of equations is given in an earlier publication (Hemmati et al., 1999). The following are the results of the integration of the equation set for several current values 0, 2×10^{-6}, 6×10^{-7}, and 6×10^{-8} ahead of the wave.

The electron velocity at the wave front is less than the wave velocity, therefore $\psi_1 < 1$. Fig. 1 shows a plot of the dimensionless electron velocity, ψ, as function of the electron position, ξ, inside the sheath. ψ reaches its maximum value at the middle of the sheath and finally reduces to one at the end of the sheath. This is the required condition at the end of the sheath because the electrons slow down to the same speeds as the neutral particles.
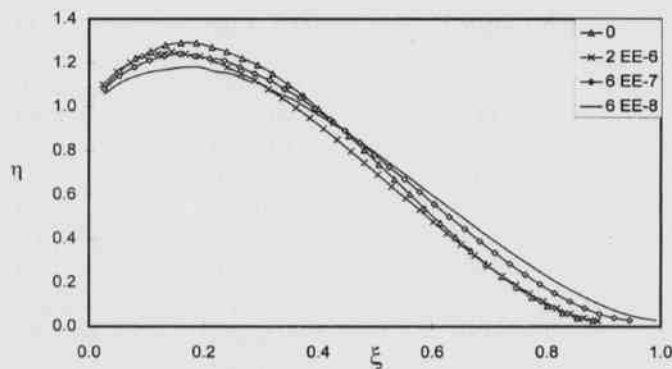
The electric field, η, as a function of ξ, starts at 1 where $E = E_o$, and increases to reach a maximum; as expected, at the end of the sheath, the electric field reduces to zero. The ionized medium can not support an electric field, and the electric field variation in Fig. 2 agrees with the expected physical conditions.

Figs. 3 and 4 show the wave profile for dimensionless electron temperature, θ, and electron number density, v, as a function of position, ξ, inside the sheath. Fig. 3 shows that the electron gas at the end of the sheath has considerable amount of thermal energy. This energy is utilized to further ionize the gas behind the sheath.

Fig. 1. Electron velocity, ψ, as a function of electron position, ξ, for four values of $J_o = 0$, 2×10^{-6}, 6×10^{-7}, and 6×10^{-8}.

Fig. 2. Electric field, η, as a function of electron position, ξ, for four values of $J_o = 0$, 2×10^{-6}, 6×10^{-7}, and 6×10^{-8}.
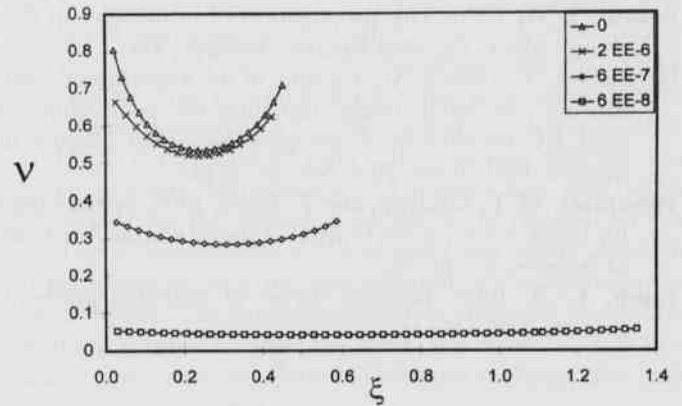
Fig. 3. Electron number density, v, as a function of electron position, ξ, for four values of $J_o = 0$, 2×10^{-6}, 6×10^{-7}, and 6×10^{-8}.
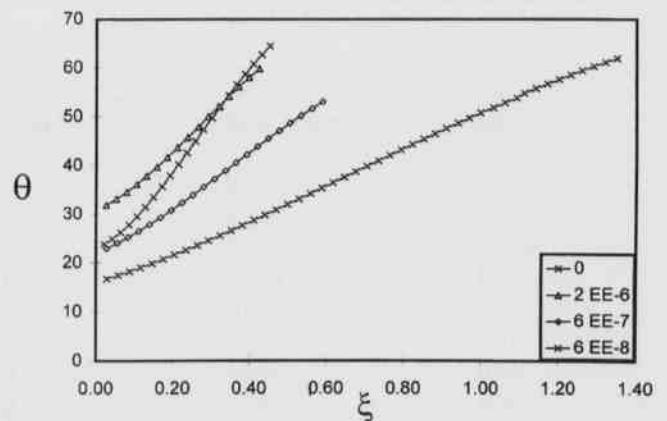
Fig. 4. Electron temperature, θ, as a function of electron position, ξ, for four values of $J_o = 0$, 2×10^{-6}, 6×10^{-7}, and 6×10^{-8}.

Conclusions

In conclusion, the electron fluid dynamical equations present a good model for the electrical breakdown waves propagating into a pre-ionized medium. The sheath thickness varies with different currents ahead of the wave. Also as expected, the electric field at the end of the sheath decreased to zero.

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Hammett Correlations of the Sulfonamide Proton Chemical Shift in a Series of N-(substituted aryl)-p-Toluenesulfonamides

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We have shown previously that excellent correlations of amide proton chemical shifts with standard Hammett substituent constants (σ) are obtained in several N-(4-substituted aryl) carboxamide systems (Setliff et al., 1992; Setliff et al., 1995). In this regard we were curious as to whether similar correlations would exist in sulfonamide systems. Thus, we prepared a series of N-(4substituted phenyl)-p-toluenesulfonamides and plotted the sulfonamide proton chemical shift (δ_{NH}), as determined in dimethyl sulfoxide (DMSO), vs the standard Hammett substituent constant (σ_G) (Exner, 1988) for the substituent G in the 4-position. As in the aforementioned carboxamide series, this note also reports the results of an additivity study using two phenyl substituents. In addition, the validity of the heterocyclic nitrogen 3-aza and 4-aza replacement constants determined previously (Setliff et al., 1993) was tested.

The N-aryl-p-toluenesulfonamides were prepared from the appropriate arylamine and p-toluenesulfonyl chloride as shown in Fig. 1. The general procedure employed was as follows: The arylamine (0.50 g), dry pyridine (2.5-3.0 mL) and 1. 1 molar equivalent of p-toluenesulfonyl chloride were combined and heated under reflux . For compounds where $G = (CH_3)_2N$, CH_3O, and CH_3, the reflux time was 15 minutes. For all other compounds the reflux time was extended to 45 minutes, except for $G = NO_2$ which required one hour.

Upon completion of reflux, the reaction mixture was cooled to room temperature and poured into cold water (300 mL). After the water was decanted, the residual oil was taken up in ethanol (200 mL) and water was slowly added in 50 mL portions until the precipitation of the sulfonamide was complete. The crude product was collected by suction filtration, washed on the filter with cold water, and recrystallized from aqueous ethanol. Yield and melting point data are reported in Table 1.
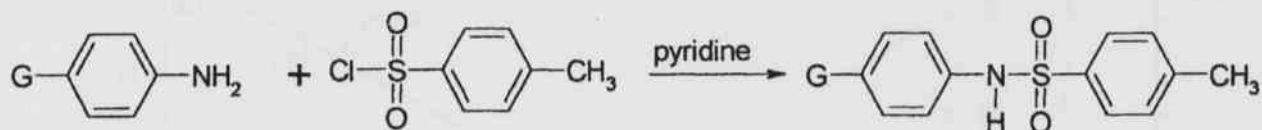
Fig. 1. Preparation of the p-toluenesulfonamides.

Table 1. Experimental data for the p-toluenesulfonamides.

G	mpt. (°C)	lit. mpt. (°C)	% Yield	δ_{NH} (ppm)	σ_G
$(CH_3)_2N$	124-125	----	59.3	9.58	-0.63
OCH_3	113-114	114	81.7	9.85	-0.28
CH_3	118-119	118	93.5	10.05	-0.14
H	101.5	103	79.0	10.24	0
F	79-80	----	80.2	10.18	0.06
4-Br-3-Me	144-145	----	64.4	10.37	0.16
Br	101	101	93.2	10.38	0.22
3-aza	171-172	----	91.0	10.52	0.26
$COCH_3$	202-205	203	85.0	10.81	0.47
CF_3	139-140	----	28.8	10.84	0.53
CN	180-181	----	83.8	11.00	0.71
NO_2	180	191	68.3	11.24	0.81
4-aza	190	----	53.1	12.20	1.71

Most of the sulfonamides' melting points were available in readily accessible tables (Rappoport, 1967), and our obtained values agreed well with those listed. The low melting point of the 4-nitrophenyl derivative was attributed to a trace quantity of residual 4-nitroaniline, as revealed in the proton NMR spectrum. Structures of all sulfonamides were verified by their infrared and ^{1}H NMR spectra as well as C,H,N elemental analyses (Quantitatative Technologies Inc., Whitehouse, NJ). The Infrared spectra were obtained (KBr disks) on a Nicolet 500 Magna FTIR instrument. The N-H stretch of the sulfonamide group was present in all compounds in the range ν 3190-3390 cm^{-1}. The symmetrical and unsymmetrical stretch frequencies of the O=S=O group (ν 1140-1160 and 1300-1350 cm^{-1}) respectively, were visible in all of the spectra..

Samples were prepared for ^{1}H NMR spectroscopy

(Bruker ACF-200 MHz instrument) at a concentration of 20mg/mL of deuterated DMSO containing 0.1% tetramethylsilane. The sulfonamide proton resonance in all compounds was clearly visible as the farthest downfield signal in the range δ 9.5-12.2 ppm (Table 1). The aromatic ring protons appeared in the expected range with the proper integration and exhibited the expected splitting patterns. Methyl, methoxy, and acetyl proton resonances appeared as sharp singlets at their normal ppm values.

Excellent linear correlation of δ_{NH} with the Hammett substituent constant σ_G (correlation coefficient 0.98) was obtained (Fig.2), and the linear relationship is expressed in slope intercept form by the equation below. The positive slope

$$\delta_{NH} = 1.16\ \sigma_G + 10.22$$

indicates the sensitivity of the sulfonamide proton to elec-
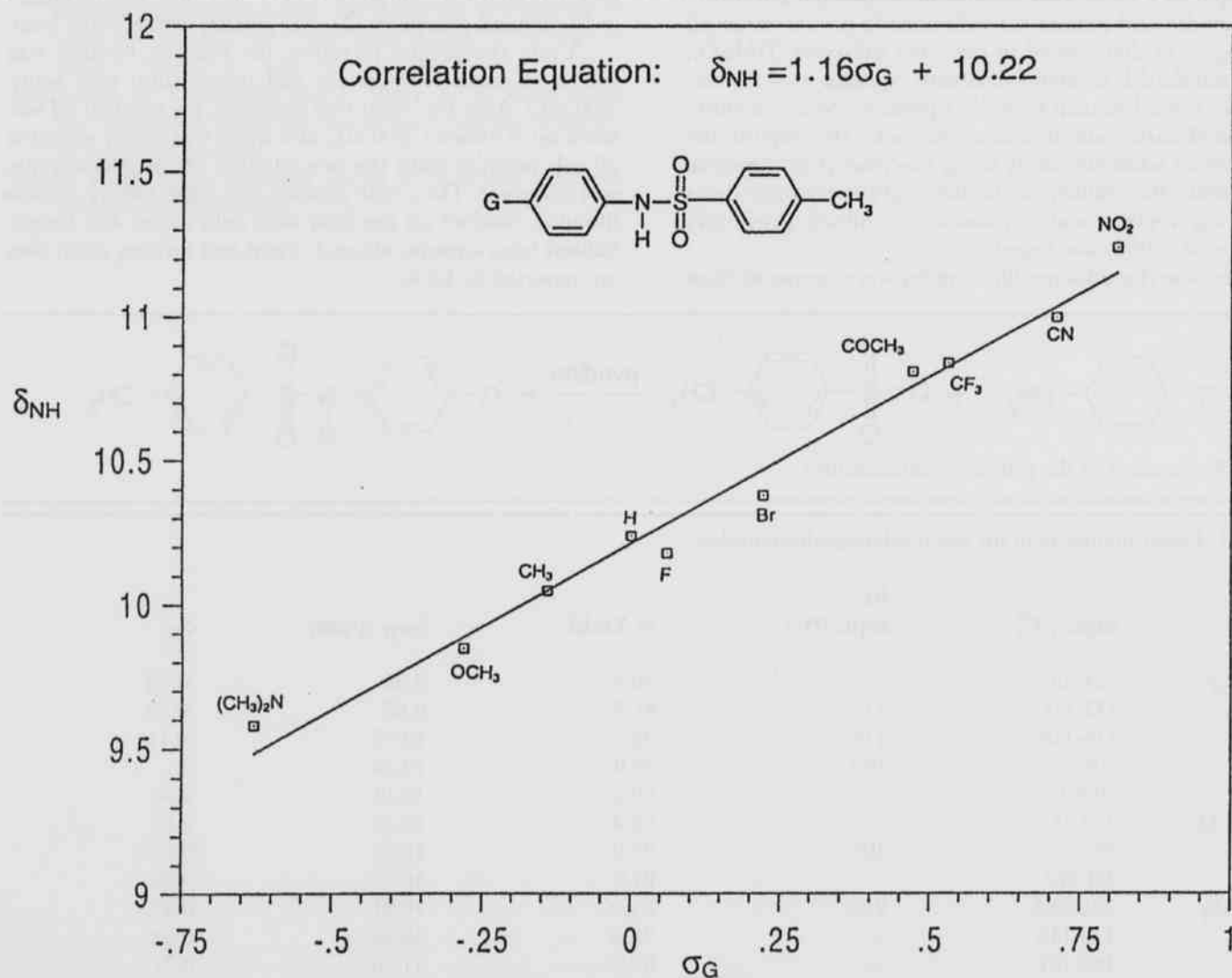
Fig. 2. Correlation of the sulfonamide proton chemical shift with the Hammett substituent constant.

tron withdrawing groups as was the case in the previous carboxamide studies. It is noteworthy that the sulfonamide slope of 1.16 is larger than any of the carboxamide slopes which were of the order 0.57 - 0.70 (Setliff et al., 1993). A direct comparison of the p-toluenesulfonamide and benzamide correlations (Setliff et al., 1995) are shown in Fig. 3. The difference in slope is likely due to the greater acidity of the sulfonamide protons owing to the adjacent sulfonyl group. Enhanced acidity in turn results in more efficient hydrogen bonding to the DMSO solvent, thus causing greater deshielding of the amide proton signal. The substituents exert proportional effects in the two systems as noted in Fig. 3.

As we had done in our earlier studies on the various carboxamide systems, we checked for additivity of the effects of two substituents on the N-phenyl ring. Thus, we prepared N-(4-bromo-3methylphenyl)-p-toluenesulfonamide and observed the δ_{NH} at 10.37 ppm (Table 1). When the algebraic sum of $\sigma_{4-bromo}$ (0.22) and $\sigma_{3-methyl}$ (-0.6) is substituted for σ_G in the correlation equation, the calculated value for δ_{NH} is 10.40 ppm. This small deviation (0.03 %) from the exper-

imental value suggests that the bromo and methyl substituents do exert a predictable additive effect on the chemical shift of the sulfonamide proton.

Finally, we were curious to see if our heterocyclic replacement constant values of σ_{3-aza} and σ_{4-aza} as determined in the previously studied carboxamide systems would be valid in the sulfonamide system. Therefore, we prepared N-(3-pyridyl)-p-toluenesulfonamide (G = 3-aza in Table 1) and N-(4-pyridyl)-p-toluenesulfonamide (G = 4-aza in Table 1) and observed their respective δ_{NH} values as shown in Table 1. Substitution of these experimental values into the correlation equation and solving for σ_G yields a replacement constant value of 0.26 for σ_{3-aza}, and 1.71 for σ_{4-aza}. The positive values indicate the electron withdrawing nature of the heterocyclic nitrogen, and the magnitude of the 4_{-aza} should be greater since the electron withdrawing "through conjugation" resonance effect that establishes a formal negative charge on the ring nitrogen is operative. Although the 3-aza value is fairly close to the mean value of 0.34 determined from the various carboxamide systems (Setliff et al., 1993), the 4-aza value of 1.71 is much greater
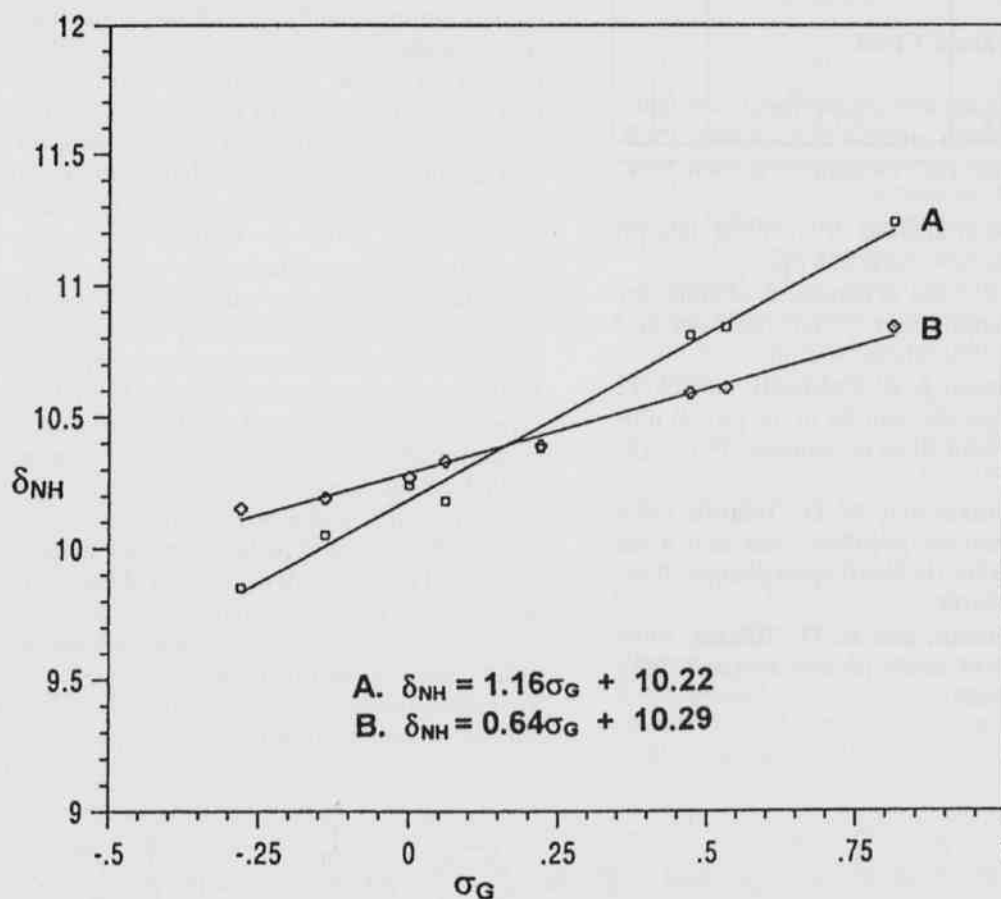
Fig. 3. Comparison of the p-toluenesulfonamide (A) and the benzamide (B) correlations.

A. $\delta_{NH} = 1.16\sigma_G + 10.22$
B. $\delta_{NH} = 0.64\sigma_G + 10.29$

than the mean carboxamide value of 0.55. This could be explained in terms of poor competitive delocalization of the sulfonamide nitrogen's lone pair with the sulfonyl oxygens owing to inefficient 2pN-3pS π overlap. This, in turn, would allow for very efficient "through conjugation" to the 4-aza nitrogen. However, in the carboxamide systems competitive delocalization of the nirogen lone pair with the the carbonyl group, which involves 2pN-2pC π overlap is more effective allowing less efficient "through conjugation" to the 4-aza nitrogen in those systems.

Although we conclude that Hammett correlations exist, and that effects of two groups are predictably additive, we can not say that the heteroatomic replacement values are interchangeable with those in carboxamide systems. Actually, the literature reports numerous values for $\sigma_{3\text{-aza}}$ and $\sigma_{4\text{-aza}}$ which vary according to the methods used to determine them (Charton, 1978). Unlike the classical Hammett substituent constants, heterocyclic atomic replacement constants are not truly constants at all.

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Hammett Correlations of the Amide Proton Chemical Shift in a Series of 1-Tosyl-3-(4-substituted phenyl)ureas

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Although direct insulin administration is the primary strategy for the management of diabetes, certain agents have been found to stimulate the production of insulin in the pancreas and, therefore, offer an alternative management option. Notable among these hypoglycemic agents are the sulfonylureas 1-tosyl-3-butylurea (tolbutamide) and 1-tosyl-3-(N-piperidyl)urea (Gilman, 1985). Aryl sulfonyl ureas have also received attention as potential anticancer agents. Howbert and coworkers prepared and studied 143 such compounds, several of which were 1-tosyl-3-(substituted phenyl)ureas (Howbert et al., 1990). The 1-tosyl-4-chlorophenyl derivative was found to have antitumor activity. A closely related compound, 1-(5-indanesulfonyl)-3-(4-chlorophenyl)urea, proved sufficiently active to warrant large scale production for clinical trials by Eli Lilly Co. and was assigned the generic name sulofenur.

Because of the medicinal importance of tosylureas and our previous studies of aryl substituent effects on the amide linkage of benzamides (Setliff et al., 1995), nicotinamides (Setliff et al., 1992) and p-toluenesulfonamides (Setliff and Spradlin, 2000), we undertook the present investigation of the 1-tosyl-3-(4-substituted phenyl)urea system. As in our previous work, we prepared a series of compounds with a variety of substituents (G) in the 4-phenyl position, obtained their ^1H NMR spectra in DMSO, and attempted to correlate the amide proton chemical shifts with the standard Hammett substituent constants (σ_G) (Exner, 1988). Unlike previous amide systems investigated, the present tosylarylurea system has two amide protons to be monitored, namely the anilide proton (on the nitrogen bonded to the benzene ring) and the sulfonamide proton (between the sulfonyl and carbonyl groups).

The series of 1-tosyl-3-(substituted phenyl)ureas (Table 1) were synthesized by the reaction of tosyl isocyanate (Aldrich) with the appropriate substituted aniline in dry chloroform (Fig. 1).

Table 1. Experimental data for the 1-tosyl-3-(4-substituted phenyl)ureas

Cpd. #	G	% Yield	M.P. (°C)
1	H	81.4	170.5-171.5
2	CH_3	99.2	152-153
3	F	Quant.	172-173
4	OCH_3	71.9	157-158
5	Cl	90.3	176-176.5
6	CF_3	72.4	189-190
7	$COCH_3$	82.2	182-182.5
8	CN	87.8	196-197
9	NO_2	91.1	245-247 d.
10	4-Br-3-CH_3	86.0	185-186
11	3-Cl-4-OCH_3	Quant.	174-175

The experimental preparation of the ureas was carried out as follows: All substituted anilines were distilled or recrystallized prior to use. The mass of the 4-substituted aniline needed to react exactly with 0.40mL (0.516 g) of the isocyanate was calculated for each reaction. This quantity of amine was dissolved in dry chloroform (2.0 mL)(8.0 mL required for 4-nitroaniline), and 0.40 mL tosyl isocyanate was then added quickly by syringe. In most cases an exothermic reaction occurred, and a solid began to form in a matter of seconds. The resulting suspension was stirred under gentle reflux for 15 min. When instantaneous precipitation did not occur, the clear solution was heated under reflux for one hour and then cooled or evaporated to isolate the product. The crude tosylureas were washed on the vacuum filter with cold chloroform and then recrystallized from ethanol-water (the 4-nitro derivative required benzene). Experimental data are summarized in Table 1. All compounds have been prepared previously (Howbert et al. 1990) by a slightly different procedure, some in lower yield.

Fig. 1. Preparation of the 1-tosyl-3-(4-substituted phenyl)ureas

Melting points of our compounds were in good agreement with those reported by Howbert's group. Our compounds were further characterized by IR and ^{1}H NMR analysis. The infrared spectra of all compounds (KBr disks; Nicolet Magna FT-IR spectrophotometer) exhibited the expected absorbtions for the anilide and sulfonamide NH stretch, the sulfonyl O=S=O symmetrical and unsymmetrical stretches, and the anilide carbonyl stretch. The proton spectra of all compounds (Bruker AC-F 200 MHz instrument, $DMSO_{d6}$ as solvent with TMS as internal standard) exhibited, in addition to the anilide and sulfonamide proton signals (Table 2), all other expected resonances with the expected multiplicities and integration.

Table 2. Proton chemical shift data and Hammett substituent constants

Cpd. #	Sulfonamide δ_{NH} (ppm)	Anilide δ_{NH} (ppm)	σ_G
1	10.65	8.82	0
2	10.67	8.71	-0.14
3	10.75	8.89	0.06
4	10.59	8.65	-0.28
5	10.79	9.00	0.22
6	11.01	9.28	0.53
7	11.05	9.24	0.47
8	11.10	9.37	0.71
9	11.15	9.56	0.81
10	10.78	8.89	0.16*
11	10.73	8.83	10.10*

*additive value

As shown in Fig. 2, good linear correlation of the amide chemical shifts (δ_{NH}) with the standard Hammett substituent constants (σ_G) was obtained. The correlation equations with their correlation coefficients are

anilide proton $\delta_{NH} = 0.82\ \sigma_G + 8.84$ $r^2 = 0.99$
sulfonamide proton $\delta_{NH} = 0.55\ \sigma_G + 10.72$ $r^2 = 0.96$

The better correlation of the anilide shifts can be ascribed to the fact that this proton is closer to the G substituent, and electronic effects can act more proportionately.

Analysis of the two equations provides additional information. The positive slopes (Hammett ρ value) indicate that the chemical shifts are sensitive to electron withdrawing groups (σ standard values > 0). As G becomes more electron withdrawing the acidity of the amide proton increases, permitting more efficient hydrogen bonding of the hydrogen with DMSO solvent, thus resulting in a farther downfield shift. The more positive anilide slope indicates the effect of G on the anilide proton is greater than its effect on the sulfonamide proton. This is easily explained in terms of the closer proximity of G to the former where the short range inductive and resonance effects can operate more efficiently. The magnitude of the Y intercept is a reflection of
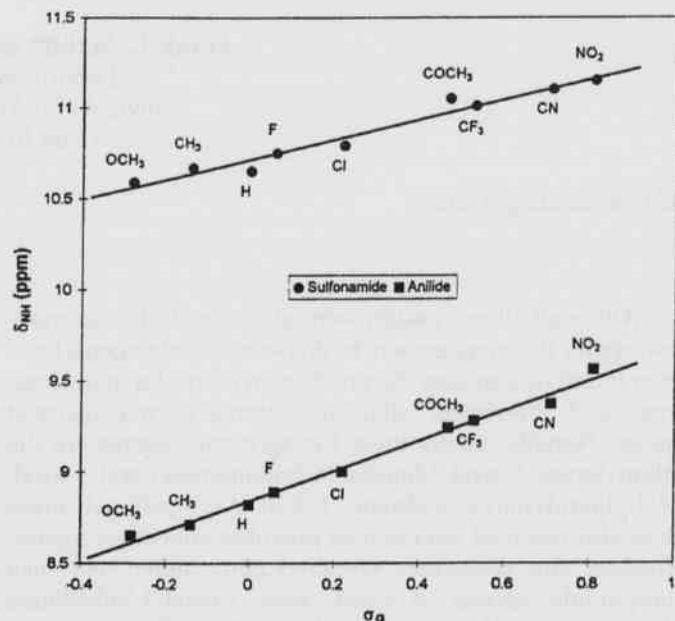
Fig. 2. Correlation of amide proton chemical shifts with Hammett substituent constants

the relative acidity of the two protons. Therefore, the sulfonamide proton (intercept 10.72) is demonstrated to be more acidic than the anilide proton (intercept 8.84). This is predictable in view of the former being situated between the sulfonyl and carbonyl groups.

In order to test for additivity of the electronic effects of two susbstituents upon the chemical shifts, we prepared two 1-tosyl-3-(3,4-diubstituted aryl)ureas, namely the 4-bromo-3-methyl derivative (cpd 10, Table 2) and the 3-chloro-4-methoxy compound (cpd 11, Table 2). For compound 10, the numerical sum of the σ values for 4-bromo (0.22) and 3-methyl (-0.06) when substituted into the respective correlation equations predicts a δ_{NH} value of 8.97 ppm for the anilide proton and 10.80 ppm for the sulfonamide proton. The experimental values obtained were 8.89 and 10.78 ppm, both within 1% of the calculated values. Similarly, for compound 11, the numerical sum of the σ values for 4-methoxy (-0.28) and 3-chloro (0.37), when inserted into the equations, yielded a predicted chemical shift of 8.91 ppm for the anilide proton and 10.77 ppm for the sulfonamide proton. The respective experimental values were 8.83 and 10.73 ppm. Again, calculated and observed values were within 1%. These results suggest strongly that the electronic effects on the proton chemical shift of both urea amide protons are additive.

In summary, we conclude that the acidity/hydrogen bonding ability of both urea protons can be controlled by the nature of the substituent in the 4-position in accordance

with Hammett theory, and that the effects of substituents in the 3-and 4-position operate in an additive fashion. Although all data were obtained in DMSO solvent, extrapolation of these data to aqueous systems could prove useful in prediction of hypoglycemic activity and/or development of synthetic strategies for the preparation of sulfonyl ureas as further candidates for antitumor therapy.

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Field Interpretation of Latitude and Longitude in Arkansas:
A Portable Coordinate Projection

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Abstract

Two- and three-dimensional coordinate systems are fundamental to most quantitative mapping applications. The Geodetic, Universal Transverse Mercator (UTM), and State Plane systems have traditional roles in various science, surveying, and government agency engineering applications. The coordinates of three-dimensional Geodetic system are latitude, longitude, and height above ellipsoid (HAE). Because of its ability to cope with the intrinsically three dimensional character of the earth's surface, the Geodetic system is capable of supporting precise relative positioning and very high accuracy computations of distance between any two positions on or near the earth's surface. The two-dimensional UTM and State Plane systems are extremely useful for the local horizontal positioning and scaling required for paper maps of county-size land areas. In the two plane systems, horizontal distance computation is a very straightforward application of the distance formula (analytic geometry) based on the Pythagorean theorem. Although precision line- and geodesic- distance formulas based on geodetic coordinates are more complex, useful horizontal distance estimates are easily derived from the latitudes and longitudes of two positions. This paper examines this premise for Arkansas. The approach to estimating horizontal distances utilizes an application of the distance formula in conjunction with an assumed constant distance/unit latitude of 30.8 m (arc sec)$^{-1}$. A linear regression equation is used to represent distance/unit longitude as a function of latitude in Arkansas. The approximation math is extremely simple, and the process as a whole is equivalent to a portable coordinate projection.

Introduction

Longitude λ and latitude ϕ are two of the three coordinates of a geodetic coordinate system. The third is height above ellipsoid, h or HAE. Due in part to their non-linear relationships, to more familiar plane distance and direction variables, interpretations of λ and ϕ can require the aid of a geodetically referenced map, a three-dimensional model (globe), or specialized computer software. In spite of their native three-dimensional positioning roles, λ and ϕ can be used for horizontal positioning operations without explicit reference to HAE. For example λ and ϕ tics appear along the neat lines of certain Arkansas Highway and Transportation Department (AHTD) maps and of United States Geological Survey (USGS) topographic maps of various scales. When they are used in a paper map context, some authors (for example, Verbyla, 1995) refer to latitude and longitude as geographic coordinates.

Plane coordinates, such as the Easting (E) and Northing (N), of the Universal Transverse Mercator (UTM) Zone 15 or of the Arkansas North Zone (AN) or Arkansas South Zone (AS) State Plane coordinate systems, are much easier to manage in basic field positioning operations than are λ and ϕ. First, the plane coordinates directly express horizontal distances east (E) or north (N) of the particular plane system's origin. Secondly, the horizontal distance separating two positions can be obtained with a calculator that supports arithmetic and square root operations. However, users are compelled to accept a given system's N-axis alignment, and the alignment does not agree, necessarily, either with the local geodetic north, with magnetic north, or with a direction that might provide a particular advantage in a given project, such as a straight road or field boundary. Finally, relating E and N of one of the plane systems to λ and ϕ requires the use of intervening projection tables or specialized computer software, such as National Geodetic Survey's (NGS) NADCON program or the Army Corps of Engineers CORPSCON program.

With today's widespread availability and use of global positioning systems (GPS) and geographic information systems (GIS), geodetic coordinates are more easily observable by a broad range of scientists, government agency personnel, and the general public (Featherstone and Langley, 1997; Hurn, 1989; Teague et al., 1999). Precise projection formulas commonly built into GPS receiver firmware can provide rapid conversion between the geodetic and either AN, AS, or UTM Zone 15 coordinates in the field. In spite of this it is likely that situations will arise in which a custom plane coordinate system that can be referenced to the geodetic system would provide an advantage in certain field operations. One example is where differential GPS (DGPS) equipment is available for one-time geodetic referencing of two or three semi-permanent markers at a particular site, but where it is desired to carry out future positioning operations with traditional distance and direction measurement devices. The λ and ϕ values could be calculated for positions

initially labeled according to their measured distances east and north of a geodetically referenced origin and without the necessity of an intervening map or specialized software. Also, a computationally lean procedure for estimating the horizontal distance, d(A, B), between $A = (\phi_1, \lambda_1)$ and $B = (\phi_2, \lambda_2)$ would facilitate rapid comparison of the relative locations of two positions with known λ and ϕ values.

The approach taken here is to use an empirical d (A, B) formula that is appropriate for Arkansas's λ and ϕ ranges. The proposed d (A, B) computation depends directly on the differences, $\Delta\lambda = \lambda_1 - \lambda_2$ and $\Delta\phi = \phi_1 - \phi_2$. It requires the use of three empirical constants and the plane Euclidean distance formula (Thomas, 1968). Horizontal distance in the E direction depends on $\Delta\lambda$ through a fitted linear equation expressing the distance per unit difference in longitude, $s_\lambda(\phi)$, as a function of latitude. Horizontal distance in the N direction depends on $\Delta\phi$ by an averaged constant value of the distance per unit latitude, s_ϕ.

One objective of this manuscript is to present the above mentioned mathematically simple expressions for $s_\lambda(\phi)$, s_ϕ, and d (A, B). A second objective is to estimate an upper bound for relative error when d (A, B) is used to approximate the ellipsoidal distance, d*, between A and B, with HAE = 0. A third objective is to show that the empirical formulas lead to a coordinate projection. Finally, examples are given to illustrate application of the empirical formulas.

Theory

Development of an accurate paper map of a portion of the earth's surface depends on the use of a map datum that is associated with a particular reference ellipsoid model. The datum provides the information necessary to reference three-dimensional position coordinates of the selected ellipsoid to the physical earth. A map- or coordinate- projection is then used to calculate two-dimensional coordinates that best represent desired geometric properties of the region of interest (Snyder, 1987; Featherstone and Langley, 1997; Bomford, 1962). Many currently available maps in the United States are based on the NAD – 27 horizontal datum, which in turn is referenced to the Clarke 1866 ellipsoid. The more recent GRS – 80 ellipsoid is the reference for maps utilizing the NAD – 83 horizontal datum (Stem, 1990; Dewhurst, 1990). A GPS receiver's position computation is carried out with three-dimensional coordinates of the WGS – 84 geodetic system. WGS – 84 utilizes an ellipsoid model essentially identical to GRS – 80 (Snyder, 1987; Langley, 1998).

Various definitions are given for a map- or coordinate-projection (Snyder, 1987; Bomford, 1962); however, the effective definition of a particular projection (Bomford, 1962) is a pair of mathematical formulas for mapping the ellipsoid model surface into the plane:

$$N = f_1(\phi, \lambda) \text{ and } E = f_2(\phi, \lambda). \tag{1}$$

The projection's convergence, γ, is the angle between a projected meridian and the N grid line of the plane coordinate system, and the tangent of the convergence is given by the equation

$$\tan\gamma = -(\partial E/\partial\phi)/(\partial N/\partial\phi). \tag{2}$$

The scale of the projection along a meridian is (Snyder, 1987)

$$h = [(\partial E/\partial\phi)^2 + (\partial N/\partial\phi)^2]^{1/2}/\rho, \tag{3}$$

while along a parallel, the scale is

$$k = [(\partial E/\partial\phi)^2 + (\partial N/\partial\lambda)^2]^{1/2}/[\nu\cos\phi]. \tag{4}$$

In the two latter equations the variables ρ and ν are the principle radii of curvature of the reference ellipsoid (Bomford, 1962)

$$\rho = \alpha(1 - e^2)/(1 - e^2\sin^2\phi)^{3/2} \text{ and} \tag{5}$$

$$\nu = \alpha/(1 - e^2\sin^2\phi)^{1/2}, \tag{6}$$

where α and e are the ellipsoid's equatorial radius and eccentricity, respectively. For the GRS-80 ellipsoid, $e^2 = 0.0066943800$, and $\alpha = 6,378,137$ m (Snyder, 1987). If h = k, the projection is orthomorphic (or conformal) – i.e. the scale at a given point is independent of direction. The radius of a parallel is $\nu\cos\phi$, so arc length along a parallel, and corresponding to a one arc-second difference in longitude, is

$$s_\lambda^* = \pi\nu\cos\phi/648000. \tag{7}$$

Also, for small latitude differences, $\Delta\phi$, arc length, s_ϕ^*, along a meridian is closely approximate by $\rho\Delta\phi$ (Bomford, 1962). Therefore arc length corresponding to a one arc-second difference in latitude along a meridian may be expressed:

$$s_\phi^* = \pi\rho/648000. \tag{8}$$

The empirical projection considered here is based on the following pair of equations:

$$E = [a\phi_0) + b\phi](\lambda - \lambda_0) \tag{9}$$

$$N = c\cdot(\phi - \phi_0) \tag{10}$$

Equations (9) and (10) define a coordinate projection by virtue of (1) above. The origin (0,0) of the E - N grid has geodetic coordinates λ_0 and ϕ_0, both constants in (9) and (10).

The distance in the plane between two projected positions A′(E_1, N_1) and B′(E_2, N_2) is

$$d = (\Delta E^2 + \Delta N^2)^{1/2}, \tag{12}$$

where $\Delta E = E_2 - E_1 = (a + b\,\phi_2)\,(\lambda_2 - \lambda_0) - (a + b\,\phi_1)\,(\lambda_1 - \lambda_0)$ and $\Delta N = N_2 - N_1 = c \cdot (\phi_2 - \phi_1) = c \cdot \Delta\phi$.

A useful approximation to the Easting difference, ΔE, is

$$\Delta E^* = (a + b\phi_a)\,(\lambda_2 - \lambda_1), \text{ where } \phi_a = 0.5 \cdot (\phi_2 - \phi_1) \tag{13}$$

The difference between ΔE and ΔE^* is $b \cdot \Delta\phi \cdot (\lambda_a - \lambda_0)$, where $\lambda_a = 0.5 \cdot (\lambda_2 + \lambda_1)$. Subsequently, equation (12) with substitution of ΔE^* for ΔE will be used to approximate the ellipsoidal distance, d^*, between (ϕ_1, λ_1) and (ϕ_2, λ_2)

Methods

Eight values of d^* were calculated using a computer program "invers3d.exe". The program was obtained from National Geodetic Survey's (NGS) web site. The eight calculated d^* values correspond to the ellipsoidal distance between two positions having the same λ but with a difference in ϕ of $\Delta\phi = \phi_1 - \phi_2 = 0.0166667$ deg (1 min). All eight d^* calculations utilized $\lambda = -93.0°$; the eight ϕ_1 values used were 33.0, 33.5, 34.0, 34.5, 35.0, 35.5, 36.0, and 36.5 deg. Each of the resulting d^* values was divided by 60 to obtain corresponding s^*_ϕ, and these six s^*_ϕ values were averaged to obtain $s^*_\phi = 30.81$m sec^{-1}. Similarly, in order to obtain the empirical linear expression for s_λ, eight new (ϕ, d^*) pairs were generated with the "invers3d.exe" program. The eight ϕ values were the ϕ_1 values used to generate sϕ. However, in this case the d^* values were computed using $\Delta\lambda = 1.0°$, with $\lambda_1 = -93.5°$. Each of the resulting d^* values was divided by 3600 to obtain a corresponding s^*_λ. A linear equation was fitted (Fig. 1) to the resulting set of (ϕ, s^*_λ) pairs. The fitted equation is

$$s_\lambda(\phi) = a' - b'\phi = 25.966 - 0.3066(\phi-33) \quad R^2 = 0.9998 \tag{14}$$

Consistent with units of s_ϕ, the values of a' and b' in (14) yield s_λ in units of m sec^{-1}. The coefficient c in (10) is now set to $c = 3600\, s_\phi = 110916$ m deg^{-1}. The coefficients a and b of (9) are determined from a' and b' so that the value of E in (9) depends on sλ evaluated at $0.5 \cdot (\phi+\phi_0)$:

$$b = 1800 \cdot b' = -551.7 \text{ m deg}^{-2};$$

$$a(\phi_0) = 3600 \cdot (a'+0.5\ b'\phi_0) = (129890 - 551.7\phi_0) \text{ m deg}^{-1}.$$

Expressions for h and k were derived by substituting partial derivatives of the E and N expressions of equations (9) and (10) into equations (3) and (4), respectively. Derived
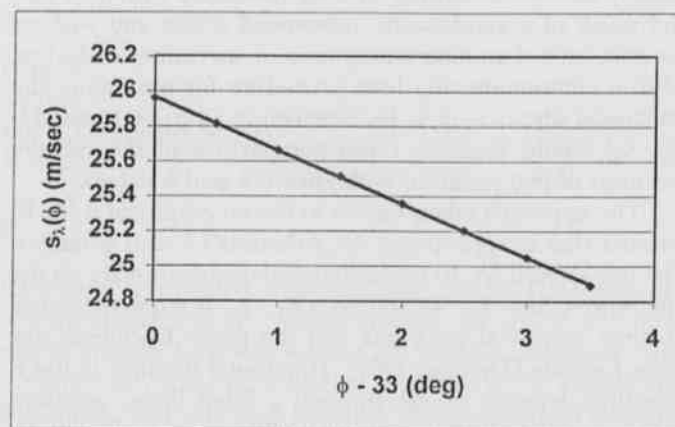
Fig. 1. Graph of calculated sλ (ϕ) values (diamond symbols) and of the fitted linear equaiton.

expressions for h and tan γ were found to depend on $\lambda - \lambda_0$, whereas k depends on both ϕ and ϕ_0. The equation defining the tangent of the convergence is $\tan \gamma = -b \cdot (\lambda - \lambda_0) / c$. Values of s_λ (ϕ), ρ, ν, h, a(ϕ_0), $a + b\phi_0$, k, $\tan \gamma$, γ, and the difference h - k, were calculated for several values of ϕ, ϕ_0, λ, and λ_0, with ϕ in the range 33° to 37°. The calculations were based on equations (14),(5),(6), and the derived expressions for h, k, and tan γ. The value of γ was determined as $\tan^{-1}$ (tan γ).

An upper bound was estimated for the relative error in d as an estimator of d^*, the ellipsoidal distance between two positions. Let $\varepsilon_\lambda = |\, s_\lambda\, (\phi) - s^*_\lambda\,| /s^*_\lambda$ where s^*_λ is the ellipsoidal distance per second of longitude difference that is estimated by $s_\lambda(\phi)$, according to equation (14). The relative error in calculated d that is due solely to ε_λ can be estimated. Similarly, the relative error in d, that is due to relative error ε_ϕ in s$_\phi$, can be estimated, and the joint contribution of ε_ϕ and ε_λ is approximately

$$\varepsilon_d \cong \varepsilon_\phi + \varepsilon_\lambda \tag{15}$$

where $\varepsilon_d = |\,d - d^*|/d^*$. In deriving (15) it was assumed that the calculation of d utilizes (12) with the earlier mentioned substitution (13) of ΔE^* for ΔE. Equation (15) only suffices for errors due to the empirical representations of s_λ (ϕ) and s $_\phi$. It does not include the effects of the failure of the plane distance formula to precisely represent geodesic or normal section lengths (Bomford, 1962) over large distances. Two independent estimates were made for the maximum values of both ε_ϕ and ε_λ over the range $33 \leq \phi \leq 36.5$. Values of ε_ϕ and ε_λ were calculated for each of the eight ϕ_1 values used to fit the empirical expressions for s $_\lambda$ (ϕ) and s $_\phi$. The maximum of the eight values of ε_ϕ thus calculated, together with the maximum of the eight values of ε_λ (Table 1) thus calculated, were substituted into equation (15), with the result that

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Table 1. $s_\lambda(\phi)$, s_ϕ, ε_λ, and ε_ϕ values used to calculate ε_{dmax}.

Latitude	$s_\lambda(\phi)$		Difference	ε_λ	s_ϕ		Difference	ε_ϕ
deg	Calculated	Equation	m sec^{-1}		Calculated	Constant	m sec^{-1}	
33.0	25.959	25.966	0.0069	2.65E-04	30.807	30.810	0.0032	1.03E-04
33.5	25.812	25.813	0.0010	4.00E-05	30.809	30.810	0.0007	2.16E-05
34.0	25.662	25.660	0.0028	1.11E-04	30.812	30.810	0.0018	5.95E-05
34.5	25.511	25.506	0.0048	1.86E-04	30.814	30.810	0.0043	1.41E-04
35.0	25.358	25.353	0.0047	1.86E-04	30.817	30.810	0.0068	2.22E-04
35.5	25.203	25.200	0.0027	1.09E-04	30.820	30.810	0.0095	3.08E-04
36.0	25.045	25.047	0.0011	4.56E-05	30.822	30.810	0.0120	3.89E-04
36.5	24.886	24.893	0.0069	2.79E-04	30.825	30.810	0.0145	4.70E-04
Estimated Maximum Value			0.0069	2.79E-04			0.0145	4.70E-04

$\varepsilon_{dmax} \cong 7.5 \times 10^{-4}$. An independent estimate of maximum ε_d used s^*_λ, s^*_ϕ, and $s_\lambda(\phi)$ values that were based on equations (7), (8), and (14), respectively, and on the constant s_ϕ. In this case ε_ϕ and ε_λ values were calculated at $0.1°$ intervals over the range $33 \leq \phi \leq 33.6$. The calculated maximum value for ε_{dmax} again was 7.5×10^{-4}, provided $33 \leq \phi \leq 33.5$. With $\phi = 33.6$ included, the maximum relative error increased to 8.2×10^{-4}.

Equations (12) and (13) were used to estimate distances, d, between positions having relatively large separations. Positions selected for this test were those having whole degree values for both λ and ϕ over the ranges $33 \leq \phi \leq 37$, and $-95 \leq \lambda \leq -90$, or 30 positions in all. This led to 435 distinct d values, with 29 non-zero distances from any one position to other positions. Corresponding exact ellipsoidal distances (d^*) were calculated using the imbedded computational procedure, "ReturnGeodesicDistance", of the GIS program, ArcView 3.2. A few of the d^* values generated with the ArcView procedure were compared to values computed with the earlier mentioned NGS program, "revers3d.exe", and agreement was excellent. Absolute error and relative error, $\varepsilon_d = |d - d^*| / d^*$ were calculated for each of the 435 d and d^* pairs. Also, maximum values of the absolute error and relative error (Fig. 2.) were determined for each of the 30 base positions.

In a second test, side length and corner angle properties of reverse projected rectangles were calculated using ellipsoidal distance and azimuth procedures imbedded in ArcView 3.2. The purpose of the test was to observe the side length and corner angle distortions of small rectangular grids that are reverse-projected to the reference ellipsoid surface. The test utilized six reverse-projections of 16 plane rectangles, each having a different L X W, or different rotation in the plane with respect to its lower left corner. The four L X W combinations were 1 X 0.2, 1 X 0.7, 10 X 2, and
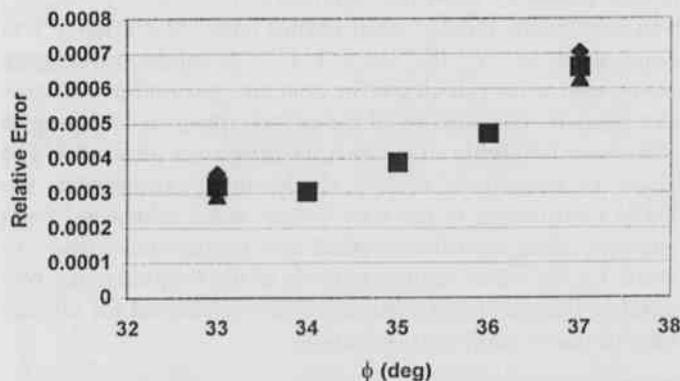
Fig. 2. Maximum relative error for the distance calculation versus latitude of base position. Diamond - $\lambda_B = -90$ and -95. Square - $\lambda_B = -91$ and -94. Triangle - $\lambda_B = -92$ and -93.

10 X 7 km. The four rotation angles were 0, 15, 50, and 75°. Plane coordinates assigned to the lower left corner of each rectangle were $(E_0, N_0) = (0, 0)$, which serves as a grid origin. Coordinates (E_i, N_i), i = 1, 2, 3, for the remaining corners were assigned according to rectangle dimensions and rotation angle (example in Table 2). Reverse projection of a rectangle was accomplished by assigning geodetic coordinates (ϕ_0, λ_0) to the grid origin, $(E_0, N_0) = (0,0)$. Equations (9) and (10) then were solved for (ϕ_i, λ_i) in terms of ϕ_0, λ_0, E_i, N_i, to complete the reverse projection of the remaining three corners. The reverse projection of the rectangles was carried out with $\lambda_0 = -90°$ or $-93°$ and with $\phi_0 = 33°$, 35°, or 37°. Side lengths of the reverse-projected rectangles were calculated by applying the ArcView 3.2 ".ReturnGeodesicDistance" procedure to adjacent corner positions. These calculated dimensions were subtracted

Table 2. Plane coordinates and parameters for calculating geodetic coordinates of the 1 X 0.2 km rectangle with 75 deg rotation with calculated corner angle and side length discrepancies

Side or Corner #	E_0	N_0	$\Delta\phi$	ϕ_i	ϕ_a	s_λ	$\Delta\lambda$	λ_i	A - 90	L - L_0
	m		deg			m sec-1	deg			m
0	0.00	0.00	0.00000	37	0.00000	----------	0.0000	-93	0.034	0.48
1	258.50	966.10	0.00871	37.0087	37.00436	24.738	0.0029	-92.9971	0.034	0.11
2	65.60	1017.80	0.00918	37.0092	37.00459	24.738	0.0007	-92.9993	0.032	0.48
3	-193.00	51.70	0.00047	37.0005	37.00023	24.740	-0.0022	-93.0022	0.032	0.09

from corresponding original side lengths to determine a side-length discrepancy, $|L_i - L_{i0}|$, $i = 0, 1, 2, 3$. Corner angles for the reverse-projected rectangles were determined by first calculating the forward and reverse azimuths, at each corner position. Then the difference $A_i = |az_{i,i+1} - az_{i,i-1}|$ was calculated. Finally, each corner angle discrepancy was determined as $|A_i - 90|$, $i = 0, 1, 2, 3$. Absolute and relative errors also were calculated for area and perimeter. The corner geodetic coordinates of the reverse-projected rectangles with base longitude, 93°, were re-projected into the UTM Zone 15 coordinate system. Following re-projection, the UTM coordinates of the base corner were subtracted from corresponding coordinates of all four reprojected corners to yield (E_i, N_i) values similar to those of the original plane rectangles. Displacement distances were calculated for all corners of the re-projected rectangles.

Discussion

Although it is beyond the scope of this manuscript to completely characterize the empirical projection, a few values of h, k, and γ were examined. Both the convergence γ and the scale factor h were relatively insensitive to variations in λ for the tests that were run, as well as to variations in ϕ. The scale factor, k, on the other hand was found to be extremely sensitive to variations in ϕ from the base latitude, ϕ_0 (Table 3). For $\phi = \phi_0$, the calculated convergence ranged from 0 to 0.29° as $\lambda - \lambda_0$ ranged from 0 to 1.0°. As $\phi = \phi_0$ increased from 33° to 37°, h decreased from 1.0001 to 0.9994, for $\lambda - \lambda_0 = 0.01$, 0.1, or 1.0. The scale factor, k, exhibited a minimum value of approximately 0.9998 for $\phi \cong$ 35°, and maximum values of 1.0003 for $\phi = \phi_0 = 33°$ and

Table 3. Principle radii of curvature and example projection parameters

$\lambda - \lambda_0 = 0.2$			$\phi_0 =$	35	$a(\phi_0) =$	110581	
ϕ	$s_\lambda(\phi)$	$\rho(\phi)$	ν	h	a+bf	k	h - k
deg	m sec-1	m	m	rad-1	m deg-1	rad-1	rad-1
34.6	25.475	6354357	6384479	1.00010	91492	0.9975	2.62E-03
34.7	25.445	6354869	6384651	1.00002	91437	0.9981	1.96E-03
34.8	25.414	6355385	6384823	0.99994	91381	0.9986	1.30E-03
34.9	25.383	6355904	6384997	0.99986	91326	0.9992	6.37E-04
35	25.353	6356427	6385172	0.99978	91271	0.9998	-3.29E-05
35.1	25.322	6356953	6385348	0.99970	91216	1.0004	-7.08E-04
35.2	25.291	6357482	6385526	0.99961	91161	1.0010	-1.39E-03
35.3	25.261	6358015	6385704	0.99953	91105	1.0016	-2.07E-03
35.4	25.230	6358551	6385883	0.99945	91050	1.0022	-2.76E-03
tan $\gamma =$	0.001	γ (deg) =	0.000995				

1.0006 for $\phi = \phi_0 = 37°$. By comparison, the UTM Zone 15 system's scale factor $(k = h)$ has its minimum value, 0.9996, along the central meridian $\lambda = -93°$. The highest values of k for UTM Zone 15 occurs along the boundary meridians $\lambda = -90°$ and $\lambda = -96°$, where k is approximately 1.0006 at $\phi = 33°$ and 1.0005 at $\phi = 37°$. The UTM system's convergence is 0° along the central meridian and approximately 0.5° along the -92° meridian for ϕ between 33° and 37°. Returning to the empirical projection with $\phi_0 = 35°$, k was found to increase from 0.998 to 1.002, as ϕ increases from 34.6° to 35.4° (Table 3), thus exhibiting nearly an order of magnitude greater variation over this limited range of ϕ than does the UTM Zone 15 scale factor over the entire state of Arkansas. The change in k between $\phi = 34.9°$ and 35.0°, equivalent to approximately 11 km north - south distance, is only 0.0006.

The distance absolute errors for the 6 X 5 array of base positions were found to be equal on a pair-wise basis for the -92 and -93, the -91 and -94, and the -90 and -95 degree meridian pairs. Absolute errors ranged from slightly greater than 50 meters to approximately 315 meters. The greatest absolute error, 312.8m, was associated with the separation distance between $(\lambda_1, \phi_1) = (-90, 37)$ and $(\lambda_2, \phi_2) = (-95, 37)$. The second highest absolute error, 235.5 m, was associated with distance between (-90, 36) and (-95, 37), and between (-90, 37) and (-95, 36). Thus the two highest absolute errors occurred with position pairs having at least one member outside the fitting range for $s\lambda(\phi)$ and $s\phi$, and also having a large east-west separation. In spite of this the relative error in calculated distance did not exceed the estimated upper bound, $\varepsilon_{dmax} = 7.5 \times 10^{-4}$. Where both position latitudes were $\leq 36°$, the relative errors were lower (Fig. 2). Similarly, in the rectangle test, maximum calculated $| L_i, - L_{i0} | / L_{i0}$ was below ε_{dmax}, for $\phi_0 = 33$ (6.9 X 10^{-4}) and for $\phi_0 = 35$ (6.8 X 10^{-4}), but for $\phi_0 = 37$, maximum calculated $| L_i - L_{i0} | / L_{i0}$ was 1.1 X 10^{-3} (Fig. 3), or 11 m in 10 km. Likewise, the maximum corner angle discrepancy was significantly larger for $\phi_0 = 37$ (Fig. 4) than for $\phi_0 = 33$ or $\phi_0 = 35$. Generally the corner angle discrepancy was lower for the 1 X 0.2 km and 1 X 0.7 km rectangles (0.002° to 0.010°) than for the 10 X 2 km and 10 X 7 km rectangles (0.007° to 0.031°).

Other rectangle properties followed a pattern different from the one pointed out for the side length and corner angle errors. Maximum relative error in calculated area was 8.0 X 10^{-4} for $\phi_B = 33°$, 8.0 X 10^{-4} for $\phi_B = 35°$, and 5.9 X 10^{-4} for $\phi_B = 37°$. Maximum relative error in calculated perimeter was 3.4 X 10^{-4} for $\phi_B = 33°$, 4.3 X 10^{-4} for $\phi_B = 35°$, and 3.9 X 10^{-4} for $\phi_B = 37°$. Finally, corners of rectangles re-projected into the UTM system along the -93° meridian had maximum corner position displacements from the original corner positions as follows: 11.2, 7.3, and 15.8m for the large rectangles with base latitude, 33, 35, and 37, respectively; 0.8, 0.3, and 1.0m for the small rectangles in
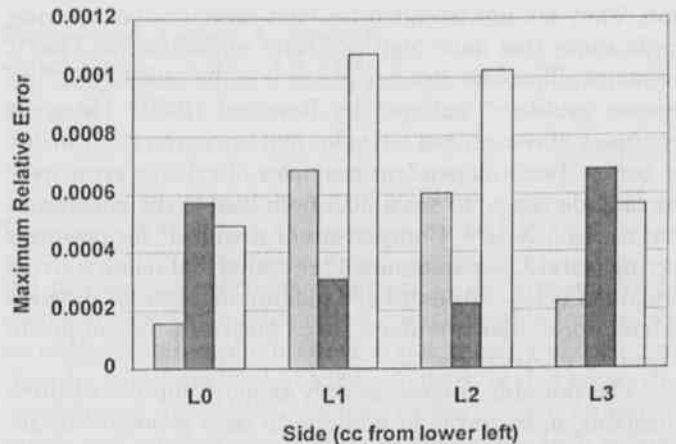
Fig. 3. Maximum relative length discrepancy for the four rectangle sides, L0, L1, L2, and L3 over all side length combinations and rotations of the rectangles. Left column - $\phi_B = 33$. Center column - $\phi_B = 35$. Right column - $\phi_B = 37$.
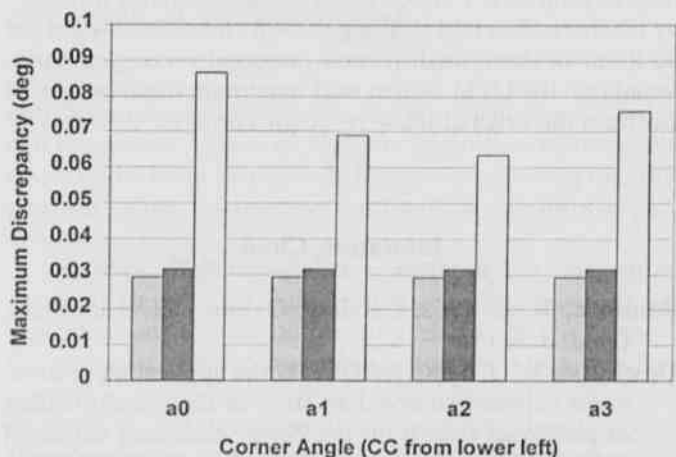
Fig. 4. Maximum corner angle discrepancy for the four rectangle corners, a0, a1, a2, and a3 over all side length combinations and rotations of the rectangles. Left column - $\phi_B = 33$. Center column - $\phi_B = 35$. Right column - $\phi_B = 37$.

the same base latitude order. In all cases the maximum displacement was associated with the upper right corner of the rectangle with 0° rotation.

Summary

A simple formula for calculating ellipsoidal distance, d, and a portable but empirical projection based on equations (9) and (10) were presented and tested. Both are intended for

field or other applications that tolerate relatively low precision. They are not intended for land survey or engineering applications that have high precision requirements. That d estimates ellipsoidal distance places it in the category of "the reverse problem" outlined by Bomford (1962). He gives examples of recognized formulas that are correct to 1 in 10^7 or better. Two independent estimates of relative error over the latitude range $33 \leq \phi \leq 36.5$ both lead to the conclusion that $\varepsilon_d \leq 7.5 \times 10^{-4}$. Comparison of d with d* for positions having ϕ and λ, separations $\leq 1°$ revealed that relative errors remained below this estimated maximum, even for distance calculations that involved two positions on opposite extremes of Arkansas.

The portable projection only requires the use of three constants, a, b, and c, in addition to base geodetic coordinates (ϕ_0, λ_0), in order to develop a small plane coordinate grid that is referenced to the geodetic system. The grid size would be limited by the precision requirements of a given project. The empirical projection's scale factor, k, is extremely sensitive to ϕ different from ϕ_0. An example (Table 3) suffices to demonstrate the sensitivity. However, differences in k were small for a more limited range of ϕ, not exceeding a 0.1° departure from ϕ_0. The corner angles in reverse-projected 1 X 0.7 km rectangles differed from 90° by no more than 0.01°. Along the -93° meridian the corner positions of these small reverse-projected rectangles reprojected into the UTM system with maximum displacement of 1m from the original plane rectangle corners.

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A Versatile Apparatus for Measuring Kinetics of Gaseous Reactions by a Relative Method

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Abstract

It is important that accurate, reproducible values for the rates of chemical reactions occurring in the atmosphere be obtained. The value of accurate kinetics measurements is to improve the accuracy of mathematical models used to forecast the state of the atmosphere. We describe a versatile, robust apparatus for obtaining atmospheric reaction rate values and their temperature dependencies by a relative method. This relative method has the advantage over absolute methods in that errors due to impurities and adsorption on walls of the reaction apparatus are minimized. In addition, relative values serve as an important verification for absolute values. The apparatus serves to mix sample and reference gases, used in the studies, with helium, water vapor and oxygen and deliver them to a quartz reaction cell whose temperature can be controlled between of -50 C and +350 C. Reaction is carried out by use of a low pressure mercury vapor lamp radiating the sample for different periods of time. The mercury lamp produces hydroxyl radicals in the presence of the water vapor in the reaction mixture. The hydroxyl radicals abstract hydrogen atoms from the sample molecules. Oxygen is needed to mimic reaction conditions in the atmosphere which is rich in oxygen. Measurement of the concentrations of unreacted and reacted mixtures are obtained by injecting these samples into a gas chromatograph having a mass spectrometer detector, GC/MS. Analysis of the rates of reaction of cyclopropane and difluoromethoxydifluoromethane, CHF_2OCHF_2, (HFOC-134) with hydroxyl radicals yields the following results: For cyclopropane, a rate of $7.85 \times 10^{-14} s^{-1}$ at 298.15 K and an activation energy, E/R, of 1323 was obtained. For HFOC-134, a rate of $2.23 \times 10^{-15} s^{-1}$ at 298.15 K and an activation energy, E/R, of 1895 was obtained.

Introduction

Because of questions raised concerning the impact of people upon their environment, especially the atmosphere, there is great need for accurate values of the rates of chemical reactions occurring in Earth's atmosphere (Belton, 1990; Albritton and Watson, 1991; Finlayson-Pitts and Pitts, 2000). It is important to know atmospheric lifetimes of gaseous pollutants arising from natural and man-produced sources (DeMore, 1997; Taylor, 1999). In this report we describe an apparatus and a method to acquire these values.

Absolute Methods.--Gaseous chemical kinetics rate measurements may be divided into absolute and relative methods (Finlayson-Pitts and Pitts, 2000). The absolute method involves making measurements of the concentration of each reactant after steady-state flow has been achieved, both before and after the reaction has occurred. This is most often done by use of a concentric tube apparatus in which one reactant flows through a central tube while the other reactant flows through a surrounding outer tube. Reaction progress is measured at different distances from the point of mixing after reaction has been initiated. Elaborate, powerful vacuum systems are required for absolute measurements. Also, there are considerable opportunities for error, such as the presence of impurities and loss of reactants by adsorption on the walls of the containing apparatus. Detection schemes used to monitor the concentrations must be very

specific, sensitive and accurate and are usually sophisticated and expensive. However, absolute methods are fundamental. Without them there would be no way of having the true, absolute values for reaction rates and temperature dependencies.

Relative Methods.--Relative methods for measuring chemical kinetics rates and temperature dependencies are also important and are simpler to perform. In this method, the rates of a reaction are measured relative to a standard reference compound whose rate has already been determined and traceable to an absolute measurement. Many errors are minimized and often cancel in the measuring process. This is because both the compound whose rate is to be determined and the standard compound are mixed together and exposed to exactly the same conditions as they flow through the reaction apparatus and are measured. Generally, the presence of trace impurities has little effect. There is additional benefit from measuring chemical kinetics rates by the relative method. They provide an important verification of the absolute rates. For example, let us measure an unknown rate two times and each time the rate of the unknown is measured using a different standard. If the same value of the unknown rate is obtained using the two different standards, each traceable to a different absolute measurement, strong evidence is provided that not only is the rate for the unknown correct, but that the absolute rates for the standard compounds are also correct.

The relative method can also provide reaction rate information accurately, less expensively, and in greater abundance than the absolute method. It can serve as a check on the accuracy of absolute values. Many different types of gaseous kinetic rates may be measured using this method. The following are examples:

- Thermolysis Reactions
- Photo-initiated reactions with oxygen
- Halogen free radical reactions
- Photo-initiated reactions with ozone
- Photo-initiated reactions with nitric oxide
- Photo-initiated reactions with hydroxyl radicals

In this report a relative rate apparatus and method is described that can be used to measure chemical reaction rates and temperature dependencies of rates reproducibly and accurately.

Theory

Our kinetic studies are focused on reactions of gaseous atmospheric pollutants as they react with hydroxy radicals. Past atmospheric research has revealed that hydroxyl radical reaction with organic compounds is the predominate, and perhaps only, pathway by which organic and other compounds are removed from the atmosphere (Atkinson, 1989). Furthermore, hydroxyl radical reaction is of primary importance in combustion processes. A hydroxyl radical abstracts a hydrogen atom from organic compounds, producing water and leaving an organic radical:

$$R\text{-}H + \cdot OH \rightarrow R\cdot + HOH$$

This reaction is a second order reaction. The rate equation for this reaction is simplified by the fact that the concentration of one of the reactants, the hydroxyl radical, is present in constant amount during the course of a reaction, just as it is in the atmosphere. The equations necessary to calculate hydroxyl reaction rates using the relative method are simple. Because sample and reference compounds are in the same reaction cell for the same amount of time, t, the concentration of hydroxyl radical, $C_{\cdot OH}$, and time, t, cancel from the defining equations yielding a simple relationship between the rate constants for sample and reference compounds.

$$\frac{Rate_S}{Rate_R} = \frac{-\dfrac{dC_S}{dt}}{-\dfrac{dC_R}{dt}} = \frac{k_S[C_S][C_{\cdot OH}]}{k_R[C_R][C_{\cdot OH}]} = \frac{k_S[C_S]}{k_R[C_R]}$$

$$\frac{\displaystyle\int_{C_{S\,Initial}}^{C_{S\,Final}} \frac{d[C_S]}{[C_S]}}{\displaystyle\int_{C_{R\,Initial}}^{C_{R\,Final}} \frac{d[C_R]}{[C_R]}} = \frac{\displaystyle\int_{t=0}^{t=t} k_S dt}{\displaystyle\int_{t=0}^{t=t} k_R dt} = \frac{\ln\left\{\dfrac{C_{S\,Initial}}{C_{S\,Final}}\right\}}{\ln\left\{\dfrac{C_{R\,Initial}}{C_{R\,Final}}\right\}} = \frac{\ln(DF_S)}{\ln(DF_R)} = \frac{k_S \times t}{k_R \times t} = \frac{k_S}{k_R}$$

$$k_{Sample} = k_{Reference} \times \frac{\ln(DF_{Sample})}{\ln(DF_{Reference})}$$

In this derivation, S and R refer to sample gas and reference gas, respectively. The concentrations of the reactants in moles per liter are denoted by a subscripted C. The specific rate constants are defined as k_S and k_R for sample and reference gases, respectively. The time of reaction is given by t. The depletion factor for sample and reference are labeled as DF. The depletion factor is defined as the concentration of sample (or reference) gas before reaction divided by the concentration of sample (or reference) gas after reacting for a period of time equal to t.

Materials and Methods

Sample and Reference Preparation and Storage.--Figure 1 shows a schematic of the apparatus. Each subsection of the apparatus will be described, beginning with the sample/reference container. The sample and reference gas mixtures are prepared and stored in containers normally used to hold propane for recreational vehicles and barbecue grills. The containers have a water capacity of 21.7 L (47.6 lb.). They can be pressurized to a maximum of 1654 kPa (240 psi). The steel compressed gas cylinders (DOT/ICC 4B-240) are purchased new and fitted with a brass adapter that screws into the outlet and terminates in a 1/2 inch NPT male fitting. These adapters can be purchased from any gas company that sells and fills the propane containers. The 1/2 inch NPT male fitting is connected by means of a 1/2 inch NPT male fitting to 1/8 inch Swagelok™ tube connector for attachment to the vacuum lines and the reaction apparatus. The containers are evacuated to a fraction of a torr pressure before filling them with the sample and reference gases. The on-off valves of these containers exhibit almost no leakage at low pressures. The sample gas is admitted into the evacuated container to a pressure of approximately 2.67 kPa (20 Torr) using normal vacuum techniques. The reference gas, 2.67 kPa, is then introduced into the same container. Finally, ultra high purity helium is added to the tank until the total pressure is 207 kPa (30 psi). The reaction mixture must stand for several hours to insure complete mixing. All vacuum and low pressure readings are obtained using a MKS Type 690A Absolute Baratron™ Pressure Transducer connected to a MKS Type 670A High Accuracy Signal Conditioner. The final pressure was measured with a 152.4 mm Ashcroft Type 1082 Test Gauge having a stated accuracy of 0.25%.

Dilution and Mixing of Sample and Reference Gases for Reaction.--Once the sample container is filled and mixing completed, it is attached to the reaction apparatus using stainless steel 1/8 inch Swagelok™ fittings and 1/8
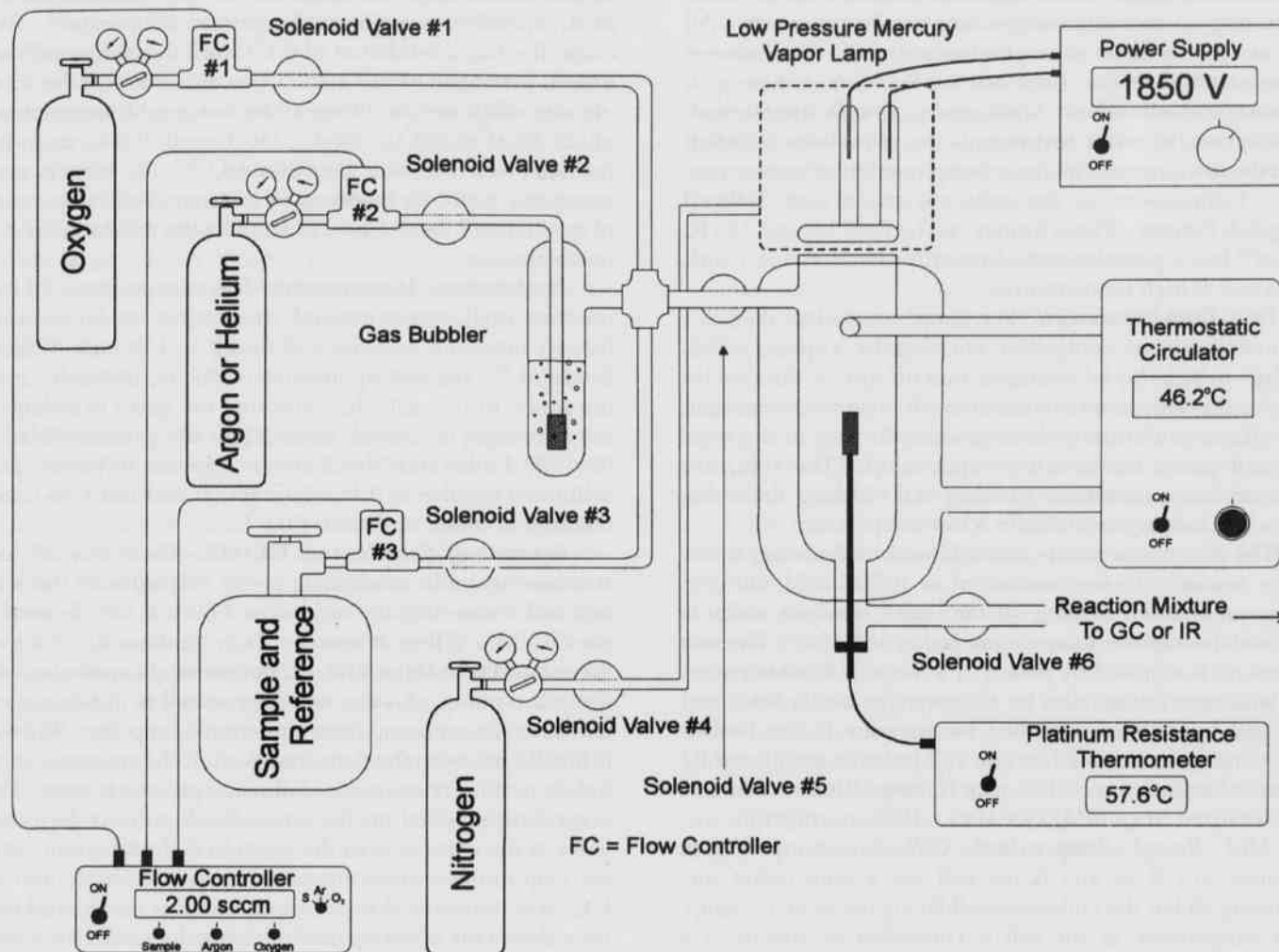
Fig. 1. Schematic of apparatus.

inch Teflon™ tubing. The sample mixture is diluted with additional ultra high purity helium and oxygen by means of stainless steel Swagelok™ 1/4 inch Tee connectors before entering the reaction chamber. The oxygen and helium are supplied by means of conventional Type H tanks fitted with pressure regulators adjusted to deliver these gases at 172 kPa (25 psi). The pressure regulators used are Model 11 Series (Two Stage) General Purpose High-Flow Regulators manufactured by Scott Specialty Gases. The sample, helium and oxygen gases have their flow into the reaction cell accurately controlled by means of Hastings Model HFC-202 Mass Flowcontrollers connected to a Hasting Model 400 Power Supply. The power supply is a combination power supply and readout device that can control up to four flow controllers. The flow controllers were calibrated for an upstream pressure of 172 kPa and downstream pressure of 101 kPa. The helium controller (HFC 202D) was calibrated

to deliver 0 to 500 sccm (standard cubic centimeters per minute) helium. The oxygen controller (HFC-202B) was calibrated to deliver 0 to 50 sccm oxygen, and the sample controller (HFC-202A) was calibrated to deliver 0 to 10 sccm helium. The accuracy and linearity of the controllers are guaranteed to have less than 1% error with a repeatability error of less than 0.1%. The helium gas is fed into a glass bubbler apparatus which can be used to saturate the helium with water vapor needed to produce hydroxyl radicals when irradiated by the low pressure mercury vapor lamp. The flow through the water bubbler can be diverted by means of a two-way stopcock to deliver dry helium gas when desired. This stopcock is not shown in Fig. 1. The final diluted gas mixture can be sent into the reaction chamber or diverted to an exhaust line by solenoid valves. The exhaust line is not shown in Fig. 1. All gases are eventually vented outside the building through 1/4 inch Teflon™ tubing.

Reaction Cells.--Three different reaction cells are used depending on the temperature range to be measured. All cells are in the shape of a cylinder having a 5 cm diameter and a length of 10 cm. Each cell has 9.53 mm (3/8 in.) o.d. entrance and exit tubes. Additionally, all cells are fabricated of quartz in order to transmit the ultraviolet radiation from the low pressure mercury lamp required to cause reaction. Connections to the cells are made with Teflon™ Swagelok Fittings. These fittings can be used to near 350 K. Teflon™ has a phase transition near this temperature which limits use at high temperatures.

Low Temperature Cell.--For temperatures less than 273 K the cell used is completely enclosed by a quartz jacket through which liquid nitrogen boil-off gas is directed to achieve the low temperatures desired. The waste nitrogen boil-off gas is ultimately directed onto the face of the reaction cell facing the mercury vapor lamp. The cold, dry nitrogen keeps frost from forming and blocking the radiation while helping to maintain a low temperature.

The low temperatures are achieved by inserting a cartridge heater into the bottom of a 30 L liquid nitrogen Dewar and slowly boiling off the liquid nitrogen which is directed through the temperature jacket of the cell. The rate of boil-off is adjusted by means of a Variac. A rubber stopper with tight fitting holes for the cartridge heater leads and nitrogen boil-off line maintain the pressure in the Dewar. The temperature of the reaction cell jacket is monitored by means of a platinum RTD sensor (Omega PR-11-2-100-1/8-9-E) attached to an OMEGA 4201A PC2 controller.

Mid Range Temperature Cell.--For temperatures between 273 K to 400 K the cell has a fluid jacket surrounding all but the end of the cell facing the mercury lamp. The temperature of the cell is controlled by means of a Neslab Constant Temperature Bath/Circulator, Model RTE-111 that controls in the range -25°C to + 150°C. Dow Corning Silicon Fluid, Dow Corning 200™ fluid with 50 centistokes viscosity at 273 K is used as the heat transfer fluid. We measured the absorbance of this fluid in a 1.00 cm quartz cell and found the fluid is transparent in the visible region of the electromagnetic spectrum down to 254 nm where the absorbance is 0.037. Below 254 nm the absorbance rises steadily to a value of 1.000 at approximately 210 nm for the 1.00 cm path length. This information is useful if filtering of the higher energy (shorter wavelength) radiation from the mercury vapor lamp is required.

High Temperature Cell.--For reaction temperatures higher than 400 K a simple quartz cell with no jacket is used. The cell is wrapped with a 10 ft. OMEGALUX™ FGR-100 500 watt/120 volt rope heater. The maximum allowable temperature for this heater rope is 755 K. The temperature of the cell is controlled by inserting a 100-ohm inch o.d. platinum RTD sensor, = 0.00385, between the cell and the heater rope. The RTD sensor (Omega PR-11-2- 100-1/8-9-

E) and heater rope are connected to an OMEGA 4201A PC2 controller to maintain the desired temperature. The controller has a resolution of 0.1°C and measures and controls in the region of ±199.9°C. The sensor/controller module was calibrated by Omega Engineering at temperatures of -25°C, 0°C, 50°C, 100°C, 150°C and 190°C to insure readings were accurate to within ±0.1°C. In theory, measurements could be made up to the transition temperature of the Teflon™ fittings used to connect the cell to the rest of the apparatus.

Temperature Measurement.--The temperature of the reaction itself was measured by placing an RTD probe directly into the reaction cell using a 1/2 inch Teflon™ Swagelok™ Tee and appropriate reducing fittings to mate the probe to the cell while allowing the gases to escape to the measuring or exhaust lines. The Cole-Parmer Model P-08117-90 Probe and Thermometer Module 02155-54 were calibrated together at 0°C, 50°C, 100°C and 150°C to insure readings accurate to within ±0.1°C.

Injection of Samples into GC/MS.--There is a 1/8 inch stainless steel tube originating at the exit valve of the reaction cell connecting the cell to the 1.00 mL sample loop of the GC/MS. There is another inch stainless steel tube on the exhaust side of the 1.00 mL sample loop connecting with a vacuum pump. A valve has been placed in this line to isolate the vacuum pump from the sample loop line. When it is time to measure the concentrations of the reactants either before or after reaction, the following process is used. First a vacuum is pulled on the entire gas line from the closed valve at the exit outlet of the reaction cell through the sample loop to the vacuum pump. To admit a sample into the GC/MS, the valve at the vacuum pump is closed and then the valve to the cell is opened allowing the gases in the reaction cell to fill the 1.00 mL sample loop. Once this is done, the GC/MS program is started. After the sample in the 1.00 mL sample loop has been admitted into the GC/MS and the exit valve on the reaction cell is closed, the vacuum pump valve is again opened to evacuate the sample loop in preparation for the next sample.

Solenoid Valves Used to Control Gas Flows.--All the valves used to control the flow of gases through and around the reaction cell are two-way electronic solenoid valves with a 2.778 mm orifice. The Burkert 1/8 in. NPT Miniature Solenoid Valves are operated by a 24 VDC power supply through a series of miniature SPST toggle valves. With no power applied, these valves are closed and open upon application of +24 VDC to the coils. If the valves are left open for more than a very few minutes, there is considerable heating of the gases in contact with the valve housing. Therefore, some of the valves will be replaced in the future with valves that are normally open when there is no power to them in order to reduce heating effects from the valving system. Another feature to be implemented is a valve dri-

ver that reduces current flow once the valve has been operated. Neptune Research and Development produce these CoolDrive™ Valve Drivers.

Low Pressure Mercury Vapor Lamp.--A low pressure mercury vapor lamp is used for producing the hydroxyl radicals necessary for reaction. The lamp is fabricated in the form of a flat coil of approximately 7.62 cm. It is powered by use of a 2 kV transformer powered directly from house 120 VAC having an SPST switch and fuse. The lamp produces a large amount of ozone in the laboratory when operated. Therefore, it has been placed in an acrylic box with a nitrogen purge to prevent the formation of ozone from atmospheric oxygen. The face of the box is open at the coil end of the lamp and the cell is mounted within 2 or 3 mm of the lamp.

Operation of the Apparatus.--A typical experiment is performed by first adjusting the flows from the sample container, oxygen tank and helium tank. In the measurements for cyclopropane we used 3.00 sccm for sample flow, 10.00 sccm for oxygen flow and 187.0 sccm for the helium saturated with water vapor flow. The thermostat circulator is adjusted to the desired temperature and the reaction cell is purged for 20 minutes. This amounts to five cell volumes sweeping through the cell to insure the cell is filled with the reactant gases at the proper concentration. Next, the cell inlet and outlet are closed for 4 minutes. The cell is opened to the evacuated sample loop line leading to the GC/MS. The unreacted sample and reference gases in the cell are measured with the GC/MS instrument, and the peak areas of each are recorded. The cell is again purged for 20 minutes and cell inlet and outlet valves are closed. The low pressure mercury vapor lamp is turned on so that hydroxyl radical production can take place. Usually, the lamp is on for 2 to 10 minutes. The reacted sample and reference concentrations are measured and recorded with the GC/MS instrument. After purging for 20 more minutes another "off

cycle" is carried out. Each time the cell is isolated the temperature is recorded at the beginning and end of the isolation period. The temperature is reported as the average temperature of all these measurements. This procedure continues until 5 measurements are made with times adjusted so that the amount of reaction occurring varies between 20 percent reacted to 80 percent reacted. This completes the rate measurement for one temperature.

Results and Discussion

We measured the rate of reaction for HFOC-134 (CHF_2OCHF_2) using FC-125 (CHF_2CF_3) as the reference. HFOC-134 is a product of commercial interest to DuPont Chemical Company for possible use as a refrigerant, foaming agent and/or degreasing solvent. The results are tabulated in Table 1 along with values obtained from previously published sources. The values obtained in our laboratory are quite close to those of which were measured at Jet Propulsion Laboratory (DeMore, 1997) also by the relative method. The other measurements were obtained using absolute methods (Garland et al., 1993). This comparison shows the difficulty of making absolute measurements that are reproducible.

Table 2 gives the results of our measurements along with those at Jet Propulsion Laboratory (DeMore, 1997), at Harvard (Donahue et al., 1998) and Dobe et al. (1992). The relative measurements at two different laboratories using two different reference materials again agree more closely than those obtained using absolute methods.

Conclusions

As the results tabulated in Table 1 and Table 2 show, the relative method of kinetic rate determinations is accurate and reproducible. The values we obtained for the rate con-

Table 1. Comparison of Results for Difluoromethoxydifluoromethane, HFOC-134

	A, s^{-1}	E/R , Kelvin	k (298 K), s^{-1}	Reference
Wilson (Wilson et al., 2000)	1.29×10^{-12}	1895	2.23×10^{-15}	FC-125
DeMore (DeMore and Bayes, 1999)	1.54×10^{-12}	1972	2.05×10^{-15}	CH_3CCl_3
Orkin (Orkin et al., 1994)	6.25×10^{-12}	1643	2.52×10^{-15}	Absolute
Garland (Garland et al.,1993)	5.68×10^{-13}	1588	2.76×10^{-15}	Absolute

Table 2. Comparison of Results for Cyclopropane

	A, s^{-1}	E/R , Kelvin	k (298 K), s^{-1}	Reference
Wilson (Wilson et al., 2000)	6.64×10^{-12}	1323	7.85×10^{-14}	Ethane
Wilson (Wilson et al., 2000)	6.85×10^{-12}	1376	6.68×10^{-14}	FC-152a
DeMore (DeMore and Bayes, 1999)	6.80×10^{-12}	1337	7.64×10^{-14}	Ethane
Donahue (Donahue et al., 1998)	1.63×10^{-12}	949	6.76×10^{-14}	Absolute
Dobe (Dobe et al., 1992)	3.96×10^{-12}	1089	1.03×10^{-13}	Absolute

stants and temperature dependencies of these two compounds agree quite well with similar measurements made at other laboratories. Having established our ability to make these kinds of measurements and having tested our apparatus, we will now begin to measure other compounds that are precursors to the tropospheric formation of ozone. The first compound to be measured will be isobutane using butane as a reference. These two compounds differ by the single tertiary hydrogen on isobutane. Knowledge of the rate of these compounds will allow us to make predictive statements as to the reactivity of primary versus tertiary hydrogens.

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Mechatronic Design of a Treaded Mobile Robot for Mine Sweeping

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Abstract

Autonomous mobile robots, which can be programmed to exhibit cooperative behaviors, are ideal mechanisms for sweeping land mines. They can spread out to hunt for the mines, using a dispersal rule. Once a mine is located, they can congregate to surround it using a clustering rule. Should a robot be destroyed by tripping an unseen mine, the cost is minimal compared to a human life. UALR has been experimenting with coupled oscillator based rule generators for several years using fragile, indoor robots in a laboratory setting to validate the clustering and dispersal behaviors. In order to accomplish outdoor trials, a rugged robot, which can negotiate uneven terrain, needed to be designed. Energy efficiency and mechanical efficiency were paramount in the selection of the batteries, motors, and controller electronics to extend the running time between recharging. An eightwheel treaded design was selected, in order to provide best traction on uneven terrain and to provide the ability to climb over obstacles or steep slopes.

Introduction

Mechatronics is an area of design which synergistically combines mechanical design, electrical design, sensor design and integration, control system design, and software design (Craig, 1999). A conventional mechanical designer combines purely mechanical elements in achieving desired specifications. Such elements include gears, linkages, and other mechanisms. A mechatronic designer augments his mechanical toolbox with other elements, including sensors and actuators, software routines, and control algorithms. By adding this design flexibility, a larger map of solutions is available, and a design which is closer to the optimum can be achieved.

In traditional design, the mechanical design is accomplished first using purely mechanical elements. Sensors and actuators are usually placed next or are retrofitted on an existing mechanical design. The control system and software are added last. The control system is usually designed for this final system. As each stage in the process develops, it becomes increasingly expensive to return to an earlier stage and perform a redesign. An optimal design can only result ftom the traditional design sequence through pure chance or through long, multi-product redesigns.

An example from the automotive industry illustrates this concept. Steering is accomplished through a mechanical linkage connecting the steering wheel to both front wheels (a rack-and-pinion). With the advent of power steering, the steering wheel's turning force is "servoed" by the power steering system to increase the turning force, eliminating the need to have the steering system mechanically amplify the driver's force. However, the mechanical linkage to maintain both wheels in their proper relative orientation remains. A mechatronic design would include a controller, which takes a command signal from the driver and delivers an appropriate signal to either a hydraulic system or an electric motor coupled independently to each front wheel. Feedback would be delivered to the controller through sensors placed on the front wheels. The mechatronic design is less expensive because it contains fewer mechanisms and uses either motors or hydraulics which are already present in the power steering. Since both wheels can be controlled independently, more creative steering strategies can be employed.

Whereas most mechanical systems (automobiles, airplanes, power generation equipment) can be made to function adequately through traditional design techniques, autonomous mobile robotic systems require a mechatronic design approach. Autonomous systems do not have a human element to direct the system. Rather, an autonomous mobile robot will have an on-board controller which must process sensor information and provide actuator signals. Autonomous systems have much more stringent energy requirements than conventional systems, since efficient transduction of battery power into mechanical motion extends the life of the vehicle. Coordination between mechanical, electrical, and control elements must be done simultaneously and synergistically from the beginning of the design process.

Many autonomous mobile robot designs have been proposed and built (Steele and Ebrahimi, 1986). The tasks which these robots perform range from pure research to planetary exploration. There are many design configurations for mobile robots. Most are either wheeled or legged configurations. There are few treaded configurations in the literature. Many of the wheeled configurations, especially the two wheeled, differential drive configurations (Gentile et

al., 1996; Wu, 1994), are only workable on a hard flat floor.

More robust systems have been designed through the Rover planetary exploration program (Gentile et al., 1996; Zimmerman, 1994). While early prototypes had eight wheels and no tread, the final design, which was used on Mars, was a six wheeled design. The choice of wheels over a treaded design was a compromise between complexity of the control strategy versus the problem associated with tread slipping from the drive wheel. In the multiple wheel design, each wheel must be controlled independently which requires more controller outputs, more motors, and more electronics to deliver power to each wheel motor. In a situation where a tread cannot be replaced if it slips, this added complexity is justified.

Mobile robots, which can be programmed to exhibit cooperative behaviors, are ideal mechanisms for sweeping land mines. They can spread out to hunt for the mines, using a dispersal rule. Once a mine is located, they can surround it using a clustering rule. Should a robot be destroyed by tripping an unseen mine, the cost is minimal compared to a human life. UALR has been experimenting with coupled oscillator based rule generators for several years using fragile, indoor robots in a laboratory setting to validate the clustering and dispersal behaviors (Anderson and Clark, 1999). In order to accomplish outdoor trials, a rugged robot, which can negotiate uneven terrain needed to be designed. For the present mine-sweeping application, a treaded design was chosen. This design preserved the differential drive configuration used in earlier UALR experimentation and allows the vehicle to negotiate hilly and rugged terrain.

Mechanical Design of Drive System

There are three components in a vehicle: frame, suspension, and drive mechanism. The frame contains the suspension, the drive mechanism, and any passenger or payload. The suspension transmits forces from the ground to the frame and from the frame to the ground. Ideally, it will decouple terrain uncertainties (pits, pot holes, bumps) from the frame motion. The drive mechanism transfers power from the drive motors to the suspension.

Requirements.--The robot interior, which contained the sensors and electronics, needed to be isolated from dirt and water. Although it did not have to be completely waterproof, the housing needed to tolerate splashes. The controller electronics needed to be mounted to provide shock and vibration resistance. The suspension and drive train needed to be sturdy so as to survive the wear and tear caused by an outdoor, uneven terrain. Energy efficiency and mechanical efficiency were paramount in the selection of the batteries, motors, and controller electronics so as to extend the running time between recharging. The treaded design employs differential steering, which allowed the control algorithms designed on the indoor robots to be used

without modification.

The target for vehicle mass, excluding controller electronics, was 13.5 kg. Although there was no exact space claim, the weight requirement limited the vehicle to a frame of 30 cm x 50 cm. The vehicle top speed was to be limited to running pace (about 2 m per sec) so that, in the event of a controller instability, the vehicle could be caught by a human observer. Maneuverability was not a primary concern, so turning rate was not considered in the design.

The Frame.--The Frame is split into two halves connected by supporting cross rods (see Fig. 1). The cross rods support a plate which holds the controller electronics and battery. The plate is attached to the frame through vibration isolating mounting posts (Small Parts part number PM-832-18SS). These posts attenuate vibrations from the frame.
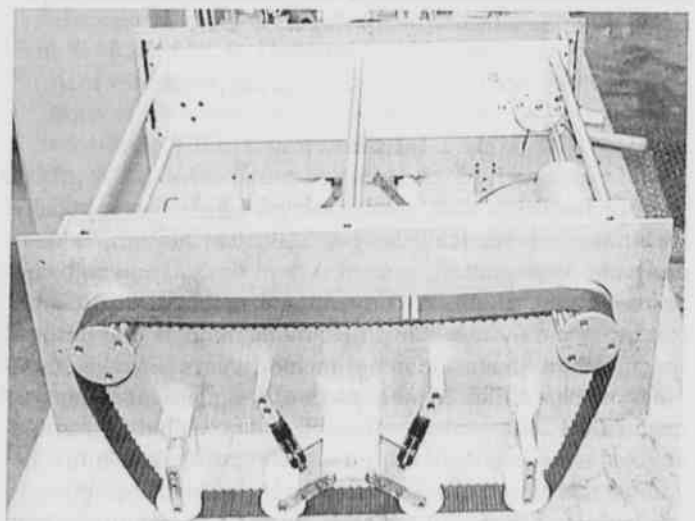
Fig. 1. Schematic of assembled vehicle.

The Suspension.--The Suspension consists of a tread (Belt Corporation of America, part number 125L), which is driven by the drive sprocket, wraps around the primary idler wheel, and loops over four road wheels (see Fig. 2). This is duplicated for each side. There are a total of eight wheels potentially in contact with the road at any given time. An eight-wheel treaded design was selected, so as to provide best traction on uneven terrain and to provide the ability to climb over obstacles or steep slopes.

The road wheels are decoupled from the frame through spring-loaded shock absorbers (Traxxas part number 3780). Each wheel travels in a circular path, pivoting about a fixed point attached to the frame (see Fig. 3). The length of the supporting link is 60 mm and the vertical travel of the wheel is limited to about 5 mm before the shock reaches its stop. The eight shock springs support the approximately 50 lb. vehicle and payload, and the spring/shock combination
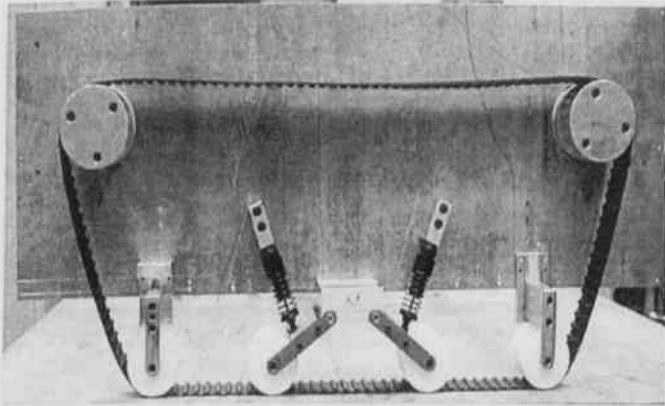
Fig. 2. Side view of drive mechanism.
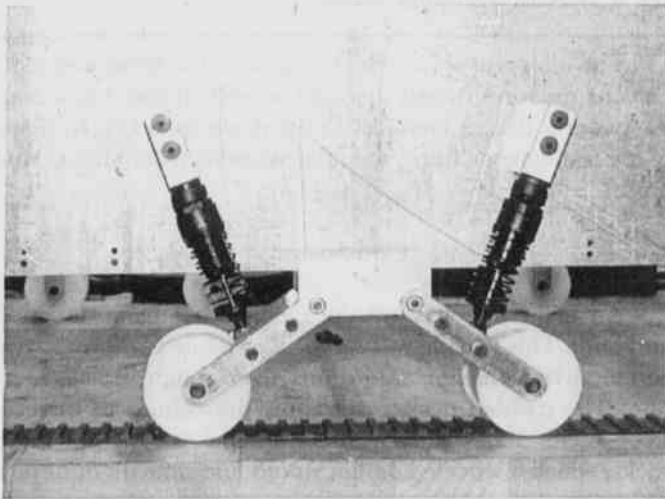
Fig. 3. Close up of suspension.

forms a first order damper to attenuate transmission of ground-induced disturbances from affecting the frame.

The road wheels are machined from Delrin with an oilite bushing (Small Parts part number Y-FBB-2/4) pressed into the wheel bore. The bushing rides on a steel axle. The road wheels contain a hub to prevent the tread from slipping. Traditional treaded vehicles contain a sprocket which grips in notches in the tread. Given the timing belt tread which was chosen, this was not feasible. Should tread slip become a problem, this aspect of the design would have to be revisited.

Although a timing belt tread is not as ideal an arrangement as manufacturing linked treads, it is much less expensive. Since this vehicle is a prototype, issues of tread slippage and traction are being investigated. The road wheels have a 3 mm hub, to prevent the 3.6 mm thick tread from slipping sideways. Although the tread only extends beyond the hub

by 0.6 mm, the vehicle is totally supported by the tread under most circumstances. If a thicker tread becomes necessary, the timing belt can be replaced with a thicker belt or an outer covering can be applied to the belt.

The Drive Mechanism.--The Drive Mechanism is the main element. The tread is driven by a timing belt drive gear made from timing gear stock (Stock Drive Products part number AGA4-18LO8), which is coupled to the drive motor (Crouzet part number 82830002) through two brass gears (Stock Drive Products part number A1B1MYKH7072 and A1B2MYKH7030). The gear ratio is 72:30. The motor maximum speed is 2100 rpm and the sprocket pitch diameter is 54 mm. This yields a maximum tread speed of 2.5 m per sec (2100 rpm * 2π radians per rev * (54 mm)/2 * 30/72). Although this is faster than the target speed, this is the no-load speed. The actual maximum speed is close to the design goal. See Fig. 4 for a close-up of the gear train.
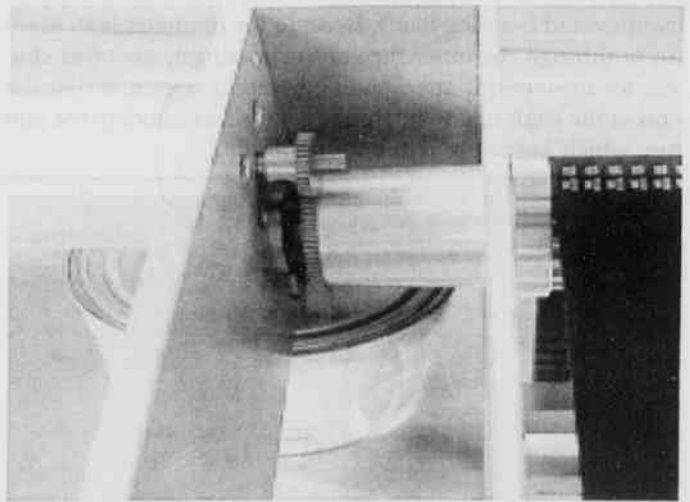
Fig. 4. Close up of motor transmission mechanism.

An encoder (Hewlett Packard part number HEDS5500 A06) is also coupled to the primary drive gear through a 16 tooth brass gear (Stock Drive Products part number A1B2MYKH7016). The encoder measures position, velocity, and acceleration of the timing belt gear. This can be used for feedback to provide regulation of the vehicle velocity. it can also provide position information for performing odometry on the vehicle. The encoder resolves one revolution of the encoder gear into 512 equal slices. By providing a 72:16 gear ratio that increases the number of revolutions of the encoder relative to the drive sprocket, the resolution of the position is increased. Therefore, the motion of the drive sprocket is divided into 512*4.5=2304 equal slices. Velocity resolution is likewise increased, which is crucial when the vehicle is moving very slowly. This has been a problem with

the previous robot design and represents an area where mechatronic design techniques have been applied.

Another solution to increasing resolution is to use an encoder with more divisions, in this case, 2048. Since encoders become geometrically more expensive with increasing resolution (in this case from $50 to $200), the cost of the higher resolution encoder exceeds the cost of adding a gear and a bearing (in this case $50). Further, once the cost of adding a gear and a bearing has been absorbed, further increasing resolution can be accomplished by changing the number of teeth on the encoder gear. Since the price of gears changes slowly with the number of teeth, this design allows resolution to be increased with minor increases in cost.

The drive sprocket uses a double bearing design in an aluminum hub to support bending loads. The drive hub (see Fig. 5) is supported by a steel spindle, which is mounted to the main support bracket. Steel was chosen for two reasons. The spindle is a small diameter shaft, which must support cantilevered bending loads. Because the diameter is so small (to fit through the inner race of the bearings), steel was chosen for its superior strength. The second reason is that the end of the shaft had to be threaded to accommodate the jam nut, which keeps the hub on the spindle.
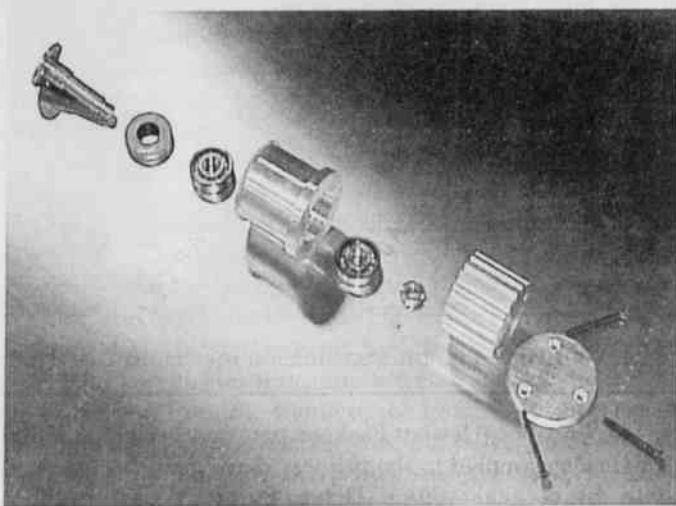
Fig. 5. Assembly of primary drive sprocket.

The hub has two angular contact bearings (Fafnir part number 7201K) pressed into it. These bearings are arranged back-to-back to support thrust loads. The hub is held onto the spindle with a jam nut, which presses against the inner race of the outer support bearing. The timing drive gear stock and the end plate are affixed to the hub with three screws. An oil seal (CR Seals part number 5840) fits between the spindle and the hub and prevents dirt and grime from penetrating the sealed area containing the bearings.
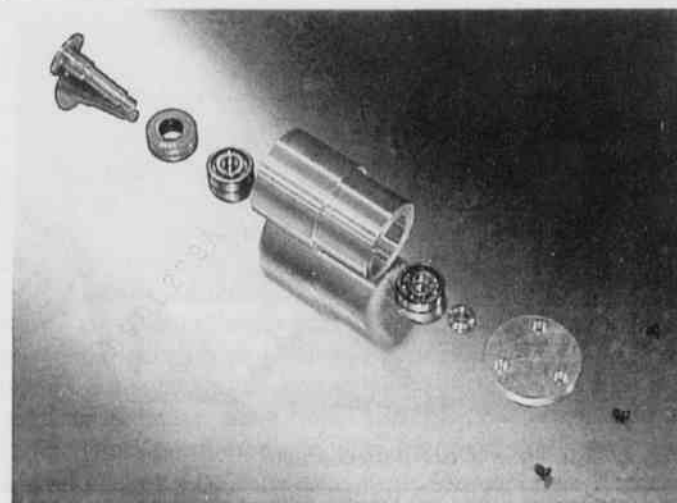
Fig. 6. Assembly of idler wheel.

The idler wheel (see Fig. 6) supports the tread and redirects its motion towards the road wheels. It also has a double bearing design identical to the drive sprocket. In place of the timing gear stock, the idler wheel is machined as one piece.

Conclusions

An eight wheeled, treaded vehicle has been designed and built. This vehicle will serve as a mobile platform to test cooperative behavior algorithms over rough, uneven terrain. The treaded design will allow the vehicle to traverse steep inclines and surface discontinuities, such as pits and rocks, which a wheeled design would find difficult or impossible.

Mechatronic principles were applied to this design such as the integration of an encoder for feedback in the drive system. The overall mechanical architecture was chosen so as to minimize control system complexity. The transmission and the choice of motors was driven by the need to extend battery life.

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A Study of the Amplitude of Pressure and Thrust Oscillations in a Lab-Scale Hybrid Rocket

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Abstract

Hybrid rockets are being studied as a potential replacement for the solid rocket boosters on the NASA space shuttle. One physical characteristic of hybrid rockets that must be understood and overcome is potentially severe pressure oscillations during combustion. Pressure oscillations inside the rocket combustion chamber lead to oscillations in the thrust of the rocket. These oscillations are damaging to potential human passengers and cargo and must be minimized. Current theories surmise that the oscillations are caused by combustion chamber geometry, oxygen feed line parameters, and/or fuel combustion characteristics. This study focuses on the role of the fuel characteristics in pressure and thrust oscillations. The standard hybrid rocket fuel is hydroxyl-terminated polybutadiene (HTPB). A fuel additive, guanidinium azo-tetrazolate (GAT), has been shown to increase thrust and impulse of the rocket when added as 15% by mass to the fuel. This study compares the amplitude of the pressure and thrust oscillations of the rocket when burning HTPB fuels and when burning GAT-added fuels. Data from several firings at oxygen flow rates from 0.018 kg/sec to 0.054 kg/sec are analyzed. Results show the GAT-added fuel combustion shows no significant increase or decrease in the amplitude of the pressure and thrust oscillations.

Introduction

The hybrid rocket facility at the University of Arkansas at Little Rock (UALR) consists of a labscale hybrid rocket motor, several transducers to measure various physical properties such as pressure and thrust, a control computer, and a data acquisition computer. The facility was originally built to investigate combustion instabilities and plume diagnostics. Several hybrid rocket fuels and fuel additives have also been studied.

The standard fuel used in hybrid rockets is hydroxyl-terminated polybutadiene (HTPB). This fuel is characterized by a low rate of regression. Several fuel additives have been studied to determine if the additives increase the regression rate and improve the performance of the hybrid rocket fuel. One such study was performed on the additive, guanidiniurn azo-tetrazolate (GAT). Results showed that GAT increased the regression rate when added in concentrations of 15%, 20%, 25%, and 30% (Wright, Wynne, Rooke, and Hudson, 1998). The highest increase in regression rate was obtained for HTPB with 25% GAT by mass added.

GAT is an organic salt with a high nitrogen content. It is a highly energetic compound due to the energy stored in the pi bond system. The regression rate of this additive is large because it is a salt. The ionic bonds of a salt are easier

to break than covalent bonds, leading to a lower heat of degradation. The bond structure of GAT is shown in Fig. 1.
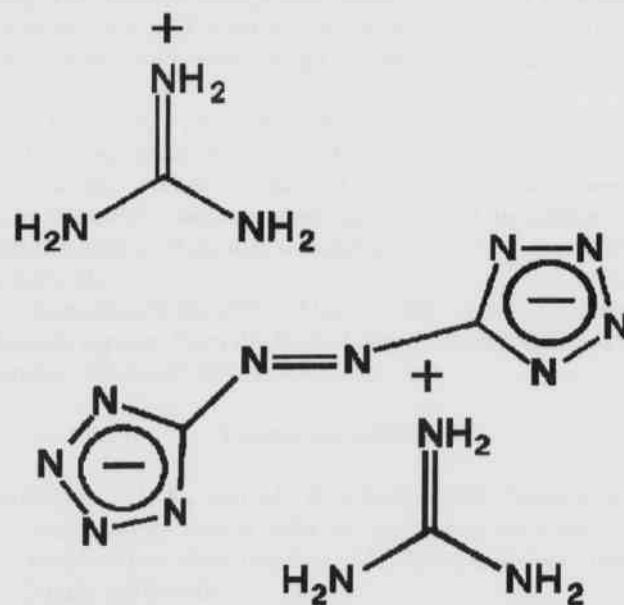
Fig. 1. The chemical structure of Guanidinium Azo-Tetrazolate (GAT).

A Study of the Amplitude of Pressure and Thrust Oscillations in a Lab-Scale Hybrid Rocket

Journal of the Arkansas Academy of Science, Vol. 54 [2000], Art.

A preliminary study of the feasibility of using GAT as a fuel additive with HTPB was presented in 1996 (Luchini, Wynne and Hudson, 1996). The results of that study detailed solutions to problems in the casting of the fuel grains and a possibility of increased regression rate, but more data was needed to fully describe the properties of the GAT/HTPB fuel mixtures. A complete regression rate study was presented in 1998 (Wright, Wynne, Rooke, and Hudson, 1998), verifying that GAT does increase the regression rate when used as an additive to HTPB fuel in Hybrid Rockets. The increase in regression rate makes GAT a desirable fuel additive to HTPB.

A study of the thrust and impulse was performed on the UALR Hybrid Rocket burning HTPB with 15% GAT by mass (Wright, Dunn, Alford, and Patton, 1999). The results showed that the GAT-added fuel produced more thrust and higher total impulse, but no significant increase in specific impulse. Another analysis of the thrust data looked at the amplitude of the oscillations.

The thrust of a rocket is the reaction force experienced by its structure due to the ejection of high-velocity matter (Sutton, 1992). The forward momentum of the rocket is equal to the rearward momentum of the ejected gases from the nozzle. Thrust is measured in Newtons of force and will be designated in this paper by the variable F. Thrust is highly sensitive to nozzle throat area (Sutton, 1992).

Pressure oscillations are a characteristic of all hybrid rocket combustion data. They can be result of combustion instabilities. Details of those instabilities are the subject of great interest. Reducing any thrust oscillations is imperative if hybrid rockets are ever to be employed in delivering valuable human and instrument cargo into space. Any strong vibrations may be harmful to passengers aboard the spacecraft. Internal rocket pressure is directly proportional to the thrust of the rocket (Sutton, 1992). Therefore, the oscillations may be studied in the thrust domain as well as the pressure domain.

Oscillations in internal pressure of the rocket combustion chamber may be a result of several factors. One factor is acoustic modes of the cylindrical pipe that composes the rocket body. Another possible source is called chuffing. Chuffing is the cyclical sloughing of a char layer of fuel as successive layers are liquefied, burned, a char layer is formed and then ejected. Chuffing is a characteristic of the fuel.

Chugging is another source of oscillations. Chugging is a factor caused by oscillations within the oxygen feed line. Tests conducted at NASA Marshall Space Flight Center (MSFC) demonstrated a low-frequency, non-accoustic chamber pressure oscillation. This oscillation was found to be generated by the motion of the oxygen feed system during firing (NASA TP-2000-209905). The UALR Labscale Hybrid Rocket Facility has been inspected by an MSFC test engineer familiar with the NASA testing. The UALR rocket was found to have a rigid oxygen feed system, and therefore eliminated the oscillations demonstrated at MSFC. Preliminary investigation of oscillations on the UALR rocket data showed a very small component of the oscillations could be attributed to chugging (Desrochers, 1997).

Materials and Methods

The hybrid rocket fuel grains were cast in paper phenolic cylinders 25.4 cm in length, 5.1 cm outer (fuel) diameter and an initial port diameter of 1.9 cm. Standard fuel grains were prepared with 85% HTPB and 15% PAPI diisocyanate used as the curative agent. A second set of fuel grains were prepared with 15% GAT by mass added to the standard HTPB and PAPI fuel mixture.

The fuel grains were fired in the UALR hybrid rocket. The gaseous oxygen flow was varied between 0.018 kg/s and 0.054 kg/s. The initial and final mass, port radii of the fuel grain, and nozzle diameter were measured for each run. The runs were set for 4 or 5 sec. However, delays in ignition caused several changes in actual length of combustion time. Pressure data was used to determine the actual length of time between ignition and shut-down.

Because thrust is very dependent upon nozzle throat diameter, care was taken to ensure that the nozzle throat diameter stayed roughly constant throughout all of the trial runs. Since the nozzle was made of graphite, exact consistency was impossible due to ablation during the runs. The nozzle throat diameter varied from 0.71 to 0.79 cm for each run.

Thrust was measured using strain gages mounted on four aluminum support beams which supported the rocket as shown in Fig. 2. The support beams were fixed on both ends, which forced them to deflect in the shape of a sigmoid curve during the firing.

The flexing beams were made from 2024-T81 aluminum with a yield strength of 448,818 kPa (Desrochers, 1997). General purpose strain gages from Measurements Group (CEA-13-125UW-350) were placed on the beams to convert strain to a voltage proportional to the thrust force. The strain gages can be seen in the photograph in Fig. 2. A two stage amplification circuit was built to collect the voltage output of the strain gages and produce a voltage between 0 and 10 volts (Desrochers, 1997). The voltage was collected by an A/D board at 1000 Hz.

The thrust detector was calibrated using a hanging weight system. Known weights between 0 and 178 Newtons were suspended from the rocket and the voltage output of the strain gages was collected. The calibration curve is shown in Fig. 3.

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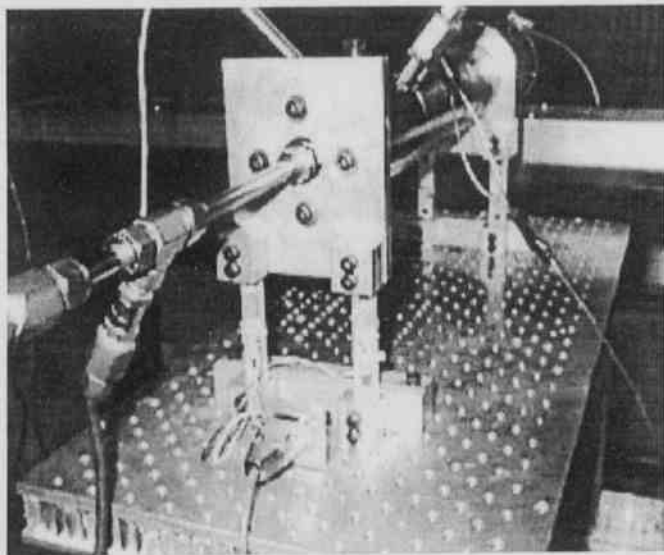
Fig. 2. A picture showing the UALR Hybrid Rocket, and the two aluminum legs supporting the rocket upon which the strain gages are mounted to measure thrust.
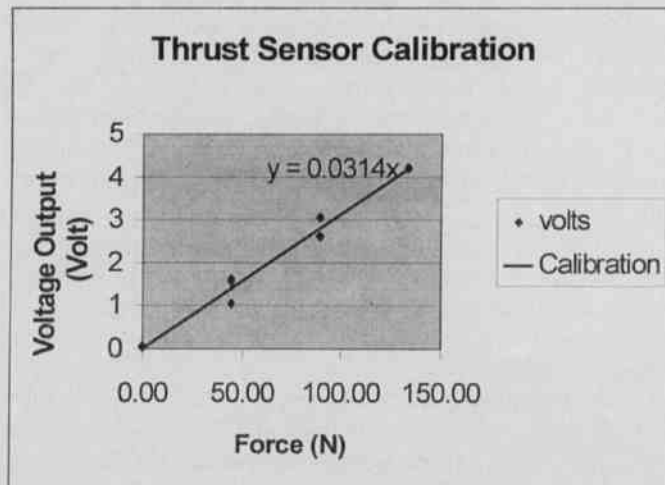
Fig. 3. Calibration of the thrust sensors. Voltage output of the strain gages as a function of known force.

Results

The thrust as a function of time was recorded for each data run. A sample plot is shown in Fig. 4. A small thrust is seen during the initial gas (oxygen and propane) flow from 0 to approximately 2 sec. A sharp increase in thrust indicates the moment of ignition, followed by several seconds of rapid oscillation during the main part of the run. The run is

then shut down as the oxygen is turned off and nitrogen gas is flowed through the rocket to quench the combustion. The flow of nitrogen is responsible for the small non-zero thrust after shutdown.
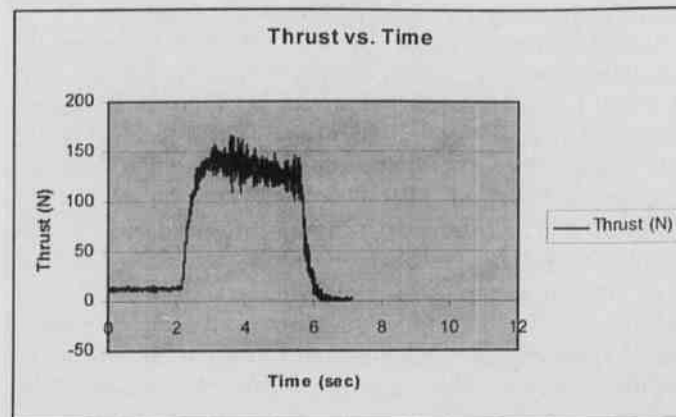
Fig. 4. A sample thrust vs. time data set.

The average and standard deviation of thrust was determined for a range between the initial start-up and the shutdown of each run. The average thrust for both the plain grain and the GAT-added grains are plotted in Fig. 5 as a function of oxidizer flow rate. The standard deviation gives a measure of the amplitude of the oscillations. The higher the standard deviation, the larger the amplitude of the pressure oscillations. Table 1 shows the average thrust and standard deviation for several different oxygen flow rates for the plain HTPB fuel runs. Also listed is the standard deviation as a percentage of the average thrust. Table 2 is similar
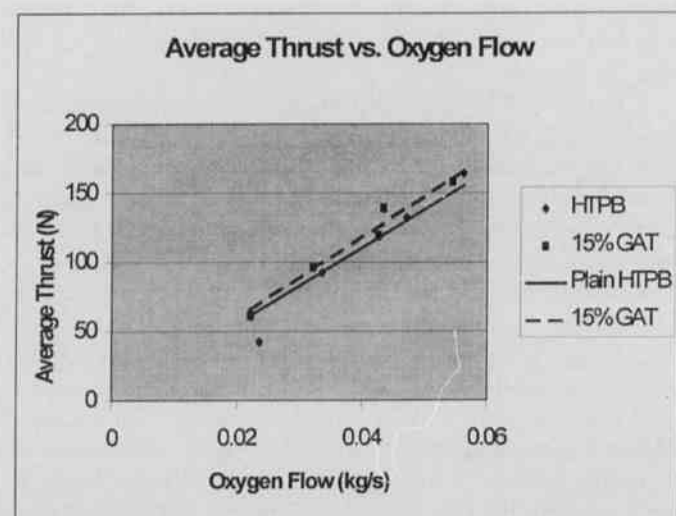
Fig. 5. Average thrust vs. oxygen flow.

Table 1: HTPB Fuel Statistics

Oxygen Flow (kg/sec)	Average Thrust (N)	St. Dev (N)	Percentage of Average Thrust
0.0236	41.95	10.49	25.02
0.0336	92.35	9.21	9.99
0.0472	131.93	10.76	8.16
0.0562	164.01	6.18	3.77

Table 2: 15% GAT Fuel Statistics

Oxygen Flow (kg/sec)	Average Thrust (N)	St. Dev (N)	Percentage of Average Thrust
0.0222	60.54	5.92	9.81
0.0322	96.48	10.23	10.60
0.0426	119.48	6.27	5.25
0.0433	138.65	10.49	7.57
0.0544	157.73	7.29	4.61
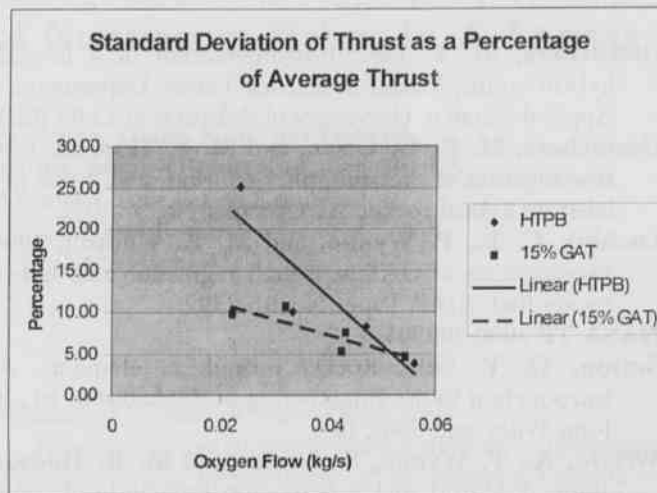
Fig. 7. Standard deviation expressed as a percentage of average thrust as a function of oxidizer flow.

Conclusions

The standard deviation is independent of oxygen flow rate and average thrust. The standard deviation is also independent of fuel. Therefore, the amplitude of the oscillations is not a factor of the fuel. Since GAT has been shown to increase regression rate and thrust, and not increase the amplitude of the thrust oscillations, it is still a viable fuel additive to HTPB Hybrid rocket fuel.

Future thrust and impulse studies are planned to investigate higher percentages of GAT in HTPB fuel. Regression rate studies indicate that 25% GAT fuel grains show the most increase in regression rate (Wright, Wynne, Rooke, and Hudson, 1998). The graphite nozzle used in these GAT studies will be replaced by a new nozzle made of a very high temperature ceramic. Variations in thrust measurements due to nozzle throat size variation will be eliminated, thus making the measurements much more accurate.

The synthesis of GAT is very time consuming and moderately expensive. Therefore, commercial use of GAT is unlikely at this time. In addition, more studies of environmental impact from combustion products needs to be conducted. NO is known to contribute to the formation of acid rain. Trace amounts in lab-scale hybrid rocket plumes would translate into a significant problem for the environment.
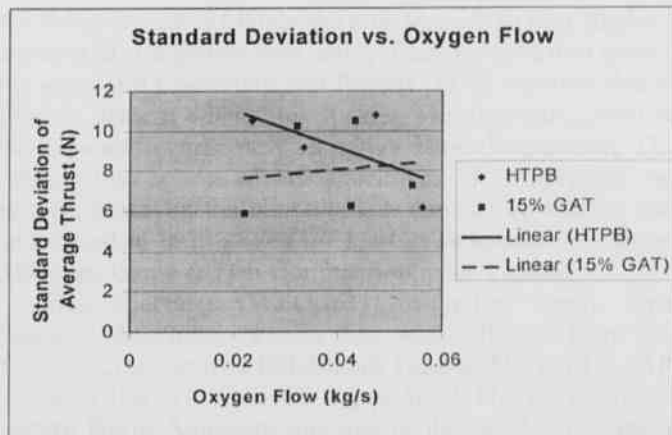
Fig. 6. Standard deviation of thrust for plain HTPB and GAT-added fuel. Shows no correlation with either fuel composition or oxygen flow.

information for the fuel with 15% GAT added. The standard deviation as a function of oxygen flow is plotted in Fig. 6. Standard deviation as a percentage of average thrust is plotted as a function of oxidizer flow in Fig. 7.

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GENERAL NOTES

New Arkansas Records for Two Nonindigenous Fish Species, With a Summary of Previous Introductions of Nonnative Fishes in Arkansas

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Fish sampling with the chemical toxicant rotenone in 1998 and 1999 produced the first vouchered specimens from Arkansas of two nonindigenous fish species. The specimens were deposited in the Westark Zoology Collection (WZC) of Westark College. On 11 August 1998, two blue tilapia, *Oreochromis aureus* (Steindachner) (WZC-1601), 190 and 193 mm total length (TL), were collected from Pool 2 of the Arkansas River in Jefferson Co., AR, 3.2 km downstream from Dam 3 (Sec 34, T6S, R6W). The identity of these specimens was confirmed by Pam Fuller, Leo Nico, and William Smith-Vaniz of the Nonindigenous Aquatic Species Program of the U.S. Fish and Wildlife Service. The blue tilapia, family Cichlidae, is native to tropical and subtropical Africa and the Middle East and has been reported from thirteen states in the United States (Fuller et al., 1999). It is considered locally established or possibly established in ten states including Oklahoma and Texas. The blue tilapia is a potential competitor with native fishes for food and spawning sites, and Courtenay and Robins (1973) reported that in Florida streams where this species was abundant, most of the vegetation and nearly all native fishes disappeared. The introduction source of our specimens of *O. aureus* is not known; however, the blue tilapia is commonly sold for bait and raised in farm ponds for food in Arkansas (A. Carter, Arkansas Game & Fish Commission, pers. comm.).

One specimen (WZC-1611) of yellow perch, *Perca flavescens* (Mitchill), 72 mm TL, was collected from the Trimble Creek arm of Bull Shoals Lake in Marion Co., AR (Sec 28, T21N, R17W) on 26 August 1999. This northern and eastern North American member of the family Percidae is native to the Atlantic, Arctic, Great Lakes, and upper Mississippi River basins south to Missouri and has been widely stocked throughout the United States as a food and sport fish (Fuller et al., 1999). The yellow perch was reportedly stocked in Arkansas in 1918 (O'Malley, 1920), but there have been no subsequent reports of its capture in this state until now. This species has become established in most areas of the United States where it has been introduced. The source of our *P. flavescens* specimen is not known, but there have been no intentional recent introductions of this species in Arkansas by state or federal agencies.

Table 1 lists the currently known nonnative fishes that have been either intentionally or accidentally introduced into Arkansas. Robison and Buchanan (1988) reported 18 nonnative fish species and later added Arkansas records for an additional species, the rudd, *Scardinius erythrophthalmus* (Robison and Buchanan, 1993). In 1995 a redbellied pacu, *Piaractus brachypomus*, family Characidae, was caught in a cemetery pond in Fayetteville, Washington Co., AR (Wright, 1995a; 1995b). There have been additional reports of unidentified pacus taken in Arkansas in the 1990s from Lake Valencia (Pulaski Co.), the Arkansas River near Little Rock, and Beaver Lake (Fuller et al., 1999). All pacu records probably represent aquarium releases because the pacu is a commonly kept aquarium fish. Additional early unsuccessful attempts were made in the 1800s to establish the American shad, *Alosa sapidissima*, and the tench, *Tinca tinca*, in Arkansas (Baird, 1878; Baughman, 1947). Buchanan (1973) reported the capture of one kokanee salmon, *Oncorhynchus nerka*, from Bull Shoals Lake in 1969. That specimen probably came from Missouri because the Missouri Department of Conservation introduced kokanee salmon into Lake Taneycomo, a White River impoundment just upstream from Bull Shoals Lake, in the mid 1960s.

Our records for blue tilapia and yellow perch bring the known number of nonnative fish species introduced into Arkansas to 25. We did not include any of the known introduced hybrid combinations in this report. Twelve of the introduced species are considered established in Arkansas because they maintain reproducing populations in the state or because they are continually restocked, e.g., the five established trout species. Eight of the introduced species are considered extirpated from Arkansas, and four of the species are of undetermined status.

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Table 1. Nonnative fishes introduced into Arkansas, with the native range and current Arkansas status listed for each species.

Taxon	Native range	Arkansas status
Family Clupeidae - Herrings and Shad		
1. *Alosa sapidissima* American shad	North America: Atlantic Coast	Extirpated
Family Cyprinidae - Minnows and Carps		
2. *Carassius auratus* Goldfish	Eastern Asia	Established
3. *Ctenopharyngodon idella* Grass carp	Eastern Asia	Established
4. *Cyprinus carpio* Common carp	Eurasia	Established
5. *Hypophthalmichthys molitrix* Silver carp	Eastern Asia	Established
6. *Hypophthalmichthys nobilis* Bighead carp	Eastern Asia	Established
7. *Scardinius erythrophthalmus* Rudd	Western Europe	Unknown
8. *Tinca tinca* Tench	Europe and Western Asia	Extirpated
Family Characidae - Characins		
9. *Piaractus brachypomus* Redbellied pacu	South America: Orinoco and Amazon River basins	Aquarium release
Family Ictaluridae - Bullhead catfishes		
10. *Ameiurus catus* White catfish	North America: Atlantic and Gulf Slope drainages	Extirpated
Family Esocidae - Pikes		
11. *Esox lucius* Northern pike	Northern North America	Extirpated
12. *Esox masquinongy* Muskellunge	Northern North America	Extirpated
Family Osmeridae - Smelts		
13. *Osmerus mordax* Rainbow smelt	North America: Great Lakes, Arctic, and Pacific drainages	Unknown

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Table 1. Continued:

Family Salmonidae - Trouts		
14. *Oncorhynchus clarki* Cutthroat trout	North America: Pacific Coast drainages	Established*
15. *Oncorhynchus mykiss* Rainbow trout	North America: Pacific Slope drainages	Established*
16. *Oncorhynchus nerka* Kokanee salmon	North America: Pacific Slope drainages	Extirpated
17. *Salmo trutta* Brown trout	Europe, northern Africa, western Asia	Established*
18. *Salvelinus fontinalis* Brook trout	North America: Atlantic, Great Lakes, and upper Mississippi River basins	Established*
19. *Salvelinus namaycush* Lake trout	Northern North America	Established*
Family Moronidae - Temperate basses		
20. *Morone saxatilis* Striped bass	North America: Atlantic and Gulf Slope drainages	Established
Family Centrarchidae - Sunfishes		
21. *Ambloplites rupestris* Rock bass	North America: Atlantic, Great Lakes, and upper Mississippi River basins	Established
22. *Lepomis auritus* Redbreast sunfish	North America: Atlantic and Gulf Slope drainages	Extirpated
23. *Micropterus coosae* Redeye bass	North America: North Carolina and Tennessee to Alabama and Georgia	Extirpated
Family Percidae - Perches		
24. *Perca flavescens* Yellow perch	North America: Atlantic, Arctic, Great Lakes, and upper Mississippi River basins	Unknown
Family Cichlidae - Cichlids		
25. *Oreochromis aureus* Blue tilapia	Africa and the Middle East	Unknown

* A species maintained in Arkansas by frequent stocking.

A Record of the Lake Sturgeon, *Acipenser fulvescens* Rafinesque, from the Caddo River (Ouachita River Drainage), Arkansas

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Records of sturgeons in Arkansas are uncommon, especially for the lake sturgeon, *Acipenser fulvescens* Rafinesque. Prior to 1988 only three records of *A. fulvescens* were known from Arkansas (Robison and Buchanan, 1988), two from the Mississippi River and one from the Little Missouri River. Buchanan et al. (1993) furnished two additional localities for lake sturgeons within the state, both from the White River in Desha and Prairies counties.

Recently, information on another record of the lake sturgeon, which has escaped the notice of fellow ichthyologists and workers in the field including Robison and Buchanan (1988), has been discovered. In the April/May 1998 (Vol. 2, No. 2) of *The Old Time Chronicle* (p. 47), a picture and short paragraph appeared about the capture of a lake sturgeon in the Caddo River.

In 1945, J.T. LaFevers of Glenwood gaffed the specimen in the Caddo River at Glenwood, Pike County, Arkansas. The specimen was "hung up on a gravel bar" (Mr. J. T. LaFevers, pers. comm.) below the railroad bridge at Glenwood. Mr. LaFevers measured the specimen at 3 m in length (9 ft, 10 inch) and estimated its mass at about 136 kg (300 lb). The Little Missouri River specimen taken in 1956, weighed 61.2 kg. (135 lb) and was 1.98 m long (6 ft, 6 inch). Robison and Buchanan (1988) reported a maximum size for this species as about 2.44 m (8 ft) and over 136 kg (300 lb). This makes the Caddo River specimen the largest individual lake sturgeon ever documented from Arkansas waters.

The discovery of this specimen is important because it represents the largest known specimen of a lake sturgeon for Arkansas. Ichthyologists and fisheries biologists should be aware of the rarity of this species in Arkansas, as this specimen is only the sixth individual specimen ever captured from the state. Buchanan et al. (1993) recommended a conservation status of endangered for this species in Arkansas based on the paucity of specimens known from the state.

The fact that this Caddo River specimen represents only the second individual ever taken from the Ouachita River drainage is most interesting. The first specimen taken from the Little Missouri River was assumed to have wandered up the wrong river course while attempting to spawn or move northward. This documentation of a large specimen from the Caddo River, along with the Little Missouri River record, provides evidence that lake sturgeon may have previously used the Ouachita River drainage more commonly than believed, rather than simply having been off course in this drainage.

Lake DeGray Dam on the Caddo River was constructed downstream from this site from 1963-1972. This historical pre-dam record provides more evidence of how man's over-enthusiastic construction of dams alters the fish fauna by preventing migration and/or spawning runs.

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Large Pleistocene Box Turtle from Southwest Arkansas

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The Red River has been recognized as a source of Pleistocene vertebrate fossils for at least seventy-five years. O.P. Hay (1924) reported an *Equus complicatus* tooth from the vicinity of Shreveport, Louisiana. Hemmings (1982) recognized *Megalonyx jeffersoni*, *Mylohyus nasutus*, *Bison*, and *Mammut americanum*. Sanders (1994) added *Geochelone* sp., *Holmesina septentrionalis*, and *Palaeolama mirifica*.

Upstream from Garland City, Sanders collected a thick fragment of turtle bone (SAU G.C.1-2) approximately 26 X 48 mm that he tentatively referred to *Terrapene carolina putnami*. The narrow end of SAU G.C.1-2 was originally interpreted as a hinge line, but it is now thought to be a midline suture overlain by the junction of two external scutes. There are seven growth lines parallel to this edge, as might be expected at the junction of two hypoplastra. The bone is 8.7 mm thick at one end of the suture and 6.2 mm at the other end, so it may still be within the size range of *T. c. putnami*. Now, the discovery of an additional specimen, described in this publication, confirms the presence of this large box turtle in southwest Arkansas during the Pleistocene.

One of the authors (JGS) collected a permineralized lower jaw and teeth of a black bear (*Ursus americanus*) near the mouth of the Sulphur River in Miller County, Arkansas, and forwarded it to the Southern Arkansas University archaeology department for evaluation. After a visit to the bear jaw discovery site, an examination of additional artifacts and bones found in southern Miller County resulted in the recognition of an unusually robust turtle bone. It proved to be a right hypoplastron recovered from the right bank of the Red River in the Dixon Bend area (Fig. 1) during July 1998 when the river was at low stage. Mr. Scoggins has generously allowed that specimen to be deposited in the vertebrate paleontology collection of the Shuler Museum of Paleontology at Southern Methodist University under the accession number SMU-75054.

The specimen (Figs. 2 and 3) is "dusky yellowish brown" (10YR 2/2 of the Munsell system, G.S.A., 1991) and has a mass of 74.2 g. Submerged in water, its apparent mass is 40.3 g, indicating an overall density of 2.19 g per cubic cm. Equivalent measurements upon an entire posterior plastron lobe of a Recent *Terrapene carolina triunguis* (specimen A in Table 1) produces equivalent measurements of 18.6 g, 6.7 g for a density of 1.56 g/cc. These two lines of evidence suggest that the specimen can be referred to the

Pleistocene epoch due to the amount of time probably required to achieve its level of permineralization.
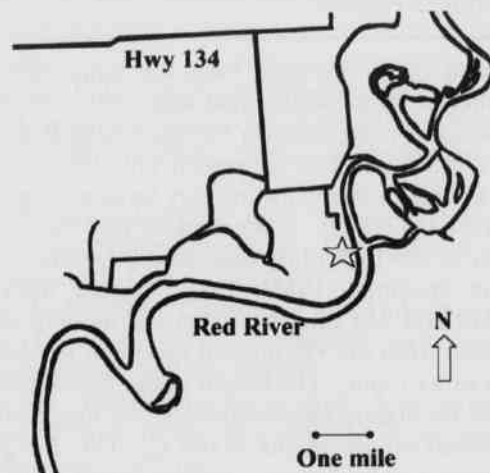
Fig. 1. Map of Red River valley in southeast Miller County, Arkansas. Location where Pleistocene box turtle specimen was recovered is indicated by star. Arkansas Highway 134 connects U.S. Highways 71 and 82.
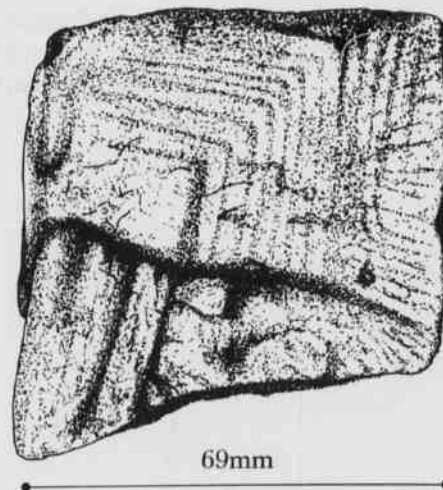
Fig. 2. Ventral view of *Terrapene carolina putnami* right hypoplastron. Anterior hinge line between plastron lobes is at top of figure.

69mm
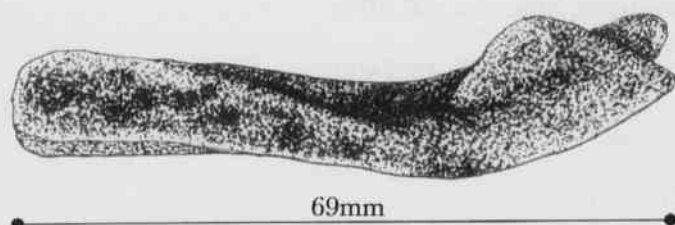
Fig. 3. Posterior view of *Terrapene carolina putnami* right hypoplastron.

The ratio of the distance from the hinge line to the median juncture of the abdominal scute suture divided by the total length of the plastron for specimens B and C in Table 1 are 19.7% and 23.5%, respectively. These ratios are similar to a value of 20.4% for the very large specimen measured by Holman (1965). It is estimated that the total plastron length of the individual represented by the Arkansas Pleistocene specimen (SMU-75054) would have been between 213 and 254 mm, based on the modern animals, with the ratio from the Pleistocene specimen resulting in a prediction of 245 mm. The length of the upper shell carapace would be slightly (approximately 5%) longer than the plastron, based on specimens A and C. The *T. c. putnami* type specimen suggests a total carapace length of 265 mm.

SMU-75054 displays a zone (2.5 X 1.0 cm) in the postero-lateral corner that lacks growth lines. That area represents embryological growth or a loss of the lines due to abra-sion. There are 14 growth lines on its ventral surface in a distance of 2 cm anteriorly and 4.1 cm medially. Zangerl (1969) has cited this pattern of asymmetry in *Terrapene* growth and states that Cagle (1948) found growth rings can be "successfully used to determine the individual age of specimens... However, the method is applicable only during the most active growing phase of the individual and should be used with caution." All the borders of the Red River specimen appear to be natural separations between bones, indicating that the animal was not old enough to fuse its sutures as it would when it reached adulthood.

The length of time the large box turtle subspecies existed is difficult to determine. The type specimen of *T. c. putnami*, described by Oliver Perry Hay in 1908, is a left hypoplastron, less complete than SMU-75054 in that it is missing the postero-lateral corner. It was dredged from the bottom of the Alifia River in Florida about a mile above its entrance into Tampa Bay by the archaeologist and ethnologist, Professor Frederick W. Putnam. The turtle genera *Trachemys* and *Hesperotestudo*, along with horses and tapirs, were recovered with what was then called *Terrapene putnami*, and the beds were correlated with beds in DeSoto County, Florida, that had been declared to be of "Older Pliocene age," but Hay (1908) recognized "the evidence appears to be contradictory." Auffenberg (1958) declared, "New material indicates that the pieces are almost certainly Pleistocene." *Terrapene carolina putnami* is known from terraces of the Trinity River north of Dallas, Texas (Holman, 1965). These terraces have been referred to the Sangamon Interglacial, which preceded the last, or Wisconsinan, glacial episode. As presently understood, the Sangamon has been dated as

Table 1. Measurements (in mm) of *Terrapene carolina* plastra and carapaces

	T.c. putnami SMU-75054 Miller Co., AR	*T.c. putnami* Lewisville Denton Co., TX	*T.c. triunguis* Specimen A Washington Co., AR	*T.c. triunguis* Specimen B Arkansas	*T.c. triunguis* Specimen C Montgomery Co., MO
hinge line to median juncture of abdominal scute suture	50	55	21.0	25.5	34.7
width of plastron	68.5 x 2	160	62.8	81.4	88.8
length of posterior lobe of plastron		169	60.4	77.1	87.4
total length of plastron	213 to 254 (estimated)	269	anterior lobe missing	129.3	147.6
total length of carapace			104	carapace fragmented	139

extending approximately from 120,000 to 110,000 years ago (Harland *et al.*, 1990). The turtle has also been found in deposits as recent as 12,000 years ago, which makes it contemporary with the Clovis culture of Paleo-Indians (Johnson, 1987).

Terrapene c. putnami is found as far west as eastern New Mexico (Johnson, 1987), as far north as Meade County, Kansas, eastward to southern South Carolina (Roth and Laerm, 1980) and is abundantly represented in the fossil deposits of Florida (Auffenberg, 1958; Holman, 1995). The Arkansas specimen therefore falls within this geographic range, but does represent the first verified record of the taxon for the state.

Even though *T. c. putnami* is thought to be extinct in its pure form, it is possible that it left a significant genetic contribution within the extant species, *T. c. major*. If this assumption is correct, "Pleistocene box turtles of the *Terrapene carolina* ssp complex document the intricacies and complexities of the speciation process over a geologically short period of time as much as any fossils have ever done" (Holman, 1995). Therefore, it is hoped that documentation of this specimen may contribute to a wider understanding of the spatial relationships between various units of this complex species in time and space.

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Curly-tail Malformity in Hatchlings of the Alligator Snapping Turtle, *Macroclemys temminckii* (Testudines: Chelydridae), from Northeastern Arkansas

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Despite several recent studies which advanced our knowledge on the biology of the alligator snapping turtle, *Macroclemys temminckii* (Harrel et al., 1996; Trauth et al., 1998; Tucker and Sloan, 1997), substantial information is still lacking, especially in the areas of hatchling development and ecology. In Arkansas, commercial harvesting of alligator snapping turtles has been prohibited by the Arkansas Game and Fish Commission since 1993 (Buhlmann, 1993); yet, at least nine turtle farmers have permits to rear this species. While visiting one of these farms (Pearrow/Jones turtle hatchery) near Batesville on 27 August 1999, we were shown three deformed hatchling *M. temminickii*. The hatchlings' tails were fixed in a tight spiral or coiled orientation; the unusual morphology (Fig. 1) was coined "squiggly-tail" by one of the local farmers.

Pritchard (1989) described and illustrated several defor-

Fig. 1. A. Dorsal view of a normal (left) and curly-tail hatchling (right) of *Macroclemys temminckii*. B. Ventral view of the same hatchlings (as shown in A). The yolk plugs are visible in both hatchlings.

mities found in alligator snapping turtles (e.g., hunchback), but he did not mention any type of tail deformity. Unreferenced malformities similar to the curly-tail condition were described briefly by Ewert (1979) in emydids and were documented by Ryan (1986) in Blanding's turtle, *Emydoidea blandingi*; by Kar and Bustard (1982) in the saltwater crocodile, *Crocodylus porosus*, and by Green (1966) in the house mouse, *Mus musculus*. Ewert (1979) also mentioned bent-tails in the turtle families Chelydridae and Emydidae. Bent-tails have been further reported in the blacktail rattlesnake, *Crotalus molossus* (Smith et al., 1985). Acaudal phenotypes of the common snapping turtle, *Chelydra serpentina*, have been reported by Finkler and Claussen (1997). Thus, our observation appears to be the first account to provide details on curly-tail in *M. temminckii*.

According to Mrs. Sandy Jones (caretaker of the turtle farm), about 10 instances of this deformity occur each year among 3,000 or so hatchlings at the hatchery. Turtle eggs are annually collected from the farm's nesting beach from June through July. The eggs are then transported to a nearby hatchery building and routinely incubated between 29.4° C and 32.0° C in air-tight plastic containers. Mrs. Jones indicated that at temperatures exceeding 36° C, the eggs die, whereas Pritchard (1989) indicated that *M. temminckii* eggs die at 39.4° C. Kar and Bustard (1982) suggested that tail malformities may result from unusually high incubation temperatures, while Yntema (1960) showed that unusually low incubation temperatures could result in reduced *C. serpentina* tails. Singh and Sagar (1991) found that 7 of 19 (36%) hatchlings of the Indian mugger, *Crocodylus palustris*, had bent or curled tails when incubated for a prolonged period under natural conditions due to higher incidences of rainy days and severe daily fluctuations in both temperature and humidity. Lynn and Ullrich (1950) further portrayed low humidity as a teratogenic factor in similar deformities. The alligator snapping turtle eggs had been packed in a moistened vermiculite substrate so humidity problems are an unlikely cause in the present scenario. Our hatchlings were returned to the laboratory and held in a plastic egg container for three days while they absorbed their yolk. They were then transferred to plastic containers containing 2 - 3 cm of water.

Ewert (1979) suggested that curly-tails may snag on objects as the hatchlings move about. Normal *M. temminckii* and *C. serpentina* may use the tail as a prehensile organ for
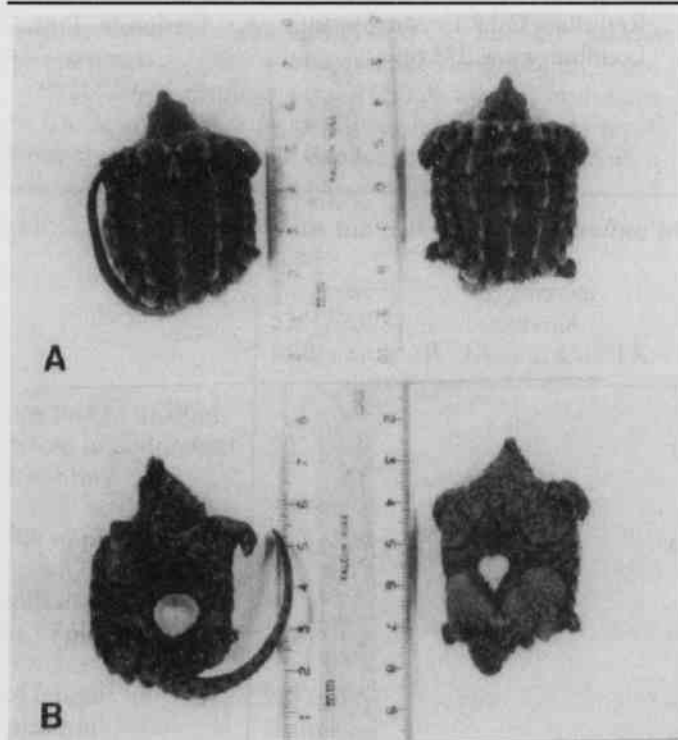
Curly-tail Malformity in Hatchlings of the Alligator Snapping Turtle, *Macroclemys temminckii* (Testudines: Chelydridae), from Northeastern Arkansas

anchoring themselves to objects on the river bottom (Brode, 1958). Curly-tailed hatchlings do not appear to possess a prehensile tail. Without its use, curly-tailed hatchlings and juveniles could easily wash downstream in swift currents where they might be more subject to predation or possibly drowning.

The curly-tail may reduce a turtle's reproductive success. Evidence suggests that the tail is used to pack dirt in the nest (Powders, 1978) and to support the female during nest excavation (Ewert, 1976). Without proper nest building skills, the female's nest may be easier for predators to find. Improper nest building could also expose the developing eggs to improper temperature and humidity. A normal tail is also essential for proper copulation (Berry and Shine, 1980).

Phenotypically acaudal juvenile *C. serpentina* required significantly more time to right themselves than did normal nest mates (Finkler and Claussen, 1997). These acaudal turtles could lift only the cranial portions of the shell. Normal individuals used both the head and the tail to flip over by lifting both the cranial and caudal ends of the shell. Curly-tailed *M. temminckii* appeared to have difficulty righting themselves; in fact, one individual was flipped over when we were initially shown them by Mrs. Jones. Curly-tailed individuals appeared unable to lift the caudal end of the shell off the substrate which appeared to contribute to their inefficiency in rolling over. Finkler and Claussen (1997) pointed out that a turtle resting on its carapace is much more susceptible to injury from predators than is a turtle resting on its plastron. They neglect to mention that flipped-over turtles that cannot right themselves are more likely to desiccate in the hot sun, or drown in shallow water.

The acaudal phenotype also compromises *C. serpentina's* ability to navigate up and down slopes (Finkler and Claussen, 1997). It is, therefore, probable that similar costs are incurred by curly-tailed *M. temminckii*. Navigation over slopes is essential for hatchling turtles finding their way to the water since water bodies are typically situated down slope from the nest and sometimes on the opposite side of a berm.

Although it is unlikely that many curly-tailed hatchlings would survive in the wild, one *M. temminckii* (unknown size) exhibiting this abnormality was reportedly observed by a local turtle trapper (Marshall Jones, pers. comm.). Survival of curly-tailed turtles would require hatchlings to exit the nest without getting entangled on eggshells, navigate down slope to the water without turning over and succumbing to predators, the sun, or drowning, and then avoid getting their tails caught on twigs and vegetation both in terrestrial and aquatic habitats. We speculate that most wild curly-tailed individuals succumb to predation before they ever enter the water.

The normal hatchling (carapace length = 37.8 mm; postanal tail length = 51.4 mm, weight = 15.97 g) and curly-

tailed specimen (carapace length = 35.8 mm, weight = 15.3 g; post-anal tail length was unobtainable as the tail could not be forcibly unwound) shown in Fig. 1 are housed in the Arkansas State University Herpetology Collection (ASUMZ 23211-12).

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First Record of the Subterranean Amphipod Crustacean
Allocrangonyx hubrichti (Allocrangonyctidae) in Arkansas

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On 6 November 1996, Mary Longley of Romance, White County, AR collected a single specimen of the subterranean amphipod, *Allocrangonyx hubrichti* Holsinger, from a water well on her property. The specimen was a mature male, measuring 16.5 mm in length (front of head to base of telson); lengths of the first antenna and third uropod were 10.0 mm and 15.0 mm, respectively. The specimen was shipped to HWR, who recognized the uniqueness of the material and forwarded it to JRH for positive determination. The specimen was originally deposited in the collection of JRH (H-3658) but has since been utilized in a DNA analysis. *Allocrangonyx* is unique among gammaridean amphipods because the first segment of the outer ramus of the third uropod of the mature male becomes secondarily segmented and greatly elongate in older specimens, sometimes becoming as long as the body and longer than the first antenna (Holsinger, 1989).

Schram and Robison (1987) provided a list of the amphipods of Arkansas but did not list the genus *Allocrangonyx* for the state. The specimen from Romance represents the first Arkansas record for this genus and brings to 12 the number of amphipod species recorded for the state. The geographic distribution of *Allocrangonyx hubrichti* is restricted to subterranean groundwater habitats in the central interior of North America. It was originally described by Holsinger (1971) from two caves in Phelps and Pulaski counties in east-central Missouri. Subsequently, Holsinger (1989) reported additional material from four caves, a natural bridge, and a spring in Phelps, Pulaski, and Washington counties, MO. Prior to its discovery in White County, AR, *A. hubrichti* was believed to be endemic to a relatively small part of east-central Missouri. However, discovery of the specimen from Romance extends the range of the species south for approximately 283 km (175 mi) and is a significant range extension for a subterranean amphipod.

In Missouri *A. hubrichti* is known from subterranean groundwater aquifers in Ordovician limestones and dolomites of the Ozark Plateaus physiographic province, specifically the Salem Plateau section. The well in Romance, AR is situated south of the Boston Mountains section. This section of the Ozark Plateaus extends east to Batesville, which lies about 64 km (40 mi) northeast of Romance. The well in Romance is drilled in the Middle Atoka Sandstone Formation of Pennsylvanian age just inside the Arkansas Valley section of the Ouachita physiographic province. The

depth of the well is 9.8 m (32 ft) and the pH is basic. The water level in the well is approximately 4.5 m (15 ft) below the surface of the ground.

The specimen from Arkansas is morphologically identical with specimens of *A. hubrichti* from Missouri. However, considering the relatively great distance (283 km) and significant changes in geomorphology between the localities in central Missouri and the one in central Arkansas, it is questionable as to whether or not these disparate populations share a common gene pool. If there is a contiguous distribution of populations between Missouri and Arkansas, diligent investigation of subterranean groundwater habitats (accessible in caves, wells and springs) should ultimately reveal new localities for this species in the intervening area and shed new light on its geographic distribution.

The only other species in the genus *Allocrangonyx* is *A. pellucidus*, which is recorded from subterranean groundwater habitats in a relatively small area of south-central Oklahoma (Holsinger, 1971; 1989). Although closely similar to *A. hubrichti* in a number of characters, this species is morphologically distinct.

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Breeding Mortality in the Wood Frog,
Rana sylvatica (Anura: Ranidae), from Northcentral Arkansas

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In order to attain maximum reproductive fitness, temperate zone anurans are inextricably dependent upon the successful completion of a suite of seasonal reproductive events. In anurans, the annual sequence includes the propagation of gametes, the location of a mate, the selection of a breeding site, the fertilization of the eggs, and the development of the eggs and young (Duellman and Trueb, 1986). To facilitate the production of offspring, one form of sexual selection, male-male competition, has evolved. This behavioral pattern has been revealed in the mating behavior of certain frog species, such as wood frogs (*Rana sylvatica*), which have relatively short, but intense breeding seasons (Berven, 1981). When male-male competition is in effect, large dominant males aggressively force smaller, less dominant males into areas where those males are less likely to find a female. In more drastic encounters, several aggressive males may clasp onto a single female forming a "mating ball" (Phillips and Wade, 1990). Apparently, these mating balls can result in the death of female wood frogs, as was observed in populations from Indiana (Phillips and Wade, 1990) and Michigan (Howard, 1980). At the Indiana breeding site, only two females were found dead, and only three females died at the Michigan site. In the following, we report on high breeding mortality in a wood frog population from northcentral Arkansas and suggest possible causes of the mortality.

Throughout its range, the wood frog, the most boreal of all the North American ranid frogs, is well known for its brief, explosive breeding activity which typically occurs in late winter or early spring (Martof, 1970). In northern Arkansas, breeding characteristically follows heavy, late winter (primarily February), rainfall (Trauth et al., 1989, 1995; Cartwright et al., 1998); wood frogs migrate to temporary or permanent pools of water (e.g., woodland ponds and man-made wildlife ponds) where oviposition of eggs occurs. At several ponds, relatively, large communal adult aggregations have been observed.

Monitoring selected wood frog breeding populations in the Sylamore Ranger District (SRD) of the Ozark National Forest of northcentral Arkansas began in 1987. Over a span of 14 years, the timing and duration of the breeding season has varied only slightly over the years (Cartwright et al., 1998). On occasion, we have observed the carcasses of a few dead wood frogs within these ponds; however, in those instances, no collection of dead frogs occurred.

On the night of 26 February 2000 a survey of a large woodland pond (commonly called Stout Pond) was conducted between 1800 and 2030 h, and a total of 140 dead adult *R. sylvatica* was found. The pond lies within a large depression in an oak-hickory forest in Stone County (T16N, R12W, S30) just south of St. Hwy 14 and ca. 1.12 km east of the Baxter-Stone county line. The pond was partially filled with water (maximum depth 40 cm) following rains on the 25th and 26th with rainfall totals of 2.44 and 3.20 cm, respectively, as recorded at Mountain View. The pond was searched repeatedly by criss-crossing and walking the perimeter during the deafening calls of approximately 850 male wood frogs. Ecological associates included spring peepers (*Pseudacris crucifer*), ringed salamanders (*Ambystoma annulatum*), spotted salamanders (*A. maculatum*), and central newts (*Notophthalmus viridescens louisianensis*). Because very few non-amplectant females were observed and because 100s of wood frog egg masses had already been laid in all areas of the pond, we assumed that most of the breeding activity had occurred on the night of the 25th. This presumption is bolstered by the condition of the dead frogs; i.e., many showed more advanced signs of morbidity than others, although some had obviously died very recently prior to collection.

The dead frogs were transported to the herpetology laboratory at Arkansas State University on the night of the 26th and were fixed in 10% formalin. Later, all specimens were transferred to 70% ethanol for permanent storage. The following body size data were gleaned from these specimens: average female snout-vent length (SVL) = 60.1 mm (range, 54.7 - 66.0 mm) in 58 of 65 individuals; average male SVL = 51.2 mm (range, 45.9 - 58.2 mm) in 67 of 75 individuals.

The condition of the specimens varied from little or no body damage to total dismemberment. Many frogs exhibited obvious signs of avian predation, and some had even been partially scavenged. The types of injuries sustained by both sexes were mostly puncture wounds which caused partial-to-complete abdominal wall rupturing in many specimens. In 40 females (61.5%), small tears or tri-cornered puncture wounds were evident in the skin just behind the

head, on the back, and laterally along the external body wall. This was accompanied by, in many individuals, a protrusion of oviducts, eggs or both from the lateral wounds. Some females were missing one or the other hind leg. We found three peculiar instances of extra-coelomic displacement of ova occurring outside of the coelomic cavity. Ova were displaced into the subcutaneous spaces in the groin, lower back , thighs, and axillary region (Fig. 1). This observation is best explained as a result of a tearing or puncturing of the abdominal wall so as to allow ova previously ovulated to move freely or to be squeezed out of the coelom and into interstitial spaces. Forty-nine males (65.3%) had similar dorsal piercing, wounds near the head and some along the back. Because several feathers (unidentifiable to species) were found floating on the surface of the water, we, therefore, tentatively conclude that an avian predator (e.g., a wading bird, Order Ciconiformes) likely caused the majority of puncture wounds.
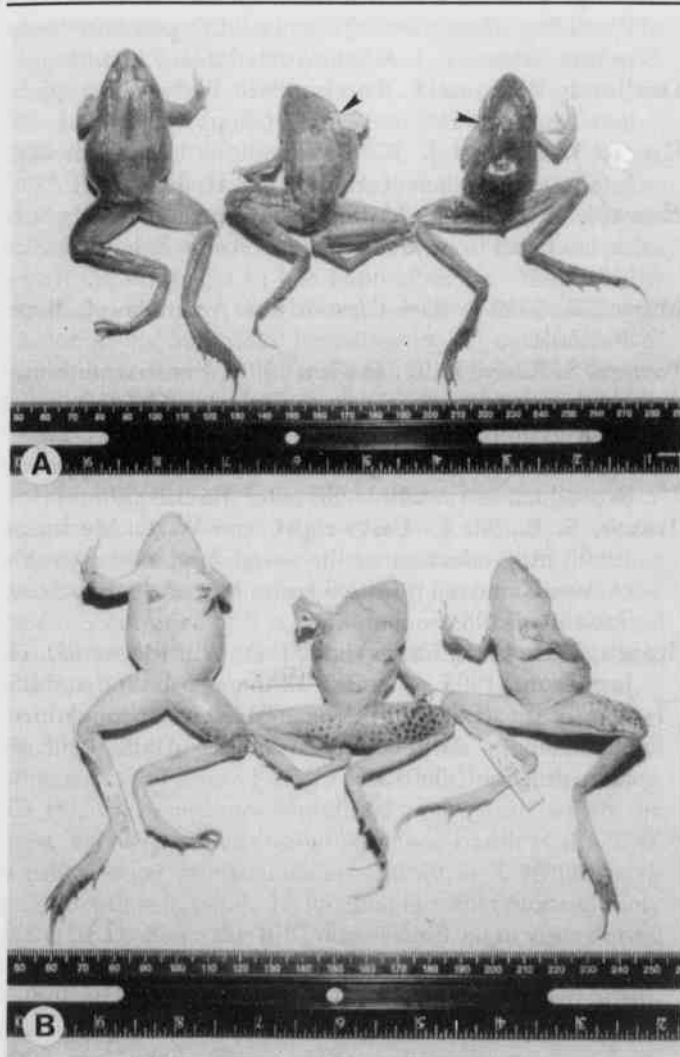
Although wood frog mortality could have resulted directly from the piercing wounds inflicted by a bird, the significance of death stemming from mating balls is the likely cause of death and cannot be over emphasized. Females that die in mating balls apparently do not reproduce, as was observed by Howard (1980) in a Michigan population (see below for comments on gravid specimens). Even though further collection data are warranted, it is probable that females weakened or dying in mating balls express lower vitality levels due possibly to agedness or pathogen/parasite exposure. This would make them highly susceptible to avian or other predators (e.g., raccoons, Trauth et al., 1995). Persistence of vitality late into life and resistence to pathogens and parasites are probably inherited traits (Greer and Baker, 1992). Weakened or diseased organisms are typically less active than healthier ones (Greer and Baker, 1992) and would be more likely to succumb to attacks by predators. Reduced activity levels can result in reduced muscle performance (Powers and Howley, 1990). Consequently, unhealthy females with reduced muscle tone would be less capable of resisting the grasp of a male or several males and, accordingly, would be less capable of avoiding predatory aquatic birds. Males who grasp weakened females "violently" during amplexus may reduce their own fitness as well if they remain amplexed with these females following the female's death.

Although it is unclear whether the male's strong grasp combined with a female's reduced strength could result in peritoneal ruptures leading to egg extrusions, 58 dead females (89.2%) were gravid (and, thus, were removed from the breeding population). In addition, four males were found amplexed to dead females. This should, coincidentally, reduce resource competition between adult frogs and between developing larvae during the ensuing summer. As stated previously, many of the observed dead females had skin ruptures in addition to extra-coelomic egg extrusions. Further data collection will be necessary in order to determine if these symptoms were initially the result from male grasping or secondarily by predators/scavengers foraging on dead or dying frogs. If egg extrusions are due to male grasping, female mortality via this mechanism may be even more prevalent than our data suggest.

Male grasping may be an effective mate health evaluative mechanism. If males are capable of recognizing female muscle tone, or female death, they could release the amplexed female (explaining the prevalence of dead

Fig. 1. Extra-coelomic eggs of *Rana sylvatica*. A. Dorsal view of specimens (left to right, ASUMZ 23638-40); arrows point to puncture wound areas. B. Ventral view of specimens in A reveals eggs lying subcutaneously in the thigh of ASUMZ 23638; in the right axillary region, groin, and thighs of ASUMZ 23639, and in the left thigh of ASUMZ 23640.

females without amplexed males) and select a new one, even if that means fighting off a currently amplectant male (explaining numerous observations in the past of multiple males amplexing single females in wood frog populations). The more capable a male is at utilizing this mechanism, the better he can avoid investing gamete currency in poor females during an explosive breeding chorus where females are plentiful and male-male competition is relatively low. Males incapable of recognizing the death of their amplectant female probably continue swimming around the pond grasping their dead mate (explaining observations of live males grasping dead females). The living male continues to grasp the female in anticipation of egg release until his energy stores are exhausted, at which time he may be pulled under the water by the dead female and drowned (explaining the observations of some dead pairs in amplexus). This scenario would be highly selective against male phenotypes incapable of recognizing the death of their amplexed mate.

The population characteristics of the wood frog chorus in our pond, though, was such that sex ratios at the onset of mating activity may have been close to 1:1 (based on the number of egg masses present). At first, this may greatly reduce male-male competition and provide the opportunity for males to evaluate females resulting in high ovipositional success. However, with the overwhelming preponderance of males (as witnessed during the second night of breeding), high male-male competition for late-breeding females likely culminated in the weakening/deaths of both sexes.

In conclusion, a total of 140 dead wood frogs (*Rana sylvatica*) was collected in a flooded, woodland depression/ pond in the Ozark National Forest of northcentral Arkansas following two days (25-26 February 2000) of heavy rains and intensive breeding activity by this species. Among the dead females, 89.2% (58 of 65) were gravid individuals; four of these females were found in amplexus with live males, and three females exhibited extra-coelomic egg extrusion. Signs of avian predation were noted (61.5 and 65.3% in females and males, respectively) and could have caused the death of some individuals. Breeding mortality in wood frogs has been reported before in the literature (northern Indiana and central Michigan) and may help explain similar unpublished observations in a Virginia population (Keith Berven, pers. comm.). The suspected cause of death in females, as suggested by previous authors, could have resulted from abdominal crushing related to the intense "mating balls" formed by multiple-amplectant males on a single female. Likewise, this type of mating behavior could also cause reduced male vitality, thus explaining the observed dead males.

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Winter Breeding as a Common Occurrence in the Ringed Salamander, *Ambystoma annulatum* (Caudata: Ambystomatidae), in the Ozark National Forest of Northcentral Arkansas

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The ringed salamander, *Ambystoma annulatum*, is a long, slender ambystomatid salamander that is endemic to the Interior Highland ecoregion of Arkansas, Missouri, and Oklahoma (Anderson, 1965; Petranka, 1998). The reproductive biology of this species has been studied relatively well within Missouri and Arkansas (Noble and Marshall, 1929; Trapp, 1956, 1959; Spotila and Beumer, 1970; McDaniel and Saugey, 1977; Brussock and Brown, 1982; Hutcherson et al., 1989; Nyman et al., 1993; Briggler et al., 1999). By all of these accounts, breeding migrations to ponds typically coincide with heavy autumnal rains which usually begin in late September; breeding activity normally ceases by mid November. The only confirmed exception to autumnal breeding in *A. annulatum* was reported by Trauth et al. (1989) from the Sylamore Ranger District (SRD) of the Ozark National Forest (Baxter County) of northcentral Arkansas; the first observation of this behavior occurred on 14 February 1987. During the intervening years since the initial winter breeding observation, my colleagues and I have observed additional records of winter breeding activity in *A. annulatum* from the same geographic region. In the following, I report on the most recent occurrence of this phenomenon in this species and summarize other instances regarding winter breeding observed over a span of 14 years.

In contrast to the initial winter breeding site (Trauth et al., 1989) which was a remarkably small, ephemeral pool (dimensions of around 3.5 m X 4.0 m; the depth was ca. 0.5 m), the temporary woodland pond from which the most recent specimens were taken (see Trauth et al., 2000) is much larger (dimensions around 30 m X 40 m; maximum depth = 0.35 m). Its location is within Stone County of the SRD. Since the 1987 observation, eight visits during the month of February to additional ponds and flooded woodland depressions within the SRD have yielded breeding ringed salamanders in four more years (1988, 1991, 1998, and 2000). Three of these observations were from the location described above. The most recent breeding incident (26 February 2000) occurred following moderate rainfall on the 25th and 26th of February. A total of 17 adults (1 male; 16 females) was collected; the breeding site is also utilized, concurrently, by a number of other amphibian species (i.e., wood frogs--*Rana sylvatica*, spring peepers--*Pseudacris crucifer*, and spotted salamanders--*Ambystoma maculatum*). Surprisingly, this woodland pond

was completely dry on 17 February 2000 as a result of a fall/winter drought (total precipitation during the preceding months of October, November, December, and January = 5.1, 3.1, 11.1, and 4.3 cm, respectively) and was nearly dry again on 17 March 2000 (February precipitation = 6.4 cm at the precipitation recording station in Mountain View, Arkansas). While returning the ringed salamanders communally in a chilled, plastic, water-filled container to the herpetology lab at Arkansas State University (on the 26th), most females began laying eggs. Egglaying continued for three days in a refrigerator and produced a combined total of 3,285 eggs which averaged 205.3 eggs per female. Females averaged 89.6 mm in snout-vent length (range, 80 - 98).

The possibility exists that these ringed salamanders were stimulated by local rainfall to migrate to breeding ponds that had previously been dry as a consequence of the lack of adequate rainfall during the normal breeding cycle the preceding fall. This hypothesis was rejected by Trauth et al. (1989) as providing the breeding stimulus for the first observation; they based their judgment on the occurrence of sufficient rainfall to fill ponds during the fall/winter months of 1986-1987. Thus, the present ringed salamanders as well as the ones of the initial discovery were not likely holdovers from the fall breeding cycle.

At present, five instances of winter breeding have been observed during February in the SRD. These data suggest that winter mating and egglaying may actually be a common phenomenon in ringed salamanders. At the present, however, it remains unclear as to why *A. annulatum* frequently breed during the winter in the SRD as well as why this observation has not been reported in other geographic areas in the Interior Highlands.

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Occurrence of a Second Subspecies of Box Turtle (*Terrapene carolina*) in Arkansas

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The three-toed box turtle (*Terrapene carolina triunguis*) is the subspecies generally accepted to occur west of the Mississippi River with a southeastern extension of the range east of the river into Mississippi and southern Alabama (Conant and Collins, 1998). The reported range of the eastern box turtle (*Terrapene carolina carolina*) extends westward into northeastern Mississippi and throughout most of Tennessee, but approaches Arkansas only in the northeast in the vicinity of Mississippi County (Conant and Collins, 1998). Carr (1952) indicated a zone of intergradation between these subspecies in western Tennessee and eastern Mississippi, but Conant and Collins (1998) indicated no zone of intergradation except with other subspecies in the extreme southeastern United States. A comprehensive examination of the distribution and taxonomy of box turtles in Arkansas is lacking at this time. The purpose of this paper is to document the discovery of a new subspecies for Arkansas.

Although the name *T. c. triunguis* implies three toes (on the hind foot), a few specimens are known to possess four toes. There is a tendency for the pattern of yellow spots on the carapace of the three-toed box turtle to be replaced by an even olive to horn color in adult specimens. The plastron generally is yellowish to horn colored with some dark markings evident in some specimens. Males have little to no concavity in the plaston. In contrast, *T. c. carolina* tends to retain a pattern of yellow spots on the carapace, often has a dark plastron, and has four toes. The rear lobe of the plastron of males has a distinct concavity (Carr, 1952; Conant and Collins, 1998).

On 26 April 1998, three specimens of box turtles, each of which possessed four toes, were collected at separate locations in southeastern Arkansas (Chicot County: Island 82, T14S R1W; Drew County: 2 mi. E Collins on Hwy 35, S32 T13S R4W; 4 mi. W Monticello on Hwy 4, S30 T12S R7W). The rear lobe of the plastron was concave on a male, and the plastrons were dark on the specimens. These traits are consistent with the appearance of the eastern box turtle and

atypical for the three-toed box turtle. The color pattern of the carapace was unusual for *T. c. triunguis*, having broad yellow blotches rather than narrow dashes or radiating lines (Fig. 1). However, this coloration is very similar to the pattern for *T. c. carolina* illustrated in various books (Carr, 1952; Ditmars, 1953; Martof et al., 1980; Ernst et al., 1994; Palmer and Braswell, 1995).
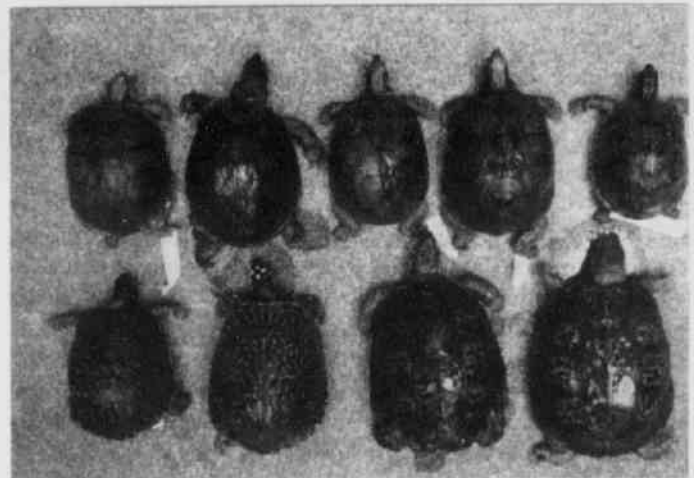
Fig. 1. A sample of sizes and patterns of adult box turtles from Arkansas, from the Henderson State University collection of vertebrates. Top row and two specimens on left of bottom row represent *Terrapene carolina triunguis*. Two specimens on right of bottom row represent *T. c. carolina*.

The new specimens from Chicot and Drew counties were appreciably larger than most three-toed box turtles in Arkansas, with an average carapace length of 149 mm (range 147-151) for the two specimens available for measurement. Carapace length averaged 114.3 mm (range 94-130) for a sample of 24 adult box turtles in the Henderson State University collection, which were obtained in 11

Arkansas counties (Ashley, Baxter, Clark, Dallas, Drew, Franklin, Garland, Hot Spring, Perry, Pike, Nevada). Of this sample, only one specimen had four toes on the hind foot (and it had been retained for that fact).

Carapace length for specimens of *T. c. triunguis* in Kansas normally range between 113-150 mm (Collins, 1993), and maximum lengths of 165 mm have been reported in Alabama (Mount, 1975) and Louisiana (Dundee and Rossman, 1989). Maximum carapace lengths of *T. c. carolina* have been given as 151 mm in Illinois (Smith, 1961), 165 mm in Alabama (Mount, 1975), and 156 mm in Virginia (Mitchell, 1994). Palmer and Braswell (1995) reported lengths of the 10 largest specimens (five of each sex, the largest being 152 mm) from North Carolina, which averaged 146.0 mm. Of these previous works, only Mitchell (1994) provided means for samples with males averaging 132.4 mm and females 130.1 mm. These values still are higher than the mean of 114.3 mm reported herein for Arkansas. However, the unusual specimens reported here are closer to these sizes, and are 35 mm longer than the average length of specimens measured from Arkansas reported herein.

The Gulf Coast box turtle, *Terrapene carolina major*, also has traits in common with the new Arkansas specimens: a concavity in the plastron and four toes on the hind foot. However, it contrasts by being considerably larger (carapace length up to 216 mm), having the pattern of adults almost obliterated, and having a flare to the posterior marginals that may produce an almost "gutter-like" appearance (Dundee and Rossman, 1989; Ernst et al., 1994; Conant and Collins, 1998).

Two of the new specimens have been examined also by Dr. S. Trauth at Arkansas State University. Based on his confirmation of the identification and data provided herein we conclude that the eastern box turtle, *T. c. carolina*, occurs in parts of southeastern Arkansas. This is based on the fact that three specimens were taken at separate locations and that all traits examined are consistent with the eastern subspecies. Normal three-toed box turtles occur sympatrically in the area. Whether our specimens may be hybrids is unclear, but no traits appeared to be intermediate to support that hypothesis. Dundee and Rossman (1989) noted that intermediates between *T. c. triunguis* and *T. c. major* seldom are seen because the two forms seem to be ecologically segregated.

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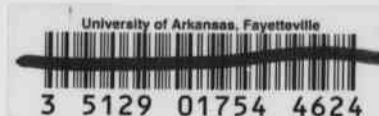
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