PAST PRESIDENTS OF THE ARKANSAS ACADEMY OF SCIENCE

Charles Brookover, 1917
Dwight M. Moore, 1932-33, 64
Flora Haas, 1934
H. H. Hyman, 1935
L. B. Ham, 1936
W. C. Munn, 1937
M. J. McHenry, 1938
T. L. Smith, 1939
P. G. Horton, 1940
L. 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. Speassard, 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

INSTITUTIONAL MEMBERS

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

ARKANSAS STATE UNIVERSITY, State University
ARKANSAS TECH UNIVERSITY, Russellville
HARDING UNIVERSITY, Searcy
HENDERSON STATE UNIVERSITY, Arkadelphia
HENDRIX COLLEGE, Conway
JOHN BROWN UNIVERSITY, Siloam Springs
MISSISSIPPI COUNTY COMMUNITY COLLEGE, Blytheville
OUACHITA BAPTIST UNIVERSITY, Arkadelphia

SOUTHERN ARKANSAS UNIVERSITY, Magnolia
UNIVERSITY OF ARKANSAS AT FAYETTEVILLE
UNIVERSITY OF ARKANSAS AT LITTLE ROCK
UNIVERSITY OF ARKANSAS FOR MEDICAL SCIENCES, Little Rock
UNIVERSITY OF ARKANSAS AT MONTICELLO
UNIVERSITY OF ARKANSAS AT FINE BLUFF
UNIVERSITY OF CENTRAL ARKANSAS, Conway
UNIVERSITY OF THE OZARKS, Clarksville

EDITORIAL STAFF

EDITOR: STAN TRAUTH, Dept. of Biological Sciences, Arkansas State University, State University, AR 72467-0599.
BIOTA EDITOR: DOUGLAS A. JAMES, Dept. of Biological Sciences, University of Arkansas at Fayetteville, Fayetteville, AR 72701.
ASSOCIATE EDITORS:
ED BACON, (UA-Monticello)
GEORGE L. HARP, (ASU)
FRANK SETLIFE, (UALR)
MOSTAPA HEMMATI, (Ark. Tech)
ROBERT ENGELKEN, (ASU)
LARRY HINCK, (ASU)
SCOTT REEVE, (ASU)
JAMES H. PECK, (UALR)

COVER: Alligator snapping turtle (Macroclemys temminckii) from Jackson Co., AR. Photo by Stan Trauth.
FIRST BUSINESS MEETING
7 APRIL 1995

Number present: 20

President James Peck opened the meeting at 1115.

1. Peck recognized Local Arrangements Chair Clifton Orr to announce specifics regarding the meeting. Orr introduced Dr. William Willingham, Dean of Science & Technology (UAPB) to extend a formal welcome. Willingham invited the Academy, recognized the organization on its work in the state and complimented the number of students involved in the Academy's activities.

2. Peck recognized Secretary Rickett who presented the minutes from the two 1994 Business Meetings and asked for additions and corrections. Rickett moved (2nd: Robison) for approval of the minutes.

3. Peck recognized Historian Robison who stated that this is the 79th Annual Meeting of the Academy and the first one at UAPB.

4. Peck recognized Treasurer Wiley who presented the Treasurer's report and briefly reviewed operating accounts, investments, income, and expenses. Wiley moved (2nd: Peck) the Treasurer’s report be accepted, pending examination by the Auditing Committee. Wiley also moved (2nd: Peck) approval of the dues restructuring plan that was approved by the Executive Committee to increase associate membership to $15, regular to $30, sustaining to $35, and sponsoring to $45.

FINANCIAL STATEMENT, ARKANSAS ACADEMY OF SCIENCE

INCOME: 1 January 1994 to 31 December 1994

1. INDIVIDUAL MEMBERSHIPS
   a. Regular 2,505.00
   b. Sustaining 400.00
   c. Sponsoring 180.00
   d. Life 425.00
   e. Associate 330.00
   Totals 3,840.00

2. INSTITUTIONAL MEMBERSHIPS
   Totals 1,800.00

3. PROCEEDINGS, LIBRARY SUBSCRIPTIONS
   Totals 900.00

4. PROCEEDINGS, MISC. SALES (UAF)
   Totals 2,923.10

5. PROCEEDINGS, PAGE CHARGES
   Totals 3,887.50

Funds

Beginning Balance - 1 January 1994 22,874.24
Total Income (Page 2) 15,445.63
Total Expenses (Page 3) 14,413.98
Balance for the Year $1,031.65
CLOSING BALANCE - 31 DECEMBER 1994 $23,905.89

DISTRIBUTION OF ACCOUNTS

Interest Bearing Checking Account (Union Bank and Trust Co., Monticello, AR) 4,164.94
Dwight Moore Endowment (Heritage Bank - A Federal Savings Bank - Monticello - No. 506698.1 - 3.85% Int.) 2,410.77
Life Membership Endowment (Heritage Bank - A Federal Savings Bank - Monticello - No. 506660.1 - 3.85% Int.) 9,704.55
AAS Endowment (Heritage Bank - A Federal Savings Bank - Monticello - No. 509942.0 - 4.35% Int.) 6,125.00
AAS General 1 (Heritage Bank - A Federal Savings Bank - Monticello - No. 509959.0 - 4.35% Int.) 1,500.00

TOTAL $23,905.89

Respectfully Submitted

Robert W. Wiley, AAS Treasurer

Proceedings Arkansas Academy of Science, Vol. 49, 1995
6. ANNUAL MEETING
1,132.02

7. INTEREST
- Interest Bearing Checking Account 99.63
- Dwight Moore Endowment 78.34
- Life Membership Endowment 401.53
- AAS Endowment 133.51

713.01 713.01

9. ENDOWMENT DONATIONS
- Dwight Moore Endowment 225.00
- AAS Endowment 25.00

250.00 250.00

TOTAL INCOME $15,445.63

FINANCIAL STATEMENT, ARKANSAS ACADEMY OF SCIENCE

EXPENSES: 1 January 1994 to 31 December 1994

1. AWARDS
- Arkansas Science Fair Association (#630) 400.00
- Arkansas Junior Academy of Science (#632) 250.00
- Jason Kilgore (#633) 50.00
- James J. English (#634) 25.00
- Michael J. Boyd (#635) 25.00
- Chris Poole (#636) 50.00
- Kimberly R. Jones (#637) 25.00
- Elsie Williams (#638) 25.00
- John Peck, Plaques - Arkansas Science Talent Search (#626) 164.30

1,014.30 1,014.30

2. PROCEEDINGS
- Stan Trauth, Editorial Consultancy and Travel Vol. 47 (#627) 200.00
- Creative Multigraphics (Vol. 47) (#631) 11,048.63
- Creative Multigraphics (Vol. 47) (#639) 1,112.63
- Joy Trauth, Editorial Consultancy Vol. 48 (#640) 500.00

12,861.26 12,861.26

3. OFFICE EXPENSES
- Secretary's Office, John Rickett (#641) 425.47

4. NEWSLETTERS
- UAM School of Forest Res. (#626) 39.55

6. DUES
- National Association of Academies of Science (#625) 52.50

7. SERVICE CHARGES (Union Bank) 19.90

TOTAL EXPENSES $14,413.98

5. Peck recognized Proceedings Editor Trauth who presented Volume 48 of the Proceedings, saying production was fairly smooth and asked individuals to carry extra copies back to their institution or agency, thus saving the Academy some postage expense. Trauth moved (2nd: Harp) the appropriation of $500 for editorial assistance and $200 for travel. Trauth also announced the intended sale of extra copies to non-members for $15 at this meeting. He reminded authors to give manuscripts intended for publication to section chairs and announced that the ExCom approved increasing page charges to $40.

6. Peck recognized Newsletter Editor Saugey who reported that he had learned a lot preparing the newsletters during the past year. He requested information suitable to be published in the Newsletter and moved (2nd: Robison) the appropriation of $1500 to support production of the Newsletter in the event we have to sue commercial facilities.

7. Peck announced, in the absence of Heidt, that the Nominating Committee has submitted Rose McConnell and James Daly as nominees for next year's Vice President. He called for nominations from the floor, but none came.

8. Peck recognized Jim Edson, Chair of the Science Education Committee who reported that his committee and ASTA are being brought into a closer working relationship in the review process of science teacher certification and will try to better keep up with the Systemic Science Initiative.

9. Peck appointed the Auditing Committee: Robert L. Watson, Chair, Tom Palko, and James Peck.

10. Peck announced the Resolutions Committee is being formed.

11. Peck recognized Doug James who reported on activities of the Biota Committee. Leo Paulissen's original 49 lists are now on diskette ready to be proofread and sent to specialists for comment. He requested the submission of new lists.

12. Peck announced the Development Committee will be chaired by Dick Kluender and will generate ideas for obtaining outside support.

13. Peck read a note from John Peck who is requesting $230 to support the Arkansas Science Talent Search and is asking to be replaced as its director (he has taken a position at Children's Hospital) (see Appendix A for a full report).

14. Peck recognized Palko who stated he will give his report at the Second Business Meeting.

15. Peck read a note from Robert Skinner requesting $250 to support the Junior Academy and from Mike Rapp requesting $450 to support the State Science
Fair for the coming year. Motion to approve was made by Peck (2nd: Dorris) (see Appendix B for Rapp's report).

16. Peck announced the ExCom had approved the list of judges.

17. Peck announced the 1996 meeting will be at Westark Community College, but we will not be officially meeting with the Oklahoma Academy of Science, as previously suggested. The meeting will be held the second weekend in April, and arrangements are in progress.

18. Peck recognized Kluender who extended an invitation for the 1997 meeting at University of Arkansas at Monticello. Peck stated the ExCom will most likely accept that invitation.

19. Peck urged members to pick up their and absent colleagues' copies of Proceedings -- will save lots of postage.

20. Peck recognized Trauth who proposed developing an annotated bibliography of vertebrate zoology from the first 49 volumes of the Proceedings and asked if the Academy would be willing to help defray the cost of publication. It would occupy approximately 20-22 pages in the next issue, and the waived page charges would be valued approximately $800. Trauth stated a formal motion (2nd: Saugey). Considerable discussion followed regarding the specific format and content of such a document. General consensus was that such an index should include all papers.

21. At 1155, Peck sought a motion to adjourn, which was provided by G. Harp, and the meeting adjourned.

SECOND BUSINESS MEETING
8 APRIL 1995

Number present: 42
President Peck called the meeting to order at 1208.

1. Peck recognized Rickett who stated no changes to the minutes of the 1994 Business Meetings had been received. Motion to accept them passed.

2. Peck recognized Wiley who briefly reviewed Treasurer's report again and explained how the bill for printing the Proceedings is paid for. Peck read the Auditing Committee's report:

"The Auditing Committee, after careful examination, found the financial records of the Academy as proposed by Treasurer Robert Wiley to be accurate and in good order." (—Robert Watson, Chair, Tom Palko and James Peck)

The motion to accept the Treasurer's report was approved.

3. Peck recognized Rickett to reread the several motions for financial support:

Trauth: $500 editorial assistance plus $200 expenses
Saugey: $1500 for Newsletter
John Peck: $230 for Arkansas Science Talent Search
Skinner: $250 for Junior Academy of Science
Rapp: $450 for State Science Fair
Total: $2,930

Motion passed as a group.

4. Peck recognized Rickett to review the dues increase motion -- no other discussion came forward, and the motion was approved.

5. Peck reviewed Trauth's proposal to produce a bibliography and appointed an ad hoc committee of Stan Trauth, Walt Godwin, Gary Heidt, George Harp and John Rickett to determine how to proceed.

6. Peck recognized Palko who reported on the Junior Science and Humanities Symposium. JSHS recently held its 29th Annual Meeting, hosting 115 students and 32 teachers; 75 papers were given, and 16 were selected as winners. Meeting activities included research presentations, seminars, tours, and a field trip to Heifer International. Winners received scholarships and trips. Kellyn Booth (LR Central High) was selected as the outstanding presenter and will compete at the National JSHS meeting for an expense-paid two-week trip to the International Fortnight in London, England. The title of her winning paper was "Effects of Fe, Mn, and Zn 3,5 di-isopropylsalicylate chelates on procine heart disphorase". Gary Hufford was her teacher and sponsor and received a certificate and $300 prize.

7. Peck recognized the officers of the Academy, first year members and life members.

8. Peck then conducted the election of Vice President.
Rose McConnell and James Daly were nominated by the Nominating Committee. No nominations came from the floor, ballots were distributed, and James Daly was elected Vice President.

9. Peck recognized Mike Matthews, Chair of the Resolutions Committee, to read the resolutions (see Appendix C).

10. Peck announced the 1996 meeting will be at Westark Community College, and Kluender has invited the 1997 meeting to the University of Arkansas at Monticello.

11. Peck recognized Rebecca Lockmann, Awards Committee Chair, who stated that 27 presentations were judged for an award. Winners in the several categories are given in Appendix D.

12. Peck recognized Orr for a report on the success of the meeting. There were 179 registrants and 97 banquet attendees. Ninety-four papers, including 60 student papers, were presented.

13. Peck asked for additional old business, but none came.

14. Peck then asked for any new business, with the same result.

15. Peck asked for final announcements —
   a. Pick up Proceedings and deliver appropriately
   b. Submit manuscripts to Trauth or Section Chairs
   c. Trauth announced page charges will be increased to $40, beginning with volume 49. Johnson asked what the cost per page has been. Wiley responded: $71-80 per page for last 10 years. Page charges have been at their current level for about that time also. Motion (Trauth; 2nd: Johnson) passed.

16. President Peck’s farewell speech extended thanks to the officers and Academy members who have helped make his year as President a success. He then called Peggy Rae Dorris to the front and presented the gavel to her as the new President.

17. President Dorris’s inaugural speech consisted of a couple of jokes, quite appropriate to the occasion.

18. President Dorris called for any new business, and hearing none, adjourned the meeting at 1250 hrs.

--- Respectfully submitted,
John Rickett, Secretary

APPENDIX A

ARKANSAS ACADEMY OF SCIENCE

Following are the winners of the 44th Annual Arkansas Science Talent Search 1994-95, held in conjunction with the 54th Annual Westinghouse Science Talent Search.

FIRST PLACE
Ruth Christine Plymale “Insects as Water Quality Indicators”
4308 Southridge
Fort Smith, AR 72916
Greenwood High School
Sponsor: Ms. Debbie Bilyeu

SECOND PLACE
Jonathan Paulk Brasher “A Characterization of Convergent Harmonic-Type Infinite Series”
10508 Meandering Way
Fort Smith, AR 72903
Arkansas School for Math & Sciences
Sponsor: Dr. Irina Lyublinskays

THIRD PLACE (TIE)
John Derrick Marker “Holographic Interferometry of Crystalline Structural Defects and Impurities in Glass”
100 Whittington Avenue
Hot Springs, AR 71901
Arkansas School for Math & Sciences
Sponsor: Dr. Irina Lyublinskays

THIRD PLACE (TIE)
Kyle Stuart Cranmer “Communication with Brain Waves”
100 Whittington Avenue
Hot Springs, AR 71901
Arkansas School for Math & Sciences
Sponsor: Ms. Annice Steadman

HONORABLE MENTION
Rani Larissa Croager “The Pythagorean Theorem”
79 Woodlore Circle
Little Rock, AR 72211
Little Rock Central High School
Sponsors: Ms. Page Daniel • Ms. Gracie Mays

HONORABLE MENTION
Douglas William Shields “Pattern of the Giants”
202 Franklin Street
Harrison, AR 72601
Arkansas School for Math & Sciences
Sponsor: Dr. Irina Lyublinskays
APPENDIX B

ARKANSAS ACADEMY OF SCIENCE

Thank you for the support the Academy has provided for the past 12 years, both in terms of members of the AAS serving as judges and in terms of contributions. This memo serves as a report of the Science Fairs and Junior Academy of Science meetings held in Arkansas during 1995:

Regional Science Fairs:

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th># Directors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>UAMS</td>
<td>11 Mar</td>
<td>301</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Jane Meadows, Margie Snider, Marian Douglas</td>
</tr>
<tr>
<td>Northcentral</td>
<td>Lyon College</td>
<td>24 Mar</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Veryl Board, Kathy Campbell</td>
</tr>
<tr>
<td>Northeast</td>
<td>ASU</td>
<td>date(?)</td>
<td>193</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Larry Mink, David Gillanders, Ron Johnson</td>
</tr>
<tr>
<td>Northwest</td>
<td>U of A</td>
<td>date(?)</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>John Hehr, Lynne Hehr</td>
</tr>
<tr>
<td>Southcentral</td>
<td>HSU</td>
<td>date(?)</td>
<td>162</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>John Hardee, Wayne Everett</td>
</tr>
<tr>
<td>Southeast</td>
<td>UAM</td>
<td>date(?)</td>
<td>268</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Guy Nelson</td>
</tr>
<tr>
<td>Southwest</td>
<td>SAU</td>
<td>date(?)</td>
<td>634</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carson Davis</td>
</tr>
<tr>
<td>Westcentral</td>
<td>ASMS (H. Springs)</td>
<td>date(?)</td>
<td>262</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Annice Steadman</td>
</tr>
</tbody>
</table>

The State Science Fair will be held April 7 and 8 at UCA, to date, 306 students (283 projects) have been registered, and 77 students have applied to present papers at the Junior Academy of Science meeting. Bob and Raynell Skinner are co-directors of the Junior Academy.

Mike Rapp

APPENDIX C

1995 MEETING OF THE
ARKANSAS ACADEMY OF SCIENCE

RESOLUTIONS

BE IT RESOLVED, that we, the members of the Arkansas Academy of Science, offer our sincere thanks to the University of Arkansas at Pine Bluff for hosting the 1995 meeting of the Arkansas Academy of Science. In particular, we thank the local arrangements committee for an outstanding job of organizing the meeting: Clifton Orr (Chairperson), Richard B. Walker, Rebecca Lochmann, David Lickleig, Komalan Jairaj, Mattie M. Glover, Miriam M. Glass, Michael A. Preston, Lawrence D. Fitz, Floristine Lovett and students from the Minority Access to Research Careers Program, Minority Biomedical Research Support Program and Mentor Advocate Program. Appreciation is expressed for the use of UAPB's facilities and the hospitality shown members of the Academy by UAPB personnel. The banquet was excellent, as was the presentation on "Science Education and Research for the 21st Century" by Dr. Juther S. Williams, Assistant Director for Education & Human Resources of the National Science Foundation.

The Academy recognizes the important role played by the various section chairpersons and expresses appreciation to: Roger Koepe, II and Richard B. Walker (Chemistry and Chemical Engineering I); Lynita Cooksey (Zoology); Keith Hundson (Physics, Mathematics and Engineering I); Nick Brown (Ecology and Environmental Science); Joseph Igietseme (Biomedical Sciences and Microbiology); Felix Tendeku and W.J. Braithwaite (Physics, Mathematics and Engineering II); Janet Lanza and Richard Meyer (Botany); Rebecca Lochmann and Joseph W. Stoeckel (Fisheries and Aquatic Biology); C. Bhuvaneswaran (Chemistry and Chemical Engineering II) and Shelton Fitzpatrick (Science Education).

A special thanks is owed the individuals who devoted considerable time and energy to judging student papers: Ali Shaikh, Bill Taylor, Frank Setliff, Susan Cady, Uttam Jagwani, Mansour Mortazavi, Aslam Chowdhury, Mohammad Miah and Mostafa Hemmati (Physical Sciences); Gaston Griggs, Joseph Igietseme, David Lortz, Peggy Rae Dorris, Victoria McDonald, David Jamieson, John Rupe, Yanfei Guo, Jameel Al-Khayri, Rebecca Lockmann, and Ron Johnson (Biological Sciences).

We express gratitude to the various directors of the science and youth activities which are supported by the Academy: Jim Edson (Chair, Science Education Committee); Mike Rapp (President, Arkansas State Science Fair Association); Tom Falko (Director, Junior Science and Humanities Symposium); John Peck (Director, Arkansas/Westinghouse Science Talent Search); and Robert and Raynell Skinner (Co-Directors, Arkansas Junior Academy of Science).

We wish to thank all those individuals who served as directors at Science Fairs and Junior Academy Meetings: Jane Meadows, Margie Snider and Marian Douglas (Central Region); Veryl Board (North Central Region); Larry Mink, David Gillanders and Ron Johnson (Northeast Region); John Hehr, Lynne Hehr (Northwest Region); John Hardee, Wayne Everett (South Central Region); Guy Nelson, Deborah Phillips (Southeast Region); Carson Davis (Southwest Region); Annice Steadman (West Central Region); Michael Rapp, Bob
The continued success of the Academy is due to its strong leadership. We offer thanks to our officers for another excellent year: James Peck (President), Peggy Rae Dorris (President-Elect), Richard Kluender (Vice President), John Rickett (Secretary), Robert Wiley (Treasurer), George Harp (Past President), Stan Trauth (Proceedings Editor), David Saugey (Newsletter Editor) and Henry Robison (Historian). In addition, the Academy expresses appreciation to all those individuals who have contributed their time and efforts on various committees of the Academy.

Finally, we congratulate all those who presented papers and posters 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.

Resolution Committee

Michael Matthews, Chairperson

Joyce Hardin

Lawrence M. Mwasi

APPENDIX D

ARKANSAS ACADEMY OF SCIENCE

PAPER PRESENTATION AWARDS, 8 APRIL 1995

Physical Science - undergraduate:
First: Delaney Kinchen, UAM, “Synthesis of pepstain analogs for proteinase inhibition”
Second: Sue Ellen McCloskey, UALR, “An introductory module for students of Monte Carlo modeling”
Third: Crissy Patterson, UAM, “Preparation of 13C-labeled leupeptin”

Physical Science - graduate:
First: Anthony Jude, UAF, “Effects of beta-branched amino acids at positions 10, 12, and 14 of gramicidin channels”
Second: Doug Maulden, UALR, “Energy-loss particle identification in 2-D silicon drift detectors”
Third: Chris Smith, UALR, “Design and construction of a small arms propellant test unit”

Biological Science - undergraduate:
First: Jennifer Burks, UALR, “Pollination biology of Passiflora”
Second: Brian Bean, Hendrix, “Mutational analysis of an idiosyncratic domain of the Neurospora mitochondrial tyrosyl-TRNA synthetase involved in group I intron splicing”
Third: David Eller, HSU, “A study involving the detour problem in toads (Bufo woodhousei)”

Biological Science - graduate:
First: Austin Richards, ASU, (he gave two papers, and it wasn’t specified which won the award)
Second: Gina Trebilcock: UAMS, “Immune dysregulation in aging: role of NFkB”
Third: William Posey, II, ASU, “Selected community characteristics of freshwater mussels (Unionacea) in the St. Francis River, Arkansas”

The following students received honorable mention:
Physical Science: Amber Climer, UALR; Steven Young, ATU; Arif Raza, ASU; Joshua Loeske, UAM; Tim Bullard, UALR

Life Science: Ronald Rambo, ATU; Billy Vann, Caddo Hills High School

----- Rebecca Lochmann, Chair
Judges Panel

---

Proceedings Arkansas Academy of Science, Vol. 49, 1995
<table>
<thead>
<tr>
<th>FIRST NAME</th>
<th>LAST NAME</th>
<th>INSTITUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Khayri</td>
<td>Jamed M.</td>
<td>University of Arkansas/Fayetteville</td>
</tr>
<tr>
<td>Isaac</td>
<td>Robert</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Baker</td>
<td>Max L.</td>
<td>University of Arkansas/Medical Sciences</td>
</tr>
<tr>
<td>Bell</td>
<td>Kenneth M.</td>
<td>El Dorado Public Schools</td>
</tr>
<tr>
<td>Ballosier</td>
<td>William H.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Barber</td>
<td>Gwen</td>
<td>Arkansas Tech University</td>
</tr>
<tr>
<td>Battles</td>
<td>Les</td>
<td>Arkansas Tech University</td>
</tr>
<tr>
<td>Beadles</td>
<td>John Kenneth</td>
<td>Arkansas State University -- retired</td>
</tr>
<tr>
<td>Bennett</td>
<td>J. Edward</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Bhuvanawaran</td>
<td>C.</td>
<td>University of Arkansas/Medical Sciences</td>
</tr>
<tr>
<td>Bragg</td>
<td>Jimmy D.</td>
<td>Henderson State University</td>
</tr>
<tr>
<td>Bramlett</td>
<td>Ann T.</td>
<td>Garland County Community College</td>
</tr>
<tr>
<td>Breen</td>
<td>David</td>
<td>University of Arkansas at Monticello</td>
</tr>
<tr>
<td>Brown</td>
<td>Art</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>Brown</td>
<td>William D.</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Brown</td>
<td>Nick</td>
<td>University of Arkansas at Monticello</td>
</tr>
<tr>
<td>Buchanan</td>
<td>Roger A.</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Buchanan</td>
<td>Thomas</td>
<td>Westark Community College</td>
</tr>
<tr>
<td>Burnsides</td>
<td>Gaylen</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Cady</td>
<td>Susan</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Cartwright</td>
<td>Michael E.</td>
<td>Arkansas Game &amp; Fish Commission</td>
</tr>
<tr>
<td>Chapman</td>
<td>Stanley L.</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Chowdhury</td>
<td>Aslam H.</td>
<td>University of Arkansas at Pine Bluff</td>
</tr>
<tr>
<td>Cisar</td>
<td>Cindy</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Clayton</td>
<td>Frances E.</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>Cloud</td>
<td>Betty G.</td>
<td>U.S. Forest Service</td>
</tr>
<tr>
<td>Collins</td>
<td>Joseph T.</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>Cordova</td>
<td>Lynadia</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Crisp, Jr.</td>
<td>Robert M.</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Crump</td>
<td>Betty</td>
<td>U.S.D.A. Forest Service</td>
</tr>
<tr>
<td>Culwell</td>
<td>Donald</td>
<td>University of Central Arkansas</td>
</tr>
<tr>
<td>Dalske</td>
<td>Fred</td>
<td>University of Central Arkansas</td>
</tr>
<tr>
<td>Daniels</td>
<td>James T.</td>
<td>University of Arkansas at Tech Br.</td>
</tr>
<tr>
<td>Davis</td>
<td>Jerry W.</td>
<td>USDA, Forest Service</td>
</tr>
<tr>
<td>DeRoschers</td>
<td>Patrick</td>
<td>Univ. of Central Arkansas</td>
</tr>
<tr>
<td>Dennis</td>
<td>Peggy Rae</td>
<td>Henderson State University</td>
</tr>
<tr>
<td>Douglas</td>
<td>Marian</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Duhart</td>
<td>Benjamin T.</td>
<td>University of Arkansas at Pine Bluff</td>
</tr>
<tr>
<td>Dunn</td>
<td>Jane</td>
<td>Henderson State University</td>
</tr>
<tr>
<td>Dussourd</td>
<td>David</td>
<td>University of Central Arkansas</td>
</tr>
<tr>
<td>Edwards</td>
<td>Richmond</td>
<td></td>
</tr>
<tr>
<td>Eichenberger</td>
<td>Rudolph J.</td>
<td>University of Central Arkansas</td>
</tr>
<tr>
<td>Eldridge</td>
<td>Hudson B.</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>Engeln</td>
<td>Robert</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>England</td>
<td>Don</td>
<td>Harding University</td>
</tr>
<tr>
<td>Epperson</td>
<td>Claude E.</td>
<td>University of Arkansas/Medical Sciences</td>
</tr>
<tr>
<td>Filer</td>
<td>E. Kim</td>
<td>University of Arkansas/Medical Sciences</td>
</tr>
<tr>
<td>Fijan</td>
<td>Nikola</td>
<td>University of Arkansas at Pine Bluff</td>
</tr>
<tr>
<td>Fitzpatrick</td>
<td>Sholdon</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>Ford</td>
<td>E. P. (Perk)</td>
<td>U.S. Public Health Service</td>
</tr>
<tr>
<td>Forrest</td>
<td>Richard</td>
<td></td>
</tr>
<tr>
<td>Foti</td>
<td>Thomas L.</td>
<td>Natural Heritage Commission</td>
</tr>
<tr>
<td>Freeman</td>
<td>Donald W.</td>
<td>USDA-University of Arkansas at Pine Bluff</td>
</tr>
<tr>
<td>Freiley</td>
<td>Kenneth</td>
<td>University of Central Arkansas</td>
</tr>
<tr>
<td>Gagen</td>
<td>Charlie</td>
<td>Arkansas Tech University</td>
</tr>
<tr>
<td>Gentry</td>
<td>Joe P.</td>
<td>Arkansas Science &amp; Technology Authority</td>
</tr>
<tr>
<td>Getz</td>
<td>Elizabeth M.</td>
<td>University of Central Arkansas</td>
</tr>
<tr>
<td>Gildeith</td>
<td>Wayne</td>
<td>Southern Arkansas University</td>
</tr>
<tr>
<td>Gilmore</td>
<td>David F.</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Goforth</td>
<td>R. R.</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Gray</td>
<td>Wayne L.</td>
<td>University of Arkansas/Medical Sciences</td>
</tr>
<tr>
<td>Grimes</td>
<td>Reid</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>Griggs</td>
<td>Gaston</td>
<td>John Brown University</td>
</tr>
<tr>
<td>Guo</td>
<td>Yanfei</td>
<td>University of Arkansas at Monticello</td>
</tr>
<tr>
<td>Hanbrink</td>
<td>Earl L.</td>
<td>Appalachian State University -- retired</td>
</tr>
<tr>
<td>Harris</td>
<td>John L.</td>
<td>Arkansas Highways &amp; Transportation Dept.</td>
</tr>
<tr>
<td>Harvey</td>
<td>Michael J.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Hawke</td>
<td>Roger M.</td>
<td>Arkansas Tech University</td>
</tr>
<tr>
<td>Hemmati</td>
<td>Mostafa</td>
<td>Westark Community College</td>
</tr>
<tr>
<td>Henderson</td>
<td>Stanley</td>
<td>Arkansas Tech University</td>
</tr>
<tr>
<td>Herbert</td>
<td>Kristine</td>
<td>Black River Technical College</td>
</tr>
<tr>
<td>Hibbourn</td>
<td>Larry R.</td>
<td></td>
</tr>
<tr>
<td>LAST NAME</td>
<td>FIRST MI</td>
<td>INSTITUTION</td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>Moore</td>
<td>Clementine</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Northrop</td>
<td>Gaylord M.</td>
<td>Arkansas Tech University</td>
</tr>
<tr>
<td>Palko</td>
<td>Tom</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Peck</td>
<td>James H.</td>
<td>University of Central Arkansas</td>
</tr>
<tr>
<td>Rapp</td>
<td>Michael W.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Rickett</td>
<td>John D.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Robison</td>
<td>Henry W.</td>
<td>Southern Arkansas University</td>
</tr>
<tr>
<td>Saugy</td>
<td>David A.</td>
<td>U. S. Forest Service</td>
</tr>
<tr>
<td>Sewell</td>
<td>Stephen A.</td>
<td>University of Mississippi</td>
</tr>
<tr>
<td>Speairs</td>
<td>Betty M.</td>
<td>Ouachita Mtns. Biological Station</td>
</tr>
<tr>
<td>Speairs</td>
<td>Richard K.</td>
<td>Ouachita Mtns. Biological Station</td>
</tr>
<tr>
<td>Templeton</td>
<td>George E.</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Tucker</td>
<td>Gary</td>
<td>FTN Associates</td>
</tr>
<tr>
<td>Wickliff</td>
<td>James L.</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Wiley</td>
<td>Robert W.</td>
<td>University of Arkansas at Monticello</td>
</tr>
</tbody>
</table>

**STUDENT MEMBERS**

<table>
<thead>
<tr>
<th>FIRST NAME</th>
<th>LAST NAME</th>
<th>INSTITUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akin</td>
<td>Jennifer</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Allen</td>
<td>Michelle</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Ashburn</td>
<td>Charles</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Baber</td>
<td>Connie</td>
<td>Henderson State University</td>
</tr>
<tr>
<td>Bangs</td>
<td>Gene Lee</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Bearden</td>
<td>Stacy Lee</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Brar</td>
<td>Moharjeet Singh</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Bray, Jr.</td>
<td>James R.</td>
<td>Henderson State University</td>
</tr>
<tr>
<td>Caster</td>
<td>Paul</td>
<td>Univ. of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Clark</td>
<td>Murray R.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Climer</td>
<td>Amber</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Davis</td>
<td>Angela Wynette</td>
<td>University of Arkansas at Pine Bluff</td>
</tr>
<tr>
<td>Dukes</td>
<td>Rebecca</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Elder</td>
<td>Ginger</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Eller</td>
<td>David</td>
<td>Henderson State University</td>
</tr>
<tr>
<td>Ezell</td>
<td>Thomas</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Flores</td>
<td>Kenda</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Freeman</td>
<td>Leah</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>George</td>
<td>Steven G.</td>
<td>Northeast Louisiana University</td>
</tr>
<tr>
<td>Gillum</td>
<td>Russell</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Hader</td>
<td>Neena</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Hansen</td>
<td>Debra</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Harris</td>
<td>Kristi</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>House</td>
<td>Kelly L.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Howe</td>
<td>Wilson</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Isenberg</td>
<td>Seth B.</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Illes</td>
<td>Denise</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Jones</td>
<td>Kimberly Rheae</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Khan</td>
<td>Imran</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>King</td>
<td>Chris</td>
<td>University of Arkansas</td>
</tr>
<tr>
<td>Martin</td>
<td>Randy</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Mauldin</td>
<td>Doug</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>McCluskey</td>
<td>Sue Ellen</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Metcalf</td>
<td>Chris</td>
<td>Northeast Louisiana University</td>
</tr>
<tr>
<td>Moore</td>
<td>Matthew T.</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Moore</td>
<td>Donna</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Murai</td>
<td>Kaz</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Persons</td>
<td>Cecil C.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Pringle</td>
<td>John</td>
<td>University of the Ozarks</td>
</tr>
<tr>
<td>Richards</td>
<td>Austin B.</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Sanchez</td>
<td>Carlos</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Smith</td>
<td>Jerome V.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Smith</td>
<td>Anna</td>
<td>Henderson State University</td>
</tr>
<tr>
<td>Smith</td>
<td>Chris S.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Snider</td>
<td>D. H.</td>
<td>University of Arkansas at Little Rock</td>
</tr>
<tr>
<td>Stickel</td>
<td>Sara</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Townsend</td>
<td>Teddy L.</td>
<td>University of Central Arkansas</td>
</tr>
<tr>
<td>Whitehead</td>
<td>Greg A.</td>
<td>Henderson State University</td>
</tr>
<tr>
<td>Williams</td>
<td>Gregg R.</td>
<td>Arkansas State University</td>
</tr>
<tr>
<td>Withgott</td>
<td>James H.</td>
<td>University of Arkansas at Fayetteville</td>
</tr>
<tr>
<td>Yang</td>
<td>Zibin</td>
<td>University of Arkansas at Little Rock</td>
</tr>
</tbody>
</table>
**PROGRAM**
Arkansas Academy of Science
Seventy-Ninth Annual Meeting
April 7-8, 1995
University of Arkansas at Pine Bluff

**SCHEDULE OF EVENTS**

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friday, April 7, 1995</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Executive Committee</td>
<td>8:30 a.m. - 10:30 a.m.</td>
<td>Research Center, Board Room</td>
</tr>
<tr>
<td>Registration</td>
<td>10:00 a.m. - 2:00 p.m.</td>
<td>HPER, Lobby</td>
</tr>
<tr>
<td>First Business Meeting</td>
<td>11:00 a.m. - 12:00 p.m.</td>
<td>HPER, Lecture Hall</td>
</tr>
<tr>
<td>Exhibits</td>
<td>11:00 a.m. - 5:00 p.m.</td>
<td>HPER, Lobby</td>
</tr>
<tr>
<td>Slide Preview</td>
<td>11:30 p.m. - 5:00 p.m.</td>
<td>HPER, Room SPV</td>
</tr>
<tr>
<td>Refreshments</td>
<td>2:30 p.m. - 3:00 p.m.</td>
<td>HPER, Lobby</td>
</tr>
<tr>
<td>PAPER SESSIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemistry and Chemical</td>
<td>1:00 p.m. - 4:45 p.m.</td>
<td>HPER, Lecture Hall</td>
</tr>
<tr>
<td>Engineering I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoology</td>
<td>1:00 p.m. - 4:45 p.m.</td>
<td>HPER, Room 304</td>
</tr>
<tr>
<td>Physics, Mathematics</td>
<td>2:15 p.m. - 4:00 p.m.</td>
<td>HPER, Room 305</td>
</tr>
<tr>
<td>and Engineering I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecology and Environmental</td>
<td>3:15 p.m. - 5:00 p.m.</td>
<td>HPER, Room 306</td>
</tr>
<tr>
<td>Science</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomedical Sciences and</td>
<td>2:15 p.m. - 4:15 p.m.</td>
<td>HPER, Room 308</td>
</tr>
<tr>
<td>Microbiology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poster Session</td>
<td>2:00 p.m. - 4:30 p.m.</td>
<td>HPER, Lobby</td>
</tr>
<tr>
<td>Arkansas Biology Department</td>
<td>5:00 p.m.</td>
<td></td>
</tr>
<tr>
<td>Chairperson Meeting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banquet</td>
<td>6:30 p.m.</td>
<td>L.A. Davis Student Union, Ballroom</td>
</tr>
<tr>
<td>BANQUET SPEAKER</td>
<td>7:30 p.m.</td>
<td></td>
</tr>
<tr>
<td>Dr. Luther L. Williams</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assistant Director</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education and Human</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Science Foundation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NSF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Science Education and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research for the 21st Century”</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Saturday, April 8, 1995

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slide Preview</td>
<td>7:45 a.m. - 11:00 a.m.</td>
<td>HPER, Room SPV</td>
</tr>
<tr>
<td>Refreshments</td>
<td>7:45 a.m. - 8:15 a.m.</td>
<td>HPER, Lobby</td>
</tr>
<tr>
<td>Registration</td>
<td>8:00 a.m. - 10:00 a.m.</td>
<td>HPER, Lobby</td>
</tr>
<tr>
<td>Exhibits</td>
<td>8:00 a.m. - 1:00 p.m.</td>
<td>HPER, Lobby</td>
</tr>
<tr>
<td>Refreshments</td>
<td>9:45 a.m. - 10:30 a.m.</td>
<td>HPER, Lobby</td>
</tr>
<tr>
<td>Second Business Meeting &amp;</td>
<td>12:00 p.m. - 1:30 p.m.</td>
<td>HPER, Lecture Hall</td>
</tr>
<tr>
<td>Awards</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PAPER SESSIONS

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics, Mathematics and</td>
<td>8:30 a.m. - 11:15 a.m.</td>
<td>HPER, Room 305</td>
</tr>
<tr>
<td>Engineering I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Botany</td>
<td>8:30 a.m. - 11:45 a.m.</td>
<td>HPER, Room 306</td>
</tr>
<tr>
<td>Fisheries and Aquatic</td>
<td>8:30 a.m. - 11:45 a.m.</td>
<td>HPER, Room 307</td>
</tr>
<tr>
<td>Biology</td>
<td>9:00 a.m. - 10:45 a.m.</td>
<td>HPER, Lecture Hall</td>
</tr>
<tr>
<td>Science Education</td>
<td>11:00 a.m. - 11:30 a.m.</td>
<td>HPER, Lecture Hall</td>
</tr>
</tbody>
</table>

TOURS

(Meet in HPER, Arena)

**Friday, April 7, 1995**

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keepers of the Spirit</td>
<td>1:00 p.m. - 2:30 p.m.</td>
<td></td>
</tr>
<tr>
<td>Exhibit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keepers of the Spirit</td>
<td>3:00 p.m. - 4:30 p.m.</td>
<td></td>
</tr>
<tr>
<td>Exhibit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fisheries Biology Facility</td>
<td>2:30 p.m. - 4:00 p.m.</td>
<td></td>
</tr>
</tbody>
</table>

**Saturday, April 8, 1995**

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fisheries Biology Facility</td>
<td>9:00 a.m. - 10:30 a.m.</td>
<td></td>
</tr>
</tbody>
</table>
SECTION PROGRAMS

** Undergraduate  **Graduate

CHEMISTRY AND CHEMICAL ENGINEERING I

HPER Complex Lecture Hall

Chairperson: Dr. Roger E. Koepp, II, University of Arkansas at Fayetteville

TIME  TOPIC
1:00  *Ginger J. Brown*, 1  Kevin D. Phelan 2  and Cynthia J.M. Kane2, Department of Biology, 1  Hendrix College, Conway, AR 72022 and Department of Anatomy2, University of Arkansas for Medical Sciences, Little Rock, AR 72205. TRANSFORMING GROWTH FACTOR-Ñ CONTROLS SURVIVAL OF CENTRAL NERVOUS SYSTEM NEURONS.


1:30  *Antonio Rice*, Lawrence D. Fitz, Gordon L. Eggleton and Richard B. Walker, University of Arkansas at Pine Bluff, Chemistry Department, Pine Bluff, AR 71601. EVIDENCE FOR COPPER COMPLEXATION OF AN OXAZOLIDINE FORMED FROM (-) EPHEDRINE AND SALICYLALDEHYDE.

1:45  Frank L. Setliff, John W. Hawley, and Alan D. Toland, Department of Chemistry, University of Arkansas at Little Rock, Little Rock, AR 72204. HAMMETT CORRELATIONS OF CARBONYL 13C CHEMICAL SHIFTS IN A SERIES OF N-(4-SUBSTITUTED PHENYL)-6-CHLORO-5-FLUOROMICINAMIDES.

2:00  *Tim Bullard*, Reynolds Metals Company, P.O. Box 97, Bauxite, AR 72011 and Department of Chemistry, University of Arkansas at Little Rock, Little Rock, AR 72204; and Ali U. Shaikh, Department of Chemistry, University of Arkansas at Little Rock, Little Rock, AR 72204. Simultaneous Analysis of Major, Minor and Trace Metals in Bauxite Ore and Other Geological Materials.

2:15  *Brandon Kemp*, Dr. Robert Engelken, Arif Raza, Arees Siddiqui, and Omer Mustafa, Optoelectronic Materials Research Laboratory, Department of Engineering, Arkansas State University, State University, Jonesboro, AR 72467. DIAGNOSTICS OF CdTe ELECTRODEPOSITION BY REST POTENTIAL VOLTAMETRY

2:30  *Arif Raza*, Dr. Robert Engelken, Brandon Kemp, Arees Siddiqui and Omer Mustafa. Optoelectronic Materials Research Laboratory, Department of Engineering, Arkansas State University, P.O. Box 1740, State University, Jonesboro, AR 72467. MOLten SALT ELECTROLYTES FOR ELECTRODEPOSITION OF CADMIUM TELLURIDE FILMS.

2:45  BREAK

Chairperson: Dr. Richard B. Walker, University of Arkansas at Pine Bluff

3:00  Scott W. Reece. OPTIMIZATION AND DIAGNOSTIC MEASUREMENTS FOR A DIRECT CURRENT ARCJET DIAMOND CHEMICAL VAPOR DEPOSITION REACTOR.

3:15  **Gopi Sirineni, Dr. H.A. Naseem, Dr. A.P. Maliseh and Dr. W.D. Brown** HiDEC, University of Arkansas, Fayetteville, AR 72701. POLISHING OF CVD DIAMOND SUBSTRATES USING REACTIVE ION ETCHING.

3:30  Quazi Galib Samdani, Hameed A. Naseem and W.D. Brown Department of Electrical Engineering, University of Arkansas, University Court, Fayetteville, AR 72701. CHARACTERIZATION OF CADMIUM SULPHIDE FILMS DEPOSITED BY CHEMICAL BATH METHOD.

3:45  *W. S. Taylor, Daniel Barnas*, and B.K. Alexander, Department of Chemistry, University of Central Arkansas, Conway, AR 72035. CHARACTERIZATION OF EXCITED STATE METAL ION PRODUCTION BY A SPILLERING GLOW DISCHARGE VIA ELECTRONIC STATE CHROMATOGRAPHY.

4:00  T.E. Exell and Darsey, J. A., University of Arkansas at Little Rock, Little Rock, AR 72204. Department of Chemistry, University of Arkansas at Little Rock, AR. SCF-MO CONFORMATIONAL ANALYSIS OF POLYCYCLOCONAINE.

4:15  *Lori L. Rayburn*, Department of Chemistry, University of Arkansas at Little Rock, AR. CONGOMRATIONAL STUDIES OF ORTHO- AND META-NITRO ISOMERS AND ORTHO- SUBSTITUTED ANALOGUES OF DANTROLENE USING AB INITIO SCF-MO AND MOLECULAR PROCEDURES.

4:30  *Hugh Simmons, W. H. Irving*, M. Wear*, I. Chowdhury1, S. Khan1, E. Williams1, W.M. Willingham1, and J.R.J. Sorenson2, 1University of Arkansas at Pine Bluff, Research Center, Box 4094, Pine Bluff, AR 71601. 2University of Arkansas for Medical Sciences, College of Pharmacy, Slot 522, 4301 West Markham, Little Rock, AR 72205. 5-SULFONAMYL SALICYLCOPPER (II) PROTECTS CS7BL/6 MICE FROM IONIZING RADIATION

ZOLOGY

HPER Complex Room 304

Chairperson: Dr. Lynita M. Cooksey, Arkansas State University, Jonesboro

TIME  TOPIC
1:00  **S. L. Baarden, L. M. Cooksey**, Dept. of Biological Sciences, Arkansas State University, State University, AR 72467, and L. R. Hilburn, Black River Technical College, Focahontas, AR 72455. ELECTROPHORETIC DETERMINATION OF SIBLING SPECIES OF THE ANOPHELES QUADRIMACULATUS SPECIES COMPLEX IN NORTHEASTERN ARKANSAS.

1:15  Ali M. S. Shams, Dewey H. Sifford and Bob D. Johnson College of Arts and Sciences, Arkansas State University, State University, AR 72467. 5'-NUCLEOTIDASE AND THROMBIN-LIKE ACTIVITIES OF SELECTED CROTALID VENOMS.

1:30  Jennifer K. Powell2, Charlotte L. Owruty2, Jeffrey E. Fletcher3 and Keith Sutton1, 1Department of Biology, Hendrix College, Conway, AR 72032; 2Department of Physiological Sciences, Oklahoma State University, Stillwater, OK 74078; 3Department of Anesthesiology, Hahnemann University, Philadelphia, PA 19102. BEE (APILERA) VENOMELITT IN CAUSES MYONECROSIS IN MICE.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
1:45 David H. Jamieson1 and Larry A. Olson2, 1ASU-Beebe (Newport Campus), Biology Department, 7648 Victory Blvd., Newport, AR 72112. 2Arkansas State University, Department of Biological Science, State University, AR 72467. THE RECENT ESTABLISHMENT OF THE ASIAN TIGER MOSQUITO (Aedes albopictus) IN INDEPENDENCE COUNTY, ARKANSAS.

2:00 *David Eller, Renn Tumilson, and Todd Wiebers. Departments of Biology and Psychology, Henderson State University, Arkadelphia, AR 71999. A FIELD STUDY OF SOLVING THE DETOUR PROBLEM IN TOADS (Bufo woodhousii) IN INDEPENDENCE COUNTY, ARKANSAS.

2:15 *David Eller, Diane Taylor, Mitzi Hunt, Todd Wiebers, and Renn Tumilson. Departments of Biology and Psychology, Henderson State University, Arkadelphia, AR 71999. A LABORATORY STUDY OF SOLVING THE DETOUR PROBLEM IN TOADS (Bufo woodhousii).

2:30 Break

2:45 Peggy Rae Dorris, Henry W. Robison, and Chris Carleton, Henderson State University, Arkadelphia, AR 71999; Southern Arkansas University, Magnolia, AR 71753; and University of Arkansas, Fayetteville, AR 72701. ADDITIONAL RECORDS OF ARKANSAS SPIDERS COLLECTED FROM OUACHITA NATIONAL FOREST SUBSTRATE.

3:00 Risa Parker and Peggy Rae Dorris, Henderson State University, Box 7544, Arkadelphia, AR 71999-0001. ADDITIONS TO THE LIST OF SCHIZOCOSA (FAMILY LYCOSIDA) FOUND IN ARKANSAS.

3:15 M. Victoria McDonald, University of Central Arkansas, Department of Biology, University of Central Arkansas, Conway, AR 72030-0001, USA. KENTUCKY WARBLER BEHAVIOR AND PATERNITY STUDIES.

3:30 William M. Shepherd, Douglas A. James, and Max D. Parker, 1Arkansas Natural Heritage Commission, 1500 Tower Bldg., 323 Center St., Little Rock, AR 72201; 2Dept. of Biological Sciences, University of Arkansas, Fayetteville, AR 72701; and 32426 S. Main St., Malvern, AR 72112. WINTER STATUS OF HENSLOW’S SPARROW (Ammodramus henslowi) IN ARKANSAS.

3:45 Chris T. McAllister and Stanley E. Trauth. Division of Natural and Applied Sciences, Cedar Valley College, Lancaster, TX 75134 and Department of Biological Sciences, Arkansas State University, State University, AR 72467. VERTEBRATE FAUNA OF MINES AT GOLD MINE SPRINGS, INDEPENDENCE COUNTY, ARKANSAS.

4:00 Stanley E. Trauth, and Chris T. McAllister, Department of Biological Sciences, Arkansas State University, State University, AR 72467 and Division of Natural and Applied Sciences, Cedar Valley College, Lancaster, TX 75134. VERTEBRATE PREY OF SELECTED ARKANSAS SNAKES.

4:15 Stanley E. Trauth, Robert L. Cox, Jr., J.D. Whilhide, and Hilary Worley. Department of Biological Sciences, Arkansas State University, State University, AR 72467-0599 (JLC-deceased). EGG MASS CHARACTERISTICS OF TERRESTRIAL MORPHS OF THE MOLE SALAMANDER, AMBYSTOMA TALPOIDEUM (CAUDATA: AMBYSTOMATIDAE), FROM NORTHEASTERN ARKANSAS AND COMPARISONS WITH OTHER AMBYSTOMA SPECIES.

PHYSICS, MATHEMATICS AND ENGINEERING I
HPER Complex Room 305
Chairperson: Dr. Keith Hudson, University of Arkansas at Little Rock

TIME

TOPIC

2:15 *Christopher Paul Sheesley, Rahul Mehta, William Victor Slaton, Terry Johnson, John McKay, Anthony E. Portoni, Department of Physics, University of Central Arkansas, Conway, AR 72035 and J.L. Duggan, Justin M. Sanders, Department of Physics, University of North Texas, Denton, TX 76203. RUTHERFORD AND NON-RUTHERFORD SCATTERING USING A PROTON BEAM.

2:30 *William Victor Slaton, Rahul Mehta, Terry Johnson, John McKay, Anthony E. Portoni, Christopher Paul Sheesley, Department of Physics, University of Central Arkansas, Conway, AR 72035 and J.L. Duggan and Justin M. Sanders, Department of Physics, University of North Texas, Denton, TX 76203-4333. NUCLEAR REACTION STUDIED USING PROTONS ON LITHIUM FLUORIDE AND CARBON TARGETS.

2:45 Felix Tendek, Department of Industrial Technology, University of Arkansas at Pine Bluff, Pine Bluff, AR 71601. RETRIEVAL OF ATMOSPHERIC TURBIDITY COEFFICIENT AND WATER VAPOR CONTENT FROM SOLAR IRRADIANCE DATA.

3:00 L. D. Klotz, J.D. Wilson, University of Arkansas at Little Rock. 2801 South University, Little Rock, AR 72203. DIGITAL IMAGING TECHNIQUES FOR MEASURING AGGREGATE SHAPE.

3:15 **Morgan T. Burks, U. of Arkansas at Little Rock and Lawrence Berkeley Laboratory, Spiros Margetis and Howard Wieman, Lawrence Berkeley Laboratory, MS 70A_3307, Berkeley, CA 94720, and W.J. Braithwaite, Univ. of Arkansas, Little Rock, AR72204. DETERMINING THE FEASIBILITY OF USING Dimethyl-Ether as a DRIFT GAS IN A MICRO-STRIP TIME PROJECTION CHAMBER.

3:30 Jianming Xu and Paul C. McLeod, University of Arkansas at Little Rock, Department of Applied Science HIGH SPEED SPECTRAL MEASUREMENT OF TRANSIENT OPTICAL EMISSION.

3:45 Siripong Malasi and Jennifer R. Martin, Department of Civil Engineering, Christian Brothers University, Memphis, TN 38104. CONSTRUCTION RESOURCE ALLOCATION USING A GENETIC ALGORITHM.

ECOLOGY AND ENVIRONMENTAL SCIENCE
HPER Complex Room 306
Chairperson: Dr. Nick Brown, University of Arkansas at Monticello

TIME

TOPIC


3:30 Nick Brown, Arkansas Forest Resources Center, UAM School of Forest Resources, Monticello, AR. AN INDEX OF FOREST INTEGRITY FOR UPLAND COASTAL PLAINS ECOSYSTEMS.

3:45 R. Kluender, D. Lortz and W. McCoy, University of Arkansas at Monticello. School of Forest Resources, Monticello, AR 71656. B. Stokes and J. Kiepac. USDA Forest Service, Southern Forest Experiment Station, Devall Drive, Auburn University, Alabama 36849. FOREST HARVESTING COSTS AND PRODUCTIVITY IN ARKANSAS.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
**Celia Fern Jason,** University of Nebraska State Museum, University of Nebraska, Lincoln, NE. BASELINE DATA FOR TURKEY RIDGE RESEARCH NATURAL AREA, ST. FRANCIS NATIONAL FOREST, ARKANSAS.

**Robert Cordova**, and Bobby Makin, Division of Engineering, Arkansas Department of Health, 4815 W. Markham, Little Rock, AR 72205. ARKANSAS’ WELLHEAD PROTECTION PROGRAM, WITH DISCUSSION OF DELINEATION METHODOLOGY.

**D. L. Moore**, and F.W. Spiegel, Department of Biological Sciences, University of Arkansas at Fayetteville, AR 72701. MICROPHENOMENON IN NATURE: PROTOSTELID ECOLOGY.

**Jeffrey Moran**, Janet Lanza and Daniel Brown, Department of Biology, University of Arkansas at Little Rock, 2801 S. University, Little Rock, AR 72204. FLY PREFERENCES FOR AND NUTRITIONAL BENEFITS OF NECTAR-BONE AMINO ACIDS.

**Igietseme*, Ijindah M. Uriri and Roger G. Rank. Department of Microbiology and Immunology, University of Arkansas for Medical Sciences, Little Rock, AR 72205. MECHANISM OF T CELL INHIBITION OF INTRAEPITHELIAL GROWTH OF CHLAMYDIA.

**Lawrence Mwusi**, Department of Biology, University of Arkansas at Pine Bluff, AR. ULTRASTRUCTURAL CHANGES IN ARTHROBACTER TH-1 WHEN GROWN WITH EITHER CIS-TERPIN HYDRATE, o-TERPINOL, OR GLUCOSE AS THE SOLE CARBON AND ENERGY SOURCE.

**Joshua V. Granderson**, David Stinchcomb, John Lawrence, and Gaston Griggs. Biology Department, John Brown University, Siloam Springs, AR 72761. UV-INDUCED CHROMOSOMAL ABERRATION PRODUCTION AND THE DNA REPLICATION FORK IN EUKARYOTIC CELLS.

**Brian T. Bean**, Chris Myers, Alan M. Lambowitz (Bruce Haggard1). 1Department of Biology, Hendrix College, Conway, AR 72032. 2Department of Molecular Genetics, The Ohio State University, Columbus, OH 43210. MUTATIONAL ANALYSIS OF AN IDIOSYNCRATIC DOMAIN OF THE NEUROSPORA MITOCHONDRIAL TYROSYL-IRNA SYNTHETASE INVOLVED IN GROUP I INTRO SPlicing.

**Gina Uyen Trebilcock** and Usha Ponnappan, Univ. of Arkansas for Medical Sciences, VA Medical Research, 4300 W. 7th, 151/LR GC-143, Little Rock, AR 72205. IMMUNE DYSREGULATION IN AGING: ROLE OF NFkB.

**T. Yerokun**, Hofflich, R.H., Lyn-Cook, B., Jin, B. and Ringer, D.P. Department of Biology, University of Arkansas at Pine Bluff, AR 71601. The National Center for Toxicological Research, Jefferson, AR 72079 and the Oklahoma Medical Research Foundation. MOLECULAR CLONING OF A RAT HEPATIC ARYL SULFOTRANSFERASE AND USE IN A CARCINOGENESIS MODEL.

**Charles Ashburn**, Nanette J. Gusick, and Wayne L. Gray. Department of Biology*, University of Arkansas at Little Rock, Little Rock, AR 72204, and Department of Microbiology and Immunology, University of Arkansas for Medical Sciences, Little Rock, AR 72205. DNA SEQUENCE ANALYSIS OF THE SIMIAN VARICELLA VIRUS URACIL GLYCOSYLASE GENE.

**NaNette J. Gusick**, Wayne L. Gray, Thomas M. Fletcher, and Kenneth Soike.* Department of Microbiology and Immunology, University of Arkansas for Medical Sciences, Little Rock, AR 72205. Tulane Regional Primate Research Center, Tulane University, Covington, LA 70433. ANTIBODY RESPONSE OF AFRICAN GREEN MONKEYS INFECTED WITH SIMIAN VARICELLA VIRUS.

**POSTER SESSION**

April 7, 1995

2:00 P.M. - 4:30 P.M.

**HER LOBBY**

Michael A. Preston, Miriam M. Glass, Mattie M. Glover and Clifton Orr

Department of Biology, University of Arkansas at Pine Bluff

ANGUIDINE DECREASES THE CYTOTOXIC EFFECTS OF VINCRISTEINE AGAINST HUMAN BLADDER CANCER CELLS (253J)

Stacey M. Johnson, Jacqueline A. Potter, Miriam M. Glass, Mattie M. Glover and Clifton Orr

Department of Biology, University of Arkansas at Pine Bluff

DIFFERENTIAL CYTOTOXIC EFFECTS OF 5 FLUOROURACIL (5-FU) AGAINST TWO HUMAN BLADDER CANCER CELL LINES

Saturday, April 8, 1995

**PHYSICS, MATHEMATICS AND ENGINEERING II**

**HER COMPLEX ROOM 305**

Chairperson: Dr. Felix Tendeku, University of Arkansas at Pine Bluff

**Sue Ellen McCloskey** and W.J. Braithwaite, Department of Physics and Astronomy, University of Arkansas at Little Rock, 2801 S University Ave., Little Rock, AR 72204. AN INTRODUCTORY MODULE FOR STUDENTS OF MONTE CARLO MODELING.

**Carlos A. Sanchez**, Kazuhiko Murai, Jason E. Elmore, and Donald C. Wold, Department of Physics and Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204. USING FRITIOF TO MODEL NUCLEUS-NUCLEUS INTERACTIONS IN A COSMIC RAY DETECTOR.

**Doug Mauldin**, A.A. Rollefson & W.J. Braithwaite, U of Arkansas, Little Rock, AR 72204. ENERGY-LOSS PARTICLE IDENTIFICATION IN 2-D SILICON DRIFT DETECTORS.

**Kazuhiko Murai**, Carlos A. Sanchez, Jason E. Elmore, and Donald C. Wold, Department of Physics and Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204. USINg GEANT TO MODEL CALORIMETER RESPONSE FOR ELECTROMAGNETIC CASCADES FROM NUCLEUS-NUCLEUS INTERACTIONS IN A COSMIC RAY DETECTOR.

**Chris S. Smith**, M. Keith Hudson*, and Paul C. McLeod, Department of Applied Science, University of Arkansas at Little Rock, Little Rock, AR 72204. DESIGN AND CONSTRUCTION OF A SMALL ARMS PROPELLANT TEST UNIT.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
**Program**

**BOTANY**  
HPER Complex Room 306  
*Chairperson:* Dr. Janet Lanza, University of Arkansas at Little Rock

<table>
<thead>
<tr>
<th>TIME</th>
<th>TOPIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30</td>
<td>Elizabeth M. Getz and Donald E. Culwell, The University of Central Arkansas, Lewis Science Center, Conway, AR 72035. VASCULAR FLORA OF CAMP JOSEPH T. ROBINSON MILITARY BASE, NORTH LITTLE ROCK, ARKANSAS.</td>
</tr>
<tr>
<td>8:45</td>
<td>Jennifer Burks and Janet Lanza, Biology Department, University of Arkansas at Little Rock, 2801 South University, Little Rock, AR 72204. POLLINATION BIOLOGY OF PASSIFLORA LUTEA.</td>
</tr>
<tr>
<td>9:00</td>
<td>James A. Rasmussen, Frank A. Einhellig, and Angela M. Hejl, Department of Biological Sciences, Southern Arkansas University, Magnolia, AR 71753-5000, Graduate Studies and Research, Southwest Missouri State University, Springfield, MO 65804-0089, Department of Biology, University of South Dakota, Vermillion, SD 57069-2390. EFFECTS OF SELECTED FLAVONOIDS ON ISOLATED CHLOROPLASTS.</td>
</tr>
<tr>
<td>9:30</td>
<td>Jennifer Akin and Richard L. Meyer, University of Arkansas at Fayetteville, Department of Biological Sciences, Fayetteville, AR 72701. BIODIVERSITY OF SACCODERM AND PLACCODERM DESMIDS (CONJUGATOPHYCEAE) FROM NORTHWESTERN ARKANSAS.</td>
</tr>
<tr>
<td>9:45</td>
<td>Break</td>
</tr>
</tbody>
</table>

**FISHERIES AND AQUATIC BIOLOGY**  
HPER Complex Room 307  
*Chairperson:* Dr. Rebecca Lochmann, University of Arkansas at Pine Bluff

<table>
<thead>
<tr>
<th>TIME</th>
<th>TOPIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30</td>
<td>Rebecca Lockmann, S.J. Parker Agricultural Experiment Station, University of Arkansas at Pine Bluff, AR. USE OF STABLE CARBON ISOTOPE RATIOS TO STUDY NUTRITION OF GOLDEN SHINERS.</td>
</tr>
<tr>
<td>8:45</td>
<td>Kendra Flores, National Biological Service cooperative Research Unit, University of Arkansas at Fayetteville, AR. DETERMINATION OF THE BEST TECHNIQUES FOR RADIOTRACKING COOL WATER SPORT FISH IN NORTHWESTERN ARKANSAS RESERVOIRS.</td>
</tr>
<tr>
<td>9:15</td>
<td>Ronald Johnson, Department of Zoology, Arkansas State University, Joneboro, AR. GENETIC STRUCTURE CORRELATED WITH AGE AND GROWTH OF THE LARGEMOUTH BASS POPULATION IN LAKE ASHBAUGH, ARKANSAS.</td>
</tr>
<tr>
<td>9:30</td>
<td>Ronald Rambo, and Joseph N. Steckel. Department of Biological Sciences, Arkansas Tech University, Russellville, AR 72801. REPRODUCTIVE BIOLOGY OF THE OUACHITA MADTOM WITH COMPARISONS TO OTHER SPECIES.</td>
</tr>
</tbody>
</table>
9:45  *Billy Vann, Caddo Hills High School, HC 65, Box 249, Norma, AR 71960; Betty G. Cockran Crump, USDA Forest Service, 101 Smokey Bear Lane, Glenwood, AR 71943; John L. Harris, Arkansas Highway Department-Environmental Division, P.O. Box 2261, Little Rock, AR 72203; Henry W. Robison, School of Science and Technology, Southern Arkansas University, Magnolia, AR 71753. PREDATION AND OTHER LIFE HISTORY ASPECTS OF THE PALEBACK DARTER A FIVE-YEAR STUDY.

10:00  Break

Chairperson: Dr. Joseph W. Stoeckel, Arkansas Tech University

10:15  *Fangquing Liang, and Ronald L. Johnson, Department of Biology, Arkansas State University, Jonesboro, AR. ALLOZYME STUDIES OF SELECTED SPECIES OF UNIONIDAE IN THE CACHE AND WHITE RIVERS, ARKANSAS.

10:30  **William Posey II, John L. Harris, and George L. Harp, Department of Biological Sciences, Arkansas State University, Jonesboro, AR 72467. SELECTED COMMUNITY CHARACTERISTICS OF FRESHWATER MUSSELS (UNIONIDAE) IN THE ST. FRANCIS RIVER, ARKANSAS.

10:45  **Anthony Holt, and George L. Harp, Department of Biological Sciences, Arkansas State University, Jonesboro, AR 72467. THE DYTISCIDAE (PREDACEOUS DIVING BEETLES) OF ARKANSAS.

11:00  **Austin Richards, and George L. Harp, Department of Biological Sciences, Arkansas State University, P.O. Box 599, Jonesboro, AR 72467. THE DISTRIBUTION AND HABITAT PREFERENCE OF GYRINUS MULLER (COLEOPTERA: GYRINIDAE) IN ARKANSAS WITH COMMENTS ON AGGREGATION BEHAVIOR.

11:15  George L. Harp, Department of Biological Sciences, Arkansas State University, State University, AR 72467, Eugene Leeds, USDA Forest Service, P.O. Box 190, Clarksville, AR 72830, and Henry W. Robison, Dept. of Biology, Southern Arkansas University, Magnolia, AR 71753. A PRELIMINARY REPORT ON THE FAIRY SHIMP (ANOSTRACE: EUBRANCHIOPODA) OF ARKANSAS.

11:30  **Austin Richards, and George L. Harp, Department of Biological Sciences, Arkansas State University, P.O. Box 599, Jonesboro, AR 72467. THE DISTRIBUTION AND HABITAT PREFERENCE OF DINEUTUS MACLEAY AND GYRETES COMPRESSUS LECONTE, 1863 (COLEOPTERA: GYRINIDAE) IN ARKANSAS.

CHEMISTRY AND CHEMICAL ENGINEERING II
HPER Complex Lecture Hall

Chairperson: Dr. C. Bhuvaneswaran, University of Arkansas for Medical Science

TIME  TOPIC
9:00  S. Cady and M. Sono, Department of Chemistry, Biochemistry and Physics, Arkansas State University, P.O. Box 419, Jonesboro, AR 72467-0419. EFFECT OF TRYPTOPHAN ANALOGS ON THE CATALYTIC ACTIVITY OF INDOLEAMINE 2,3-DIOXYGENASE.

9:15  Roger M. Hawk and Gene Lee Bangs, Department of Applied Science University of Arkansas at Little Rock, 2401 South University, Little Rock, AR 72204. A 31P, 13C, AND 1H NMR STUDY OF THE DIRECT INTERACTION OF COCAINE AND MAGNESIUM ATP.
Callus Induction and Plant Regeneration of Commercial Rice (Oryza sativa L.) Cultivars

Jameel M. Al-Khayri and Edwin J. Anderson  
Department of Plant Pathology  
University of Arkansas  
Fayetteville, AR 72701

Abstract

Manipulation of agronomic traits at the cellular and molecular levels offers an efficient approach to enhance conventional breeding efforts for rice improvement. Plant regeneration protocols, required for biotechnological applications, have not yet been developed for a number of important rice cultivars. This study was conducted to establish a system for plant regeneration of elite rice cultivars adapted to the southern U.S.A. Callus was induced from dehusked grains of cultivars Alan, Katy, and LaGrue, on MS media containing 0.5, 2, and 4 mg L\(^{-1}\) 2,4-D, with 0.5 mg L\(^{-1}\) kinetin or without kinetin. Plant regeneration was accomplished by transferring the callus to a hormone-free medium. Callus proliferation was influenced by 2,4-D, kinetin, and genotype in two-way interactions. The effects of these factors on embryogenesis and rhizogenesis was expressed in a three-way interaction. Depending upon the genotype up to 50% plant regeneration was obtained. In most cases treatments consisting of 0.5 to 2 mg L\(^{-1}\) 2,4-D plus 0.5 mg L\(^{-1}\) kinetin produced the best callus proliferations with the highest embryogenic capacity. Regenerants grew to maturity in soil and produced viable seeds. The establishment of this regeneration system is essential for the development of a genetic transformation system for the aforementioned commercial rice cultivars.

Introduction

Rice (Oryza sativa L.) is the staple food of more than half of the world population (Pathak, 1982). The importance of rice makes it a prime target for genetic manipulations through biotechnology. In general, the application of biotechnological approaches for crop improvement is limited by the availability of plant regeneration methods. Rice has been the focus of numerous studies aimed at inducing somatic embryogenesis that will lead to plant regeneration (Heyser et al., 1983; Raghava and Nabors, 1984; Oard and Rutger, 1988; Mirlohi et al., 1989; Tsukahara and Hirosawa, 1992a; Tsukahara and Hirosawa, 1992b; Rueb et al., 1994). Intraspecies variability, reflected in the genotype-dependent response of in vitro cultures, necessitates empirical determination of suitable plant regeneration conditions for individual cultivars (Pierik, 1987; Al-Khayri et al., 1991). Our goal was to determine the regeneration requirements for commercially important rice cultivars adapted to the southern U.S.A., particularly Arkansas, the leading rice-producing state.

The current investigation is part of a strategy designed to develop transformation systems for Arkansas rice cultivars that will facilitate the introgression of transgenes conferring resistance to diseases and, ultimately, leading to the development of improved cultivars by enhancing conventional breeding programs. The objectives of this study were to 1) test the effects of 2,4-D and kinetin on callus induction from mature rice seeds, 2) evaluate the effect of callus induction treatments on subsequent plant regenerations, and 3) examine the genotypic responses of three commercial rice cultivars.

Materials and Methods

Seed Sterilization.—Seeds of rice cultivars 'LaGrue', 'Katy', and 'Alan' were obtained from the Arkansas Agricultural Experiment Station Rice Research and Extension Center, Stuttgart, Arkansas. The seeds were dehusked manually to preserve the embryos from mechanical damage. The dehusked seeds were surface sterilized in 70% ethanol for 1 min and then shaken for 30 mins on a gyratory shaker at 200 rpm in 2.6% w/v sodium hypochlorite (50% Clorox) containing 3 drops of Tween 20 per 100 ml Clorox solution. The seeds were rinsed in sterile distilled water and cultured on callus induction media.

Culture Medium.—The culture medium consisted of MS basal salts (Murashige and Skoog, 1962) containing 1 mg L\(^{-1}\) each of thiamine-HCl, pyridoxine-HCl, and nicotinic acid, 2 mg L\(^{-1}\) glycine, 100 mg L\(^{-1}\) inositol, 40 g L\(^{-1}\) sucrose, and 10 g L\(^{-1}\) agar [Agar-agar/Gum agar] (Sigma Chem. Co., St. Louis). The medium was adjusted to pH 5.8 with 1N KOH, autoclaved, and dispensed in 100-mm x 15-mm petri dishes. Callus induction medium was supplemented with 2,4-dichlorophenoxyacetic acid (2,4-D) (Sigma) at 0.5, 2, or 4 mg L\(^{-1}\) and fufurylaminopurine.
Callus Induction and Plant Regeneration of Commercial Rice (Oryza sativa L.) Cultivars

(kinetin) (Sigma) at 0 or 0.5 mg L⁻¹. Plant regeneration media contained no growth regulators.

Culture Stages and Conditions.—The seed cultures were incubated at 24°C under a 12-h photoperiod of cool-white fluorescent light (40 μE m⁻² s⁻¹). After 4 weeks, calli were separated from the seed explants and transferred to a fresh callus induction medium and incubated for an additional 4 weeks. Calli were then weighed and transferred to plant regeneration medium. After 10 weeks, the number of embryogenic calli, with the capacity to regenerate plants, and the number of rhizogenic calli, with the capacity to form only roots, were determined.

Plant Establishment.—When plantlets were approximately 10 mm long, they were separated and transferred from the petri plates to a hormone-free medium dispensed in 150-mm x 25-mm tubes to allow for elongation. After 2 to 3 weeks, agar was washed from the root regions and the plantlets were transplanted to a potting mix (Redi-Earth Peat-Lite Mix, Grace-Sierra Hort. Products Co., Mipitas, CA), watered with half-strength MS salts, misted with water to maintain humidity, placed in clear plastic containers and maintained under the same cultural conditions as prior to transplanting. The humidity was gradually reduced by increasing the opening of the container over a period of 2 weeks. The plants were then relocated to a greenhouse and grown to maturity.

Statistical Analysis.—The experiment was set up as a completely randomized three-factor factorial design, 3x3x2. The factors tested were cultivar (three genotypes), 2,4-D (three concentrations), and kinetin (two concentrations). Data were subjected to analysis of variance (ANOVA) based on 20 replications for mean callus weight and 10 to 20 replications for percentage of morphogenesis, plant regeneration and root formation. Transformation of the percentage data was not necessary. The means were separated, where appropriate, at the 5% significance level using the least significant difference (LSD) for the callus weight and a multiple t-test for the percentage of morphogenesis.

Results and Discussion

Callus Induction.—Callus formation was observed within 2 weeks of culturing. Seed germination often preceded callusing on media containing the lowest 2,4-D concentration, but on either of the higher 2,4-D concentrations, callus formed directly (Fig. 1). While the percent of callusing (90 to 100%) was not influenced by the experimental factors, callus fresh weight was significantly affected by the plant genotype and the concentrations of 2,4-D and kinetin expressed in the two-way interactions illustrated by the ANOVA (Table 1). Table 2 shows the means associated with each of these three two-way interactions. The top section of Table 2 represents the cultivar/kinetin interaction, the middle section describes the cultivar/2,4-D interaction, and the bottom section illustrates the kinetin/2,4-D interactions.

Callus proliferation differed significantly among cultivars and depended upon the concentration of 2,4-D and the concentration of kinetin in a two-way interaction determined by the ANOVA (Table 1). On kinetin-free medium there was no significant difference between Katy and LaGrue, but Alan produced significantly larger callus (Table 2). With 0.5 mg L⁻¹ kinetin, however, callus proliferation among cultivars differed significantly. Alan produced the largest callus, followed by LaGrue, and then Katy.

Kinetin had no significant effect on callus weight of Alan and Katy. However, a significant increase of callus weight of LaGrue was associated with the addition of 0.5 mg L⁻¹ kinetin to the callus medium (Table 2).

The concentration of 2,4-D significantly influenced callus fresh weight (Table 2). In general, as the concentration of 2,4-D increased, callus growth decreased at a rate that was cultivar-specific, hence the two-way interaction. Significant decreases in callus weight occurred in all three cultivars when the concentration of 2,4-D was increased from 0.5 mg L⁻¹, the level at which the greatest callus growth was achieved, to 2 mg L⁻¹ (Table 2). Although, an increase in 2,4-D from 2 mg L⁻¹ to 4 mg L⁻¹ did not cause a significant difference in callus growth for Katy or LaGrue, it caused a significant reduction in callus weight for Alan. On media supplemented with 0.5 mg L⁻¹ 2,4-D, mean callus weights for the three cultivars differed significantly. With 2 mg L⁻¹ only Katy produced signifi-
Table 1. ANOVA of callus weight, percentage embryogenesis, and percentage rhizogenesis of callus induced from mature rice seed explants.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Mean square</th>
<th>P-value</th>
<th>Mean square</th>
<th>P-value</th>
<th>Mean square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Callus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultivar</td>
<td>2</td>
<td>699284</td>
<td>0.0001*</td>
<td>8123</td>
<td>0.0012*</td>
<td>4465</td>
<td>0.1155</td>
</tr>
<tr>
<td>Kinetin level</td>
<td>1</td>
<td>18</td>
<td>0.9493</td>
<td>7919</td>
<td>0.0102*</td>
<td>555</td>
<td>0.6100</td>
</tr>
<tr>
<td>2,4-D level</td>
<td>2</td>
<td>562107</td>
<td>0.0001*</td>
<td>1947</td>
<td>0.1942</td>
<td>1557</td>
<td>0.4737</td>
</tr>
<tr>
<td>Cultivar x Kinetin</td>
<td>2</td>
<td>23307</td>
<td>0.0060*</td>
<td>29</td>
<td>0.9755</td>
<td>9680</td>
<td>0.0097*</td>
</tr>
<tr>
<td>Cultivar x 2,4-D</td>
<td>4</td>
<td>42480</td>
<td>0.0001*</td>
<td>4168</td>
<td>0.0080*</td>
<td>6552</td>
<td>0.0141*</td>
</tr>
<tr>
<td>Kinetin x 2,4-D</td>
<td>2</td>
<td>31666</td>
<td>0.0010*</td>
<td>2268</td>
<td>0.1486</td>
<td>459</td>
<td>0.7906</td>
</tr>
<tr>
<td>Cult x Kin x 2,4-D</td>
<td>4</td>
<td>10451</td>
<td>0.0562</td>
<td>3198</td>
<td>0.0308*</td>
<td>21121</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Error, callus</td>
<td>342</td>
<td>4494</td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Error, plant or root</td>
<td>258</td>
<td></td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

*Significant at p = 0.05

2,4-D increased to 2 mg L\(^{-1}\) callus growth was insensitive to the addition of kinetin, but when the level of 2,4-D reached 4 mg L\(^{-1}\) callus proliferation was significantly inhibited by the addition of 0.5 mg L\(^{-1}\) kinetin (Table 2).

**Somatic Embryogenesis and Rhizogenesis.**—When callus tissues were transferred to regeneration media, some exhibited no response or became necrotic, but the majority developed either roots (rhizogenic calli), or plantlets (embryogenic calli). Plant regeneration (Fig. 2) was observed as early as 3 weeks after calli were placed on regeneration medium, especially from calli that had formed on the lowest level of 2,4-D (0.5 mg L\(^{-1}\)). The cultures were maintained for 12 weeks to allow time for potential regenerative calli to respond. Observations made at the end of the culture period revealed that the percentages of embryogenic and rhizogenic calli were variable among genotypes. This variability was influenced by the callus-induction treatments, i.e. kinetin and 2,4-D combinations, hence the three-way interaction (Table 1).

Upon transfer to the hormone-free regeneration medium, calli induced on 0.5 mg L\(^{-1}\) 2,4-D and 0.5 mg L\(^{-1}\) kinetin resulted in the highest plant regeneration percentage for both Katy and Alan cultivars (Table 3). At this concentration of 2,4-D, the omission of kinetin from the callus induction medium did not significantly alter the regeneration percentage for Alan but significantly inhibited regeneration for Katy. The highest percentage of regeneration obtained for LaGrue was from calli induced on 2 mg L\(^{-1}\) 2,4-D and 0.5 mg L\(^{-1}\) kinetin. At this level of 2,4-D, omitting kinetin also significantly reduced the percentage of plant regeneration for LaGrue.

Based on the ANOVA of callus weight (Table 2), the influence of the hormones was dependent upon the concentration of both hormones, thus the two-way interaction between 2,4-D and kinetin. At 0.5 mg L\(^{-1}\) 2,4-D, the addition of kinetin significantly stimulated callus growth for all three cultivars (Table 2). As the concentration of 2,4-D increased to 2 mg L\(^{-1}\) callus growth was insensitive to the addition of kinetin, but when the level of 2,4-D reached 4 mg L\(^{-1}\) callus proliferation was significantly inhibited by the addition of 0.5 mg L\(^{-1}\) kinetin (Table 2).

Table 2. Effects of 2,4-D, and kinetin levels on callus induction from mature seeds of three rice cultivars.

<table>
<thead>
<tr>
<th>Mean Callus Weight (mg)</th>
<th>Cultivar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetin (mg L(^{-1}))</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>Katy</td>
</tr>
<tr>
<td>129c(^1)</td>
<td>LaGrue</td>
</tr>
<tr>
<td>130c</td>
<td>Alan</td>
</tr>
<tr>
<td>0.5</td>
<td>Katy</td>
</tr>
<tr>
<td>169c(^2)</td>
<td>LaGrue</td>
</tr>
<tr>
<td>171c</td>
<td>Alan</td>
</tr>
<tr>
<td>2.0</td>
<td>117e</td>
</tr>
<tr>
<td>120de</td>
<td>149cd</td>
</tr>
<tr>
<td>4.0</td>
<td>102e</td>
</tr>
<tr>
<td>104e</td>
<td>112e</td>
</tr>
<tr>
<td>2,4-D (mg L(^{-1}))</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>169e</td>
</tr>
<tr>
<td>222b</td>
<td>289a</td>
</tr>
<tr>
<td>202b(^3)</td>
<td>135c</td>
</tr>
<tr>
<td>111c</td>
<td>95d</td>
</tr>
<tr>
<td>0.5</td>
<td>251a</td>
</tr>
</tbody>
</table>

Means are based on 20 calli per hormonal treatment. Means within a group followed by the same letter do not differ significantly.

\(^1\)LSD (0.05) = 24; \(^2\)LSD (0.05) = 30; \(^3\)LSD (0.05) = 24.
A comparison of the regeneration percentages (shown by columns in Table 3) revealed that the three cultivars did not differ significantly for calli induced on 0.5 mg L⁻¹ 2,4-D, regardless of the kinetin concentration; the same was true for 4 mg L⁻¹, but they did differ significantly at the 2 mg L⁻¹ level.

In contrast to callus induction data where Alan produced the largest callus (Table 2), overall, the percentage of plant regeneration was the lowest (average of 9% for all treatments) for this genotype (Table 3). Katy and LaGrue produced a total average of 14% and 27% regeneration, respectively (Table 3).

Generally, rhizogenesis was inversely related to the percentage of plant regeneration (Table 3). However, this relationship did not hold for all the treatments. For example, calli induced from LaGrue on 4 mg L⁻¹ 2,4-D produced 6% embryogenesis and rhizogenesis.

The percentage of rhizogenesis among the cultivars was highly variable. Rhizogenesis in Katy was the least from calli induced on 2 mg L⁻¹ 2,4-D in the presence of kinetin. All other treatments resulted in similar amounts of rhizogenesis (Table 3). LaGrue produced the least rhizogenesis from calli induced on 4 mg L⁻¹ 2,4-D, while all other treatments resulted in similar amounts of root-producing calli. Rhizogenesis in Alan was highest on 4 mg L⁻¹ 2,4-D in the absence of kinetin and on 2 mg L⁻¹ 2,4-D in the presence of kinetin. The other treatments had similar effects (Table 3).

**Plant Establishment.**—Eighty five to 100% regenerat-ed plantlets survived in soil regardless of cultivar or in vitro treatments (Fig. 3). Under greenhouse conditions, the regenerants exhibited normal growth and produced viable seeds.

---

**Conclusions**

A plant regeneration system for three commercial rice cultivars has been established using mature seed as a source for explants. The system consists of two stages, callus induction and plant regeneration. A callus induction medium suitable for all three cultivars consisted of MS medium containing 0.5 mg/L 2,4-D and 0.5 mg/L 2,4-D and 0.5 mg/L 2,4-D.
kinetin. Transfer of calli induced by this treatment to a hormone-free medium resulted in callus redifferentiation into somatic embryos that germinated into plantlets. Although increasing the 2,4-D level to 2 mg/L 2,4-D resulted in higher percentages of regenerative calli for LaGrue, in general, the reduced 2,4-D concentration in the callus induction medium expedited subsequent plant regeneration. For long-term callus maintenance, however, concentrations of 2,4-D higher than 0.5 mg/L would be more appropriate to suppress unwanted redifferentiation.

In summary, optimum callus growth was obtained on the lowest level of 2,4-D. The addition of kinetin to the callus induction medium modified callus growth based on varying 2,4-D concentrations and plant genotype. Kinetin enhanced the regeneration capacity of callus induced from Katy and LaGrue but made no difference for Alan. This investigation was a critical step in the development of a regeneration system for the application of biotechnological approaches to Arkansas rice improvement. This highly efficient, reproducible system will be used to develop genetic transformation techniques for these important rice cultivars. Another potential application of this regeneration system is the development of plants with desirable agronomic characteristics from in-vitro-selected mutant cell lines. To our knowledge there is no previous report on the regeneration of these rice cultivars.

Literature Cited


Proceedings Arkansas Academy of Science, Vol. 49, 1995

21
A $^{31}\text{P}$, $^{13}\text{C}$, and $^1\text{H}$ NMR Study of the Direct Interaction of Cocaine HCl and Magnesium ATP

Gene Lee Bangs and Roger M. Hawk
Department of Applied Science
University of Arkansas at Little Rock
2801 S. University Ave.
Little Rock, AR 72204

Debi Patangia
Central High School
1500 Park Street
Little Rock, AR 72202

Abstract

In vivo $^{31}\text{P}$ NMR studies recently have shown that cocaine causes an imbalance of the free magnesium in the brain which results in pH lowering, ischemia, and even death. This direct interaction with the free Mg$^{2+}$ in the brain also affects the Ca$^{2+}$ balance which controls arterial and vascular contraction. This research has addressed the mechanism of the cocaine interaction with magnesium adenosine 5-triphosphate (ATP) using $^{31}\text{P}$, $^{13}\text{C}$, and $^1\text{H}$ NMR using a Bruker 200 MHz nuclear magnetic resonance (NMR) system. Data are presented and discussed which shows that cocaine and ATP form a complex species which directly affects the NMR spectra.

Introduction

There are numerous articles on cocaine, cocaine diastereoisomers, isomeric cocaine, and tropepe alkaloids involving the use of NMR for structure elucidation, syntheses conformation, detection, quantification, solvation characterization, drug differentiation, etc. A representative number are listed (Jochims et al., 1967; Stenberg et al., 1976; Baker and Borne, 1978; Taha and Räcker, 1978; Allen et al., 1981; Liu et al., 1981; Carroll et al., 1982; Valensin et al., 1985; By et al., 1988; Dawson, 1991). There has been controversy regarding the carbon-13 peak assignments, but these have been confirmed (Awdovich and Neville, 1983).

Since cocaine and its analogues are drugs of abuse, there has been great interest in the medical and forensic community regarding their psychological and medical action. Recent in situ observations on the rat brain have shown that reduced intracellular levels of Mg$^{2+}$ result in rapid and progressive spasms of arterioles and venules followed by rupture of venules and capillaries leading to local hemorrhages and brain edema (Altura et al., 1991). Administered doses of cocaine have been shown to induce intracellular Mg$^{2+}$ deficits, ischemia, and stroke as observed by in vivo phosphorus-31 NMR of the brain (Altura et al., 1992). These findings have been related to imbalanced Mg$^{2+}$ gating action of Ca$^{2+}$ necessary for contractility in cerebral smooth muscle thereby causing cerebral vasospasm and stroke (Altura et al., 1993). Magnesium ion also stabilizes vascular endothelium and serves as an anticoagulant (Altura, 1988). Studies have shown that Mg$^{2+}$ can prevent excessive neurotransmitter release, as well as, block the N-methyl-D-aspartate (NMDA) receptor (Watkins et al., 1990). Phosphorus-31 has demonstrated sensitivity to cerebral energy metabolism and phospholipid changes in brain regions showing decreased levels of phosphomonoester and phosphodiester in the white brain matter of polysubstance abusing subjects. These cerebral tissue effects have been linked to chronic use of cocaine (MacKay et al., 1993). Numerous medical studies led the authors to speculate whether cocaine would directly interact with ATP and if so, was the interaction with the adenosine moiety of the ATP or with only the bound Mg$^{2+}$ ion attached to the ATP anion? To address these questions, proton, carbon, and phosphorus spectra were taken of cocaine HCl and ATP alone and then spectra were run for mixtures of the two compounds.

Materials and Methods

Proton NMR spectra were determined in deuterium oxide using a Bruker AC 200/52 spectrometer operating at 200.133 MHz; carbon NMR spectra were recorded in deuterium oxide using the same Bruker spectrometer operating at 50.323 MHz; the phosphorus spectra likewise were determined with the Bruker instrument operating at 81.015 MHz. All pertinent acquisition parameters are shown in Table 1. The proton and carbon spectra were measured in 5-mm tubes, using approximately .075 mM and .10 mM concentrations for the ATP and cocaine HCl solutions, respectively. The cocaine HCl/ATP mixtures were recorded in 5-mm tubes. The phosphorus spectra were obtained in 10-mm tubes with an external standard of phosphoric acid in an inserted 5-mm tube. An internal deuterium lock was used for all NMR samples. Chemical shift values are reported in parts per million.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
(ppm) relative to 4.63 ppm (the lower frequency of the HDO doublet due to proton exchange with the solvent D_2O) for proton spectra, whereas chemical shift values for carbon are reported in ppm values relative to acetonide (29.8122 ppm relative to tetramethyl silane (TMS)), and chemical shift values for phosphorus spectra were reported relative to phosphoric acid (Aldrich Chemical Company, Milwaukee, WI 53233). All samples were pH adjusted to approximately 7.0 using NaHCO_3 (Aldrich Chemical Company, Milwaukee, WI 53233) prior to data collection. All NMR solvents and standards were obtained from Cambridge Isotope Laboratories, Inc., Andover, MA 01810. ATP (Adenosine 5'-triphosphate magnesium from equine muscle) was obtained from Sigma Chemical Co., St. Louis, MO 63178. All spectra were run at room temperature (21°C).

Table 1. Acquisition parameters.

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Carbon</th>
<th>Hydrogen</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Width (µ sec)</td>
<td>50.523</td>
<td>200.153</td>
<td>81.015</td>
</tr>
<tr>
<td>Relaxation Delay (sec)</td>
<td>6</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>Sweep Width (Hz)</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Number of Scans</td>
<td>10,000</td>
<td>4,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Results and Discussion

Proton Spectra.—The proton spectra are shown in Fig. 1A. The proton peak assignments for the cocaine HCl (100 mM) and MgATP (0.075 mM) are shown in Table 2. Figures 4 and 5 summarize the numbering systems for the cocaine HCl and MgATP. The proton cocaine HCl assignments were made by comparisons with the literature (Carroll et al., 1982). Slight differences are attributed to solvent concentration, pH, and temperature effects. Our C4 protons are in a range of 2.22 ppm to 2.34 ppm and, therefore, cannot be distinguished. Further spectra run on the 300 MHz NMR would allow better resolution between the equatorial and axial protons. No assignments were made for the phenyl protons which are in the range of 7.27 to 7.77 ppm.

The MgATP assignments were made by comparisons with the literature (Davies and Danylik, 1974; Bock, 1980; and Jochims, 1967). Higher field experiments (300 MHz) would aid greatly in resolving the proton resonances in the 4.0-6.0 ppm range. These additional experiments are planned using a GE GN 300 NMR located at UAMS. The amine protons attached at the C6 position on the adenine ring are not resolvable from the HDO peak at 4.63 ppm.

A plot of H8, H2, H1', and H(5'5") chemical shifts versus increasing concentration of both MgATP and cocaine HCl (approximately 1:1 ratios) would indicate stacking as a result of ring-current shielding. ATP self-associates in solution due to base-stacking interactions and this ATP association complex is dependent on the concentration of the ATP concentration. In the complex, the charged phosphate of one ATP molecule interacts electrostatically with the charged adenine ring of the second ATP molecule. The two adenine rings are stacked head-to-head and the ATP molecule is in the anti configuration. (Lam and Kotowycz, 1977). These studies are planned. Additionally, relaxation measurement studies on protons H2 and H8, both in the presence and absence of 2% EDTA, will be used to access any increased contributions to intermolecular dipole-dipole mechanism from close neighbor cocaine HCl interactions. The viscosities of the solutions would be measured so that viscosity corrections (incorporated in the reorientational correlation time, τc, via the Stokes-Einstein relation (Hawk, 1973), could be made to the measured T1 values. Again these relaxation studies would be versus increasing concentration of both the MgATP and cocaine HCl (approximately 1:1 ratios).

Proton homonuclear NOE experiments, with irradiation of protons H2' and H3' will be done to measure signal enhancements of the H2 and H8 protons of the adenine ring versus concentration of both the MgATP and cocaine HCl (approximately 1:1 ratios). Only nuclei which are spatially close to the irradiated nucleus experience any observable intensity change with the absence of the 300 MHz NMR spectra. NOE difference experiments may be run which will aid in the study of the preferred conformations for the large flexible complex involving MgATP and cocaine HCl versus concentration ratios.

No 31P decoupling experiments were done to collapse the H(5'5") splitting patterns due to the coupling of the C(5') protons with the 31P of the exocyclic phosphate group. Higher field proton spectra (300 MHz) would be required to resolve the essentially coalesced multiplet at 200 MHz for the C(5'5") protons. Spin-decoupling experiments at the proper 31P frequency would collapse the C(5'5") proton multiplet. However, as a result of the near magnetic equivalence of the two C(5') protons, individual values for H(4')-H(5'), H(4')-H(5'5'), 31P-H(5'), and 31P-H(5') couplings could not be determined, but their sums, that is, J_{4'5'}+J_{4'5'5} and J_{4'5'}+J_{5'5'} could be determined. Additionally, 31P decoupling experiments would simplify the multiplet at 4.3 ppm due to the C(4') proton four-bond long-range coupling to give the coupling constant

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Table 2. Proton peak assignments.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solvent</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4_{AX,4eq}</th>
<th>5</th>
<th>CH_{3}N</th>
<th>CH_{3}O'</th>
<th>Phenyl-Protons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cocaine HC1 (.1 mM)</td>
<td>D_{2}O:CD_{3}COCD_{3} 95:5</td>
<td>4.09</td>
<td>3.41</td>
<td>5.37</td>
<td>22.22 to 2.54</td>
<td>3.93</td>
<td>2.74</td>
<td>3.47</td>
<td>7.27 to 7.77</td>
</tr>
</tbody>
</table>

Proton Chemical Shifts for Magnesium ATP at pH 7.0

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solvent</th>
<th>1'</th>
<th>2'</th>
<th>3'</th>
<th>4'</th>
<th>5'</th>
<th>5'</th>
<th>5'</th>
<th>2</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cocaine HC1 (.1 mM)</td>
<td>D_{2}O</td>
<td>5.90</td>
<td>Under HDO peak</td>
<td>4.40</td>
<td>4.24</td>
<td>4.12</td>
<td>7.95</td>
<td>8.26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

J^{31P,H(4')}. When the 5.5-8.5 ppm regions are compared in the mixture (Fig. 1C) with cocaine HC1 (Fig. 1A and MgATP (Fig. 1B), extra peaks are evident at 7.1 - 7.4 ppm. Additionally, in the region (1.0 - 4.0), the cocaine HC1 peaks are shifted (compare Fig. 1A and Fig. 1C), and there is the appearance of an additional peak at 3.0 ppm (Fig. 1C).
Phosphorus Spectra. -- The effect of the interaction of cocaine HCl and MgATP is shown in Fig. 2 where the splitting of the $\beta$ triplet and $\gamma$ doublet are greatly affected. This indicates an overlap of the two molecular species which influences the electron distribution in the phosphate groups. Plots of the $^{31}$P chemical shifts for the alpha, beta, and gamma resonances versus increasing concentration of both MgATP and cocaine HCl (approximately 1:1 ratios) would indicate stacking affects. It is anticipated that there will be insignificant changes in the $^{31}$P coupling constants between the phosphorus nuclei. The cocaine N and phenyl groups could interact with the adenine and phosphate groups of ATP through a similar base stacking association.

Carbon Spectra. -- 1. Cocaine HCl. The carbon-13 spectrum as shown in Fig. 3-A for .1 mM cocaine HCl in a solvent system, $D_2O:CD_3COCD_3$ (95:5), was compared to the literature (Avdovich and Neville, 1983) where slight ppm differences were attributed to solvent, concentration, and temperature affects. Additionally, the pH of the literature system may not have been adjusted to pH 7.0 as in our system. All peak assignments are listed in Tables 5 and 4.

II. ATP. The carbon-13 spectrum (Fig. 3-B) for .075 mM in $D_2O:CD_3COCD_3$ (95:5) shows the normal number of peaks (10 carbon environments) for the molecule. The solid sample was kept at approximately 0°C prior to dissolving in the solvent system to insure minimum degradation.

---

Fig. 2. Phosphorus-31 Spectra A. MgATP (.075 mM) in $D_2O$; B. MgATP (.062 mM); Cocaine NCl (.027 mM) in $D_2O$. 

Proceedings Arkansas Academy of Science, Vol. 49, 1995
III. Mixture of Cocaine HCl and ATP. The carbon-13 spectrum (Fig. 3C) for .027 mM cocaine HCl and .062 mM ATP in D$_2$O was compared to the carbon-13 spectra of .075 mM ATP and of .100 mM cocaine HCl (both in D$_2$O:CD$_3$COCD$_3$ (95:5)). The peaks are listed in Table 4. Five extra peaks at 23.565, 58.012, 49.189, 62.699, and 65.171 ppm were observed. All peaks were shifted 0.3 to 1.5 ppm away from the assigned peaks of C6 (or 7), NCH$_3$, C2, C5, and C8 of cocaine alone and are of interest. The four extra peaks at 128.470, 129.059, 129.572, and 134.218 ppm that are shifted 0.1 to 0.4 ppm from the assigned aromatic peaks of C3',5': C25': C1: and C4' for cocaine alone are also noteworthy. The two extra peaks at 70.212 and 84.003 ppm are in the aliphatic spectral region for ATP. This leads to the supposition that three molecular species are present in the mixed solution: free cocaine HCl, free ATP, and a complex of cocaine HCl/ATP. The areas of each molecule apparently involved in this interaction are the phenyl and 7 carbon ring of cocaine and some of the aliphatic carbons (and possibly the triphosphate group) of the ATP.

Conclusions

NMR spectra (shown in Figs. 1, 2, and 3) evidence that cocaine HCl and MgATP directly interact to form a complex species, at least under these concentrations, pH, and solvent system. Research (2D NMR-NOESY and COSY) is underway to determine connectivities between the proton and carbon environments. Samples will be degassed 5 times using the freeze-pump-thaw technique and then sealed in their respective tubes for the proton homonuclear NOE experiments or 2D NOESY experiments. The pD of all solutions will be 7.0. All nucleotide concentrations are determined using UV techniques. Samples will be prepared both with and without EDTA (2% as a mole fraction of the ATP concentration) to check for any effects arising from any trace metal ion impurities (Wasylishen and Cohen, 1974). Proton and carbon chemical shifts, as well as, relaxation times will be determined at 25°C. Commercial samples of nucleotides contain amounts of bound H$_2$O, and exchangeable acidic, base-ring, and hydroxyl protons. These contribute to a residual HDO peak which has obscured the ribose H2' peak in the MgATP spectrum shown in Fig. 1B. In future studies, the nucleotides will be lyophilized 5 times with 99.8% D$_2$O and the final lyophilized sample will be dis-
Table 3. Carbon-13 peak assignments.

Carbon-13 Chemical Shifts for Cocaine HCl at pH 7.0

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solvent</th>
<th>1,5</th>
<th>2,4</th>
<th>3</th>
<th>6,7</th>
<th>9</th>
<th>11</th>
<th>C=O</th>
<th>1'</th>
<th>2',5'</th>
<th>3',5'</th>
<th>4'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cocaine HCl (.1 mM)</td>
<td>D$_2$O:CD$_3$COCD$_3$</td>
<td>64.10 (1)</td>
<td>46.51 (2)</td>
<td>64.55</td>
<td>24.80*</td>
<td>39.06 (eq)</td>
<td>NCH$_3$</td>
<td>OCH$_3$</td>
<td>128.69</td>
<td>129.11</td>
<td>129.24</td>
<td>134.67</td>
</tr>
</tbody>
</table>

Carbon-13 Chemical Shifts for Magnesium ATP at pH 7.0

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solvent</th>
<th>1'</th>
<th>2'</th>
<th>3'</th>
<th>4'</th>
<th>5'</th>
<th>2</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>8</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg ATP (.075 mM)</td>
<td>D$_2$O:CD$_3$COCD$_3$</td>
<td>87.17</td>
<td>70.50</td>
<td>74.66</td>
<td>83.79</td>
<td>65.54</td>
<td>152.77</td>
<td>148.77</td>
<td>118.26</td>
<td>155.23</td>
<td>140.00</td>
<td></td>
</tr>
</tbody>
</table>

* Denotes interchangeable pairs of chemical shifts.

solved in 100% D$_2$O. If additional water suppression is required, presaturation will be the desired starting point.

Additionally, enriched $^{25}$Mg NMR studies are being pursued to ascertain whether cocaine HCl will directly bind to free Mg$^{2+}$.

Literature Cited


MacKay, S., D.J. Meyerhoff, W.P. Dillon, M.W. Weiner

Proceedings Arkansas Academy of Science, Vol. 49, 1995


Proceedings Arkansas Academy of Science, Vol. 49, 1995
Table 4
Comparison of the $^{13}$C spectral peaks for Cocaine HCl, MgATP, and the mixture of Cocaine HCl/MgATP

<table>
<thead>
<tr>
<th>Mixture Peaks</th>
<th>Cocaine HCl</th>
<th>Assignment</th>
<th>MgATP</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>173.50</td>
<td>173.38</td>
<td>C=O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>167.24</td>
<td>167.50</td>
<td>C=O(Me)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>155.57</td>
<td>155.23</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>152.45</td>
<td>152.77</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>149.07</td>
<td>148.77</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>140.07</td>
<td>140.00</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>134.54</td>
<td>134.67</td>
<td>C4'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*134.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>129.75</td>
<td>129.71</td>
<td>C1'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*129.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>129.16</td>
<td>129.24</td>
<td>C2',6'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*129.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>128.93</td>
<td>128.68</td>
<td>C3',5'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*128.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>118.63</td>
<td></td>
<td></td>
<td>118.26</td>
<td>5</td>
</tr>
<tr>
<td>87.22</td>
<td></td>
<td></td>
<td>87.17</td>
<td>1'</td>
</tr>
<tr>
<td>#84.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>83.84</td>
<td></td>
<td></td>
<td>83.79</td>
<td>4'</td>
</tr>
<tr>
<td>74.57</td>
<td></td>
<td></td>
<td>74.66</td>
<td>3'</td>
</tr>
<tr>
<td>70.51</td>
<td></td>
<td></td>
<td>70.50</td>
<td>2'</td>
</tr>
<tr>
<td>#70.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65.51</td>
<td></td>
<td></td>
<td>65.54</td>
<td>5'</td>
</tr>
<tr>
<td>*65.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64.61</td>
<td>64.55</td>
<td>C3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>64.08</td>
<td>64.10</td>
<td>C1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>63.27</td>
<td>63.29</td>
<td>C5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*62.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53.50</td>
<td>53.44</td>
<td>OCH$_3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*49.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46.29</td>
<td>46.31</td>
<td>C2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39.07</td>
<td>39.06</td>
<td>NCH$_3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*38.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32.92</td>
<td>32.82</td>
<td>C4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23.86</td>
<td>23.89</td>
<td>6 (or 7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*23.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.81</td>
<td>22.79</td>
<td>7 (or 6)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Extra Cocaine peak  # Extra ATP peak

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Carnations (Dianthus caryophyllus L.) are among the most widely used cut flowers in the world. Tissue culture techniques offer an efficient method for the micropropagation of carnations. This study was conducted to test the effect of thidiazuron (TDZ) and benzylaminopurine (BAP), artificial cytokinins, on shoot multiplication of two carnation cultivars, Barlo II Nora and Raggio di Sole. Isolated axillary buds were cultured on Gamborg's (B-5) basal medium supplemented with 30 g/L sucrose and 8 g/L agar. The cultures were maintained at a 10-h photoperiod (40 μEm²/s¹) and 23°C±2°C. Number of multiple shoots produced was dependent upon the genotype and was also influenced by the cytokinin type and concentration. Barlo II Nora produced the highest shoot number with 14 shoots per explant on a medium containing 20 mg/L BAP. The cultivar Raggio di Sole cultured on BAP-containing media produced a maximum of 4 shoots per explant. Barlo II Nora cultured on TDZ-containing media produced a maximum of 8 shoots per explant, however, large amounts of calli were associated with these shoots. Increasing the concentration of cytokinin was associated with an increase in shoot number and a decrease in shoot height. Shoots were rooted on Gamborg's medium containing 2 mg/L of 3-indole-butyric acid (IBA) and then transferred to pots. Once acclimatized the carnations were transferred to a greenhouse where they exhibited normal growth. This method could be useful for the rapid propagation of carnations in commercial production.

Introduction

Carnations (Dianthus caryophyllus L.) are among the three most important cut flowers in the world. Tissue culture of carnation has progressed rapidly from the first application as a means of virus elimination to its current extensive use in micropropagation. Adventitious shoot regeneration of carnation has been achieved with many different explants varying from hypocotyls (Petru and Landa, 1974), petals (Gimelli et al., 1984; and Frey and Janick, 1991), ovules (Demmink et al., 1987), anthers (Villalobos, 1981), leaf (Altvorst et al., 1992), nodal stems (Roest and Bokelmann, 1981), axillary buds (Choudhary, 1991; Miller et al., 1991), to shoot tips (Johnson, 1980).

Axillary bud culture can be used for the clonal multiplication of carnations since there is no callus phase, and therefore, the shoots that develop are genetically identical to the parent (Broerjies and Keen, 1980). This technique can also be used for crop improvement through Agrobacterium-mediated transformations since the lack of a callus phase reduces the chance of somaclonal variation (Altvorst et al., 1992). Explant, culture environment, plant genotype, and hormonal type and concentration affect the regeneration capacity of a plant, with the parental genotype potentially exerting the greatest influence (Gimelli et al., 1984). The intent of this study was to evaluate the effectiveness of axillary bud explants in the micropropagation of two carnation cultivars which have not been previously reported.

The objectives of this experiment were to: 1) test the effect of thidiazuron (TDZ) and benzylaminopurine (BAP) on shoot multiplication, 2) examine the genotypic response of cultivars Raggio Di Sole and Barlo II Nora to shoot multiplication treatments, and 3) induce the rooting of regenerated shoots and the establishment of plants in soil.

Materials and Methods

Disinfection of plant material.--This study was conducted with rooted cuttings obtained from California Florida Plant Co. (P.O. Box 5310 Salinas, CA 93915). Roots and leaves were removed and the stems were washed thoroughly with tap water. The plant material was then washed in a diluted soap solution (5 drops liquid soap/L of water) and surface-sterilized for 30 s in 70% ethanol followed by immersion for 20 minutes in 20% vol/vol Clorox (commercial bleach) containing 3 drops of Tween 20, a detergent, (Sigma Chemical Company, St. Louis, MO) per 100 ml Clorox solution. The plants were then rinsed 4 times with sterile distilled water. The axillary buds were aseptically removed (Fig. 1) and cultured onto 16 x 100-mm culture tubes (5ml/tube) with the basal
end inserted into the medium.

**Fig. 1.** Carnation axillary bud being removed in preparation for culturing.

**Culture medium and conditions.**—The culture medium contained Gamborg's salt (Gamborg et al., 1968) augmented with 70 mg/L myo-inositol, 50 mg/L casein hydrolysate, 0.1 mg/L d-pantothenic acid, 1 mg/L nicotinic acid, 1 mg/L pyridoxine-HCl, 1 mg/L thiamine-HCl, 2 mg/L glycine, 30 g/L sucrose, and 8 g/L tissue culture grade agar [Agar-agar/Gum agar](Sigma). The pH of the medium was adjusted to 5.7 with 1 N KOH and 1 N HCl. To test the in vitro response of the cultivar Raggio di Sole, the medium was supplemented with one cytokinin (BAP) at 2.5, 5, 10, 15, and 20 mg/L. To test the in vitro response of the cultivar Barlo II Nora, the medium was supplemented with the same concentrations of BAP or TDZ at 0.01, 0.05, 0.5, and 1 mg/L. The media were autoclaved at 121°C and 1 x 10^6 Pa (10.8 N/cm²) for 15 min.

Cultures were maintained at 23°C±2°C under a 10-h photoperiod of cool-white fluorescent light (40 μE m⁻² s⁻¹). Six weeks after culture initiation, data were taken on number of explants that exhibited multiplication, number of shoots per explant and shoot length. Observations on callus formation and shoot vitrification were also made.

**Plant establishment.**—Regenerated shoots were rooted in GA-7 Magenta vessels (Magenta Corp., Chicago, IL) containing 50 ml of rooting medium which consisted of the same medium used in multiplication, except the cytokinins were replaced with the addition of 2 mg/L of IBA. After 3 weeks in culture, the plantlets were removed from the culture vessels and the roots washed to remove the agar. Plantlets were transplanted into pots containing a potting mix (Redi-Earth Peat-Lite Mix, Grace-Sierra Hort. Products Co., Milpitas, CA), then misted and covered with clear plastic containers to maintain high humidity. The misting and cover was gradually reduced to acclimatize the plants to the ambient atmosphere. The plantlets were maintained under cool-white fluorescent light for 3 weeks after which they were transferred to a greenhouse.

**Results and Discussion**

The explants began to enlarge within 24 h of culturing. After 4 to 5 days shoot growth was observed from the buds and, in six weeks, multiple shoots developed (Fig. 2). The percent shoot multiplication for Barlo II Nora was 100 percent at all BAP levels. This cultivar showed increases in average shoot number with increased concentrations of BAP (Table 1). Levels of BAP higher than 20 mg/L may further promote shoot multiplication and merits further study. There seems to be a negative correlation between BAP concentration and shoot length (Table 1). This is in accordance with the findings of Sankhla et al., (1994) with silktree shoots.

**Fig. 2.** Shoot multiplication from axillary bud of carnation.

Callus formation was observed at the base of the explants. The percent of explants that produced calli varied from 70 to 90 percent. The presence of a callus is not desirable in shoot multiplication and, therefore, treatments that produce minimal or no callus are preferred. The calli produced on BAP-containing media (2.5 to 1.5
mg/L) were approximately 3 mm or less in size and increased to 3 to 6 mm as the concentration increased to 20 mg/L (Table 1). Callus production, however, did not interfere with the shoot multiplication.

Table 1. Effects of BAP on shoot multiplication and callus formation in the carnation cultivar Barlo II Nora.

<table>
<thead>
<tr>
<th>BAP (mg/L)</th>
<th>%¹ Shoot² Shoot Length (cm)±SE</th>
<th>Callus Formation %³ Callus Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>100 4.9±1.1 2.5±1.0</td>
<td>70 small</td>
</tr>
<tr>
<td>5</td>
<td>100 6.2±1.9 3.8±0.6</td>
<td>80 small</td>
</tr>
<tr>
<td>10</td>
<td>100 7.7±1.1 2.6±1.0</td>
<td>60 small</td>
</tr>
<tr>
<td>15</td>
<td>100 13.0±2.0 1.4±0.4</td>
<td>70 small</td>
</tr>
<tr>
<td>20</td>
<td>100 14.0±1.5 1.2±0.3</td>
<td>90 medium</td>
</tr>
</tbody>
</table>

¹Percent of explants which produced multiple shoots.
²Mean shoot number ±SE (n=10).
³Percent of explants which produced callus (n=10).
⁴Relative callus size (diameter): small <5mm, medium 5-6mm, large >6mm.

The percentage of explants that produced multiple shoots from Raggio di Sole at 2.5 mg/L was 70 percent. The mean shoot number per explant in Raggio di Sole increased with the increase of BAP up to 15 mg/L where it appeared to level off (Table 2). The maximum mean number of shoots produced is significantly less than that of Barlo II Nora. This difference may be attributable to the genotype, since the plant genotype has been shown to be an important factor in plant regenerability (Gimelli et al., 1984). Shoot length decreased with the increase of BAP concentration.

Table 2. Effects of BAP on shoot multiplication and callus formation in the carnation cultivar Raggio di Sole.

<table>
<thead>
<tr>
<th>BAP (mg/L)</th>
<th>%¹ Shoot² Shoot Length (cm)±SE</th>
<th>Callus Formation %³ Callus Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>70 1.5±0.3 6.4±1.4</td>
<td>70 small</td>
</tr>
<tr>
<td>5</td>
<td>90 2.5±0.4 5.5±1.5</td>
<td>90 small</td>
</tr>
<tr>
<td>10</td>
<td>100 3.7±0.5 4.5±1.5</td>
<td>80 small</td>
</tr>
<tr>
<td>15</td>
<td>100 4.1±0.5 4.0±1.0</td>
<td>90 medium</td>
</tr>
<tr>
<td>20</td>
<td>100 4.0±0.6 2.0±0.5</td>
<td>80 medium</td>
</tr>
</tbody>
</table>

¹Percent of explants which produced multiple shoots.
²Mean shoot number ±SE (n=10).
³Percent of explants which produced callus (n=10).
⁴Relative callus size (diameter): small <5mm, medium 5-6mm, large >6mm.

Shoot multiplication of 40% was obtained from explants of Barlo II Nora cultured on a medium containing 0.1 mg/L TDZ. The addition of 0.01 to 0.5 mg/L TDZ to Barlo II Nora did not significantly affect the shoot number (Table 3). The low mean shoot numbers obtained in these two treatment could be attributed to the large amounts of callus that formed. Treatments containing BAP, produced less callus than TDZ-containing treatments (Table 1 and 3). The addition of 1 mg/L TDZ caused a significant increase in shoot number. Concentrations higher than 1 mg/L TDZ may further promote shoot multiplication for this cultivar. As was observed with BAP, the shoot length decreased with increasing TDZ concentrations.

The callus size obtained on 0.01 mg/L of TDZ ranged from 3-6 mm. All other treatments produced calli larger than 6 mm (Table 3). The large quantity of callus tissue produced in these treatments appeared to inhibit shoot multiplication. However, at a 1 mg/L TDZ the increase in shoot number is attributed to the high level of cytokinin that may have had overriding activity on the callus affect (Table 3). Vitrification is a common problem in carnation micropropagation (Lesham, 1989). The amount of vitrification observed in this study, 7% of regenerants, was negligible. The rooted plantlets were transferred to a green house where they displayed normal growth.
Conclusions

There was a significant difference in the average number of shoots produced between the cultivars; Barlo II Nora produced higher average shoot numbers than Raggio di Sole. Within the BAP concentrations in this experiment, the optimum range was between 15 and 20 mg/L. Levels of BAP higher than 20 mg/L may further promote shoot multiplication for Barlo II Nora. The amount and percent of callus produced with BAP did not seem to be a limiting factor for shoot multiplication in either cultivar.

The optimal TDZ concentration within the range tested was 1 mg/L, which resulted in a maximum average of 8.3 shoots per explant in Barlo II Nora. The shoot length tended to decrease with increasing cytokinin concentrations. Large amounts of callus were produced on TDZ-containing media. The addition of 1 mg/L of TDZ to the multiplication media promoted shoot multiplication. Higher levels of TDZ may further increase shoot multiplication for this cultivar.

The maximum shoot numbers obtained in our study were higher than those previously reported for carnation axillary bud explants (Miller et al., 1991; Choudhary, 1991). This study resulted in the development of a micropropagation system for these two genotypes. Furthermore, it provided an improvement in shoot multiplication of axillary buds that could be applied to other cultivars. The fact that the highest multiplication was achieved at the highest concentration of cytokinin tested indicates the possibility of further increase of the multiplication rate with the increase in concentration of these cytokinins. This is an area that merits further investigation.

Literature Cited


Proceedings Arkansas Academy of Science, Vol. 49, 1995
A Conceptual Basis for an Index of Forest Integrity for Upland Coastal Plain Ecosystems

Nicholas R. Brown, Brian R. Lockhart, Philip A. Tappe, Lynne C. Thompson, Robert C. Welh, Jr. and Richard A. Williams
Arkansas Forest Resources Center, School of Forest Resources
University of Arkansas at Monticello
Monticello, AR 71656

Abstract

Following the recent trend to manage natural resources for "sustainability," ecologists, resource managers and policymakers are beginning to think of the management of forest ecosystems in terms of "ecosystem health" or "ecosystem integrity." Biologists are increasingly recognizing that use of chemical assays in assessing the condition of an ecosystem has limited value, and that biological factors, e.g., species diversity and composition, can be useful characters in the analysis of "biotic integrity." An index of biotic integrity (IBI) has been developed for riverine ecosystems in the Midwest U.S., using fish species diversity, indicator population analysis, trophic structure assessment, and physiological abnormalities in fish as measurable surrogates for "biotic integrity". This paper explores the development of an analogous index of forest integrity (IFI) to be applied to the upland coastal plain forests of southern Arkansas and northern Louisiana. The IFI developed here includes sampling and analysis of population trends of dominant plant taxa, plant species diversity, and horizontal and vertical vegetative structure at midstory, shrub and detritus levels.

Introduction

The term biotic integrity was coined by Karr (1981) in a paper concerning the monitoring of stream ecosystems in Illinois. Karr reasoned that the use of biological parameters is a more proximal and, therefore, more accurate approach to understanding biological systems than the use of chemical assays. His fish monitoring system was intended to quickly and accurately assess the "health" of riverine ecosystems, thereby superseding the use of water chemistry measures as ecosystem health monitoring tools. The system is based on seven measures of diversity and five measures of population and guild structures (Table 1).

Table 1. Parameters for Aquatic Index of Biotic Integrity. After Karr (1981).

<table>
<thead>
<tr>
<th>Species composition and richness</th>
<th>Population and guild analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of species</td>
<td>Number of individuals per sample</td>
</tr>
<tr>
<td>Presence of tolerant species</td>
<td>Proportion of omnivores</td>
</tr>
<tr>
<td>Richness and composition of darters</td>
<td>Proportion of insectivorous cyprinids (carp and minnows)</td>
</tr>
<tr>
<td>Richness and composition of suckers</td>
<td>Proportion of top carnivores</td>
</tr>
<tr>
<td>Richness and composition of sunfish (except green sunfish)</td>
<td>Proportion of abnormal individuals (e.g., disease, tumors)</td>
</tr>
<tr>
<td>Proportion of green sunfish</td>
<td></td>
</tr>
<tr>
<td>Proportion of hybrid individuals</td>
<td></td>
</tr>
</tbody>
</table>

Karr termed his system an index of biotic integrity (IBI). Its utility lies in its simplicity and cost-effectiveness, as the necessary field data can be collected from a site in one or two days of field work with basic equipment. Subsequent to Karr's work in Illinois, it has been used to assess the environmental quality of streams in Wisconsin (Lyons, 1992) and Ohio (Gatz and Hartig, 1993).

The IBI does not transfer readily to terrestrial ecosystems, because trophic structures are not as readily distinguished and assessed, and because the trapping of mammals, insects and herpetofauna, and the censuring of birds are far more time-consuming and costly than the capture and release of fish. The study of metabolic processes (e.g., analysis of nutrient budgets, analysis of productivity and respiration rates, and energy flows) might provide significant insight into the "integrity" of an ecosystem, but like animal population studies, those studies are also expensive and complex.

Recognizing the practical and budgetary limits posed by zoological and ecosystem-level studies, and the conceptual limitations associated with the use of abiotic factors as indicators of integrity, we began to look for other, more easily-obtained biological metrics that might serve as surrogates for zoological and ecosystem balance characters. We determined that plant species composition and structure, which is known to define habitat for animal species (Webb, 1948; MacArthur and MacArthur, 1961; Otte, 1976), can be used to characterize the completeness and level of forest ecosystem functionality, and are there-
by a suitable basis for assessing forest integrity. We have termed our approach an index of forest integrity (IFI).

Discussion

The integrity of very small forest stands is dependent upon size. They lack the coolest and most humid regions; they have lower species richness; their reproductive processes are higher risk and they are more likely to be adversely disturbed by humans than larger areas. Edge effect creates an environment different from forest interior. Edge effect can be detected up to 100 m toward the interior of an ecotone (i.e., forest boundary) for plants (Matlack, 1994) and up to 200 m toward the interior for birds (Cieslak, 1994). This limits the utility of community diversity analysis in stands smaller than 20 ha, depending on the shape of the stand. Each taxon has its unique sensitivity to habitat boundary.

Landscape-level analysis (e.g., > 500 ha or 1000 ha) is often hampered by disjunctive land ownership, natural patchiness, and fragmentation caused by farms, highways and other developments. At the landscape scale, natural β diversity (between stands) patchiness begins to confound α diversity (within-stand) analysis.

A stand (or habitat or site) is often somewhere in between these sizes. The IFI is designed to assess stands (or habitats or sites) within this size range that are relatively homogeneous in vegetative association. From a practical standpoint, forests often manage compartments of 20 to 50 ha, so this is a useful scale for analysis. Larger areas might also be evaluated if natural patchiness and land use histories do not prevent it. In stands several hundred hectares or larger, β diversity begins to dominate over α diversity (within stand), and the evaluation would be modified accordingly.

The IFI assesses sites in relation to two conditions. First, it is compared with the plant community composition before industrial forestry began making major modifications to the Gulf Western Coastal Plain [See Galatowitsch (1990) and Cornett (1994) for methods. Foti and Glenn (1991) have also used this technique in the Ouachita Mountains]. This composition is derived from tree species and density data from 1830s land surveys that are available at each county's courthouse and at the State Land Commissioner's Office.

The second condition against which the IFI can be held is an "optimally managed" forest stand. We are soliciting consensus (via mail poll) about the meaning of "forest integrity" from scientists, policymakers, hunters/fishers, wildlife managers, foresters, forest land owners, and environmentalists. The model for forest integrity based on forest management concerns will be constructed with the results of that poll.

In development of the ecology-based IFI model, we evaluate three areas of vegetative diversity and forest physical structure (Table 2): 1) population dynamics of dominant tree species; 2) α diversity of trees, shrubs and herbaceous vascular plants; and 3) physical vegetative structure of the stand (e.g., canopy cover; shrub, midstory, and canopy densities; leaf area indices; and vertical and horizontal vegetative profiles).

| Table 2. Parameters for index of forest integrity. |
|----------------|---------------------------------|-----------------|
| Population     | α diversity and similarity indices | Vegetative      |
| dynamics       |                                | structure       |
| dominant tree species | woody species | leaf area index |
| co-dominant tree species | vascular herbaceous species | ground cover |
| pioneer tree species | test site/natural site comparisons | canopy cover |
|                  | test site/desired site comparisons | vertical profile |

The decline of dominant species is sometimes a sign of a community in transition, and is often an indication of disturbance. In managed forest stands, dominant species can decline because of overharvesting of marketable species, or because inadequate regeneration was in place before harvest was undertaken. More generally, population declines occur when a community is subjected to stresses that change the balance of resource availability among existing species, and which allow new opportunities for opportunistic or pioneer species. Tree species provide habitat and physical structure for birds, insects and small mammals, they alter the thermal regime through direct shading and evapotranspiration; they create significant amounts of detritus which is vital to ground insects and they provide food resources for many taxa of forest inhabitants. Accordingly, the integrity of the forest is closely associated with the vigor of tree population structures.

Because every site has a unique level of maximum species diversity, the question of whether a site is represented by a full complement of species that might "naturally occur" is a difficult one. In reality, practically all sites have been compromised in this regard, so the theoretical maximum species diversity for a site is not of practical importance. Therefore, existing diversity (at all levels) is interpreted as a fraction of a theoretical maximum. High species diversity corresponds with completeness, and lower species diversity corresponds with missing components. Low diversity also suggests reduced redundancy, which can limit the ecosystem's functionality.

Over the past century, many measures have been developed to assess species diversity (Baev and Penev, 1995). Most indices of species diversity evaluate some aspect of evenness (dominance), or richness (total number of species) or both of these. The IFI uses several
indices which evaluate evenness, dominance and similarity between sites.

Vegetative, dead wood and detrital structure have long been recognized as key factors in determining the number of niches in a habitat, and therefore the extent of species diversity at the habitat or stand level. In particular, more physical complexity has been correlated with larger deer populations (Webb, 1948), higher bird diversity (MacArthur and MacArthur, 1961; Whittaker, 1970), higher gastropod diversity (Kohn and Leviten, 1976), and higher orthopteran diversity (Otte, 1976). Field methods of determining and quantifying the complexity and patchiness of vegetation have been available for over a half century (Wight, 1939). MacArthur and MacArthur (1961) and Nudds (1977) further refined techniques for using a "density board" or "vegetation profile board" to assess physical vegetative structure. The IFI uses density board readings at several horizontal distances and heights through the understory and midstory. Volumes of dead wood and detritus are measured. These structural measures provide a surrogate for insect and small mammal habitat quality.

The IFI described here is an attempt to assess habitat, population, and community viability, through the simple and inexpensive measurement of vegetative parameters. Field data are being collected in the 1995 field season. Analysis of these data will determine which of the factors discussed above are the most robust, and how they must be weighted in order to best distinguish among sites of varying integrity.

Acknowledgments.—The authors wish to express appreciation for financial support from the Arkansas Forest Resources Center, a University of Arkansas Center for Excellence which is partly funded by the USDA/Cooperating State Research, Extension and Education Service; and from Georgia-Pacific Corporation. Ideas expressed in this paper are those of the authors, and may not represent the views of these funding sources. We also appreciate helpful reviews and useful suggestions by Chris Bennett, Yanfei Guo and Boris Zeide.

Literature Cited


Creation and Implementation of a Tracking Module for a Small-Geometry, Vertex Time Projection Chamber

Christine A. Byrd, Wilson H. Howe, Amber D. Climer and W.J. Braithwaite
Department of Physics and Astronomy
University of Arkansas at Little Rock
Little Rock, AR 72204

Abstract

A charged-particle tracking module was written and tested using pixel data generated from CERN’s Monte Carlo detector-modeling program GEANT. This tracking module was customized for testing the design of a micro-strip gas time projection chamber, designed by Drs. Margetis and Wieman of the Relativistic Nuclear Collisions Group at Lawrence Berkeley Laboratory. This low-mass, high-resolution, small-geometry vertex time projection chamber was designed for possible use with a larger instrument in an experiment using the relativistic heavy ion collider, RHIC, under construction at Brookhaven National Laboratory in New York. Implementing this tracking module involved generating tables and source code in a manner which is accessible to any user who is familiar with general purpose programming, using event-based data-processing. This charged-particle tracking module project was initiated in Summer-1994 as part of a 10-week, undergraduate research project at Lawrence Berkeley Laboratory, sponsored by LBL’s Office of Science and Engineering Education. Further research on this project is underway at UALR.

Introduction

The Relativistic Heavy Ion Collider (RHIC) is currently under construction at Brookhaven National Lab (BNL) in Upton, New York. RHIC is scheduled to be completed in 1999. It will be used to accelerate two gold nuclei to within 1 part in 20,000 of the speed of light. At these speeds, each gold nucleus in the colliding pair has a kinetic energy over 100 times its rest mass energy and relativistic effects must be taken into account. Densities in the hot spot of the collision can reach up to 20,000 times that of a neutron star. The Standard Model predicts pairs of colliding gold nuclei will form a Quark-Gluon-Plasma (QGP), a state in which quarks and gluons are deconfined. It is believed that the QGP was the dominant form of matter in the universe during the first microsecond after the big bang (Schukraft, 1993).

To detect the QGP by examining its decay products, detectors are being built around the RHIC beam pipe. QGP is extremely short-lived, breaking up into thousands of secondary particles. The goal of the detectors at RHIC is to pick up signatures of the QGP secondary charged particles which are emitted as the QGP expands and cools. By detecting these secondary charged particles, researchers will be investigating the behavior of strongly interacting matter at high energy densities. One of the main detectors being built at RHIC is the solenoidal Tracker (STAR). STAR is comprised of a solenoidal magnet containing six sub-detectors. This magnet surrounds the beam pipe, providing a uniform magnetic field along the beam axis. Charged particles bend in this magnetic field, allowing a determination of both charge and momentum from the measurement of track curvature, using track data reconstructed in the subdetectors (Sauli, 1987).

The presence of a large amount of strange matter is one signature of a QGP. The abundance of strange quarks is observed by detecting kaons and lambda particles, which contain strange quarks.

The Vertex Tracker (VTX) is a small, low-mass, high-resolution, vertex time projection chamber (TPC) with a Micro-strip read-out. This technology is being explored to provide tracking in the forward region, close to the beam-pipe, and is the subject of a feasibility study underway as part of STAR’s flavor physics program. This type of detector could potentially provide tracking at smaller polar angles, more space-point measurements per track and less material than would a silicon system placed in this region (Angellini et al., 1990).

Materials and Methods

The VTX design is fairly simplistic, consisting of a cylindrical gas-filled drift volume (of length 20-cm) with an electric field in the center parallel to the magnetic field of the detector solenoid (Wieman and Gong, 1994). The read-out endplate is a glass substrate with thin metal anode and cathode strips. When a charged particle passes through the detector it ionizes the gas. The ionization electrons drift up towards the 4 rows of pads on each end of the detectors and their signals are channeled into the
data acquisition system. The measurement of the z-coordinate of the track is provided by a timing measurement. r and phi coordinates are provided by an array of crossing strips on the micro-strip endplates. This enables tracking at smaller polar angles and more space-point measurements per track.

In this study, software was created to analyze and process the data by tracking particles passing through the VTX. The particle tracking software for VTX is based upon a previously developed grouping algorithm (Prindle, 1993). This algorithm is based on the assumption of particle trajectories being nearly straight lines over small arc-lengths measured in the VTX-TPC. Reconstructed points are mapped onto a phi-z space. Each group on the phi-z map is a set of points topologically consistent with having been created by a single charged particle. The z axis is defined in the direction of the beam (which is the same direction as the solenoidal magnetic field), r is defined as the line created by the track, and phi is an angle defined in Fig. 1.

![Tracking geometry for the STAR TPC.](image)

Fig. 1. Tracking geometry for the STAR TPC.

The detector software used by the STAR collaboration is run within the TPC Analysis Shell, (TAS), a general purpose analysis program for event-based data processing. TAS consists of modules containing tracking software and information about the geometry of the corresponding detector. The data is processed as a sequence of steps from raw data into physics summary data. TAS uses data structures called tables, which are 2-dimensional objects with columns and rows, which record data at any stage of event processing (Olson, 1993).

Simulations of particle transport following central Au-Au collisions were run using the CERN (Center for European Nuclear Research) Monte Carlo detector-design package (GEANT, 1994), with properly defined geometries. A file was created in a special post-GEANT format, which was run through TAS to create tables which were filled with the results of the simulation data. The first stages of this analysis consisted of implementing and adding a new tracking module to TAS. To implement tracking, tables and source code were generated which could be accessed within TAS.

The source code input consists of TAS tables defining the TAS structures themselves (libraries, etc.) as well as vertex information, kinematics information, and table holding specific GEANT data about the particles. The output is a table which records the input data processed into data pixels.

The code first sets up a pixel map to which the hit data is transferred. The maximum number of hits per pixel is specified as well as the number of bins in phi and z-scaled. The minimum and maximum phi and z-scaled values are specified as well, and routines are called to reset the pixel map after each search, to add points to the pixel map, and to check for hits surrounding the particular hit being considered.

The code loops through all the points in the table holding the Monte Carlo data and reads the data in. Space-point data are read in cartesian coordinates, and are converted to cylindrical coordinates.

The hits in cylindrical coordinates are transferred to the phi-z pixel map. Clusters of 3 or 4 hits form on the pixel map. The code starts at the first pixel (lower left-hand corner) and searches for all the hits within it. Each hit is marked as having been recorded in pad-row one, two, three or four. The code opens its box-size (window) in four passes. In each pass the box-size is doubled. The code searches for a set of a minimum of three and maximum of four hits, consisting of one hit from each pad row. This set of three or four hits constitutes a group or track.

Another piece of software called the EVALUATOR, was written to run outside TAS. Once the tracking software has created tracks, the EVALUATOR takes the tracks and calculates the maximum distance in phi and z for each hit in every track and checks to see if the grouper's reconstructed tracks are reasonable. If a track fails this test it is marked as a wrong track. The EVALUATOR was used to determine the efficiency of the tracking algorithm.

One of the strongest features the VTX has to offer is
its low mass. The tracking software was tested adding the effects of multiple coulomb scatterings, and subsequently, adding both the effects of coulomb scattering and point smearing. Point smearing accounts for the error in the electronics. This was done by writing a short code simulating these effects and adding them to the tracking software.

Results and Discussion

The grouping algorithm projects points radially in r, while phi is projected to the middle of the pad planes (Prindle, 1993). The maximum distance in phi (dphi) of the projected points in each cluster versus the transverse momentum as well as maximum distance in z (dz) versus transverse momentum are shown in Fig. 2. The first two plots are without multiple coulomb scattering, and the second two with multiple coulomb scattering. This figure shows multiple scattering effects in the detector are negligible.

![Fig. 2 Four plots from a central Zn + Au collider event. The bottom two plots include Multiple Coulomb Scattering, but the top two plots do not.](image)

Figure 3 shows plots of the maximum distance in phi (dphi) and in z (dz) versus transverse momentum respectively with Multiple Coulomb scattering and "smeared" points. Comparing the Fig. 3 plots to the previous Fig. 2 [dphi/pt and dz/pt] plots, we see that smearing has its dominant effect on the momentum curve for primaries generated by a central Au + Au event.

![Fig. 3 These plots show the effect of smearing due to Multiple Coulomb Scattering on the momentum curve, for secondaries generated from a primary, central Au + Au event.](image)

Figure 4 shows plots of secondary tracks of 3 groups of 1000 neutral Kaon events. The efficiency for these charged secondaries for dz less than 0.1 cm is much less than that for primaries (at about 8.5%). This suggests that the box size in the pixel map must be optimized or another approach must be followed for the tracking of secondaries. The problem with increasing the box-size is that electron contamination becomes a problem. The problem with tracking these secondaries is currently being researched.

Acknowledgments.—Support was provided by the U.S. Department of Energy through Grant DE-FG05-93ER40753, and from the STAR Collaboration. The first three authors acknowledge support from the UALR Donaghey Scholars Program and from the Lawrence Berkeley Laboratory Summer Research Fellowships. This manuscript is part of the bachelor of science senior thesis of Christine A. Byrd for the honors program in physics, partially fulfilling her senior-project requirement for the Donaghey Scholars Program at the University of Arkansas at Little Rock.
Fig. 4. Plots of secondary tracks from neutral Kaons.

Literature Cited


GEANT. 1994. GEANT user's guide: Detector Description and Simulation Tool, CERN Program Library Internal document, CERN Data Division, Geneva, CH.


Nuclear Physics A 553:31c-44c.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Arkansas’ Wellhead Protection Program with Discussion of Delineation Methodology

Robert Cordova and Bobby Makin
Department of Health
Division of Engineering
4815 West Markham (Slot 37)
Little Rock, AR 72205

Abstract

The Wellhead Protection (WHP) program was authorized by the 1986 Amendments to the Safe Drinking Water Act. The Arkansas Department of Health in July, 1986, was designated by Governor Clinton to be the lead agency in carrying out the WHP program. The program is designed to protect the ground-water resource tapped by public water-supply wells from contaminants which are injurious to the public health. It is the first formal attempt by the federal government in its environmental protection role to prevent contamination from taking place, in contrast to costly clean-up or remediation programs. Among its several requirements, the program includes: 1) delineating a wellhead protection area for each well or wellfield; 2) identifying all potential man-made sources of contaminants injurious to public health within each WHP area; and 3) developing outreach activities for increasing public awareness. Some major accomplishments since program start-up in 1991 include delineations for more than 200 wells and implementation of the WHP program for more than 50 public water systems. Since the actual implementation of the program, experience and investigation have shown that several methods of delineation are usable in Arkansas. Some methods are most pertinent to aquifers in the Coastal Plain and others to aquifers in the Interior Highlands.

Introduction

The Wellhead Protection program is part of the 1986 Amendments to the Safe Drinking Water Act. The program is designed to protect the ground-water resource tapped by public water-supply wells from contaminants which are injurious to the public health. The program is the first formal attempt by the federal government in its environmental protection role to prevent contamination from taking place, in contrast to costly clean-up or remediation programs. The WHP program applies to existing and to future public water-supply wells.

The Arkansas Department of Health in July, 1986, was designated by Governor Clinton to be the lead agency in carrying out the WHP program. As lead agency, ADH administers the program by guiding its development, coordinating the wellhead protection activities with other state agencies and organizations, providing the technical expertise and assistance required to implement the local programs, developing a management framework, and by encouraging the public to actively participate in the implementation of the program.

A question that may be reasonably asked is why is such a program needed. Three good reasons answer this question:

1.) Arkansas uses a lot of ground water: for all purposes, 17,820,348 cubic meters (4,708 million gallons) per day based on 1990 figures. To put such a large number in perspective, Arkansas’ usage is about 25 percent of that of California, about 55 percent of that of Texas, and Arkansas is 7th among all the states in ground-water usage. The fact that such an enormous amount of ground water is pumped from wells in Arkansas tells us clearly that contamination of the ground-water reservoir is an enormous possibility. The state’s aquifers are literally pin cushions pricked by thousands if not tens of thousands of wells (water, gas, and oil), many of which are abandoned or unused. Usage for public supply is only about 2.5 percent of the total usage in Arkansas, or about 450,226 cubic meters (120 million gallons) per day. However, this amount supplies about 500 public water systems and about 40 percent of the state’s population. From these numbers, there is no doubt that Arkansas relies heavily on its ground-water resource for public as well as other supplies.

2.) There are numerous potential sources of contamination. They may be divided into three main categories. First, the potential sources that are on the land surface including such things as animal feed lots and aboveground chemical storage tanks. Second, potential sources that are located in the ground, but above the water table, like septic tanks and underground petroleum storage tanks. Thirdly, the potential sources that are located in the ground below the water table including mainly wells and mines. Wells, both water and oil, are one of the most common potential sources in Arkansas, especially old,
abandoned wells that may have casings perforated second-
darly by corrosion and cement sheaths cracked by subsi-
dence.

3.) There are numerous chemicals dangerous to health that may infiltrate to the water table if they are not managed or used properly. For example, the U.S. EPA's (Environmental Protection Agency, 1993) National Primary Drinking Water Standards list includes more than 70 organic and inorganic chemicals like arsenic, mercury, benzene, ethylbenzene, toluene, and vinyl chlor-
ide, to name a few familiar ones. A much longer list is the U.S. EPA's (1994) list of hazardous substances developed for the CERCLA program which contains more than 1,000 chemicals.

Discussion

The WHP program requires that each public water-
supply well or wellfield be protected by an environmentally
managed area that surrounds a well or wellfield on the
land surface and also in the subsurface. This three
dimensional zone is called the Wellhead Protection Area
(WHPA). The longest dimension of the WHPA at the
land surface may be measured in hundreds or thousands
of feet. The WHPA's size and shape depend on hydrogeo-
logic, economic, legal, and political factors. The WHPA
should be determined scientifically by a ground-water spe-
cialist using site specific hydrogeologic data. The philo-
sophy behind the size of the WHPA is that it should be
small enough to be effectively managed, but also large
even to be environmentally useful.

The purpose of delineating a Wellhead Protection
Area around a public-supply well is to protect the aquifer
supplying the well from contamination. The part of the
aquifer that supplies the well is termed the zone of contribu-
tion (ZOC) and within this zone is the zone of influ-
ence (ZOI) of the pumping well. The size and shape of
the ZOC are limited primarily by an aquifer's hydrogeo-
logic boundaries, whereas, the size and shape of the ZOI
are limited primarily by an aquifer's hydraulic properties.

Therefore, the ZOC may be considerably larger than the
ZOI and is most likely to extend beyond the legal jurisdic-
tion of the well's owner. That is, the ZOC may extend
into adjacent counties, states, and drainage basins. The
sheer size coupled with the jurisdictional ramifications
faced by a well owner trying to develop a wellhead protec-
tion program based on the ZOC may present problems
that are exceedingly impracticable to surmount. The ZOI
may also be extensive, especially in artesian aquifers. The
ZOI is essentially, but not exactly coincident with the
cone of depression caused by pumping. Some cones of
depression in the Arkansas part of the Coastal Plain
extend over a considerable part of a county or even into
adjacent counties. Many, and perhaps most, extend out of
the jurisdictional boundaries of the communities owning
the wells. Considering the possible large size of a ZOI or
ZOI and also considering the need for effective manage-
ment (economically, legally, and politically), the goal in
Arkansas is to delineate WHPA's that are manageable
from a strongly utilitarian and practicable standpoint.

Since the actual implementation of the Arkansas pro-
gram in 1991, experience and investigation by the pro-
gram hydrogeologist has shown that several methods of
delineation are usable in Arkansas:

- Arbitrary fixed radius
- Volumetric
- Hydrogeologic mapping and hydrologic budget
  combined
- Mathematical flow equation

The method of delineation that may be chosen for a
specific well depends on the availability of site-specific
hydrogeologic and hydraulic data. Driller's logs, geologic
maps and geologic cross sections are relatively abundant
and easily obtainable and therefore, are the main sources
of basic information for determining the geologic composi-
tion and geometry of the aquifer. Logs are obtainable
from the files of the public water systems, drilling com-
panies, the state's Geological Commission and the Water
Well Construction Commission. Aquifer hydraulic data by
comparison are not abundant or easily obtainable. The
U.S. Geological Survey's reports and files are the main
sources of this kind of information because it has con-
ducted aquifer tests and hydrogeological investigations
in many parts of the state. However, most aquifer-test data
are not site specific to public-supply wells, so generaliza-
tions and extrapolations from test sites have to be made.

The large degree of heterogeneity of the consolidated
and unconsolidated rocks in Arkansas makes it largely
untenable hydrogeologically to extrapolate from well to
well, especially if the distance between wells is large.
Extrapolation may easily result in significant errors in
computing local ground-water conditions and therefore
in WHPA delineation. The specific capacity test generally
conducted by the water-well driller is usable as a source of
hydraulic data but is limited in its hydraulic applications.
In summary, the most prudent approach to delineating a
WHPA is to choose the simplest method involving the
smallest number of estimated or extrapolated quantities.

The arbitrary fixed radius method relies on rough
judgement and not on science to determine the size and
shape of the WHPA. The method is not used extensively
in Arkansas, but is used where one of the scientific meth-
ods is not viable. The method is most applicable to
aquifers in the Interior Highlands because of the various
limitations put on standard hydrologic analytical tech-
niques by consolidated-rock terranes comprising the
Highlands.
The volumetric method uses a modified formula for the volume of a cylinder to calculate the radius of any WHPA, viz:

\[ \text{Volume} = Qt = \Pi r^2 h \]

where, \( Q = \) pumping rate of well or wellfield
\( t = \) travel time to well from boundary of WHPA
\( \Pi = \pi = 3.1416 \)
\( r = \) radius of circular WHPA
\( h = \) thickness of aquifer or water producing zone
\( n = \) effective porosity of the aquifer

This method is most tenable for the unconsolidated aquifers of the Coastal Plain and of alluvial stream valleys of the Interior Highlands. The hydraulic factor of porosity may be estimated with a fair degree of certainty because of the large amount of laboratory determinations that have been made on sands and gravels, the main aquifer materials. The results of such determinations have been published in reports of the U.S. Geological Survey and are the primary source used for WHPA calculations in Arkansas (Morris and Johnson, 1967). The other factors, aquifer thickness and pumping rate, are relatively easy to obtain and are fairly accurate. Aquifer thickness may be determined from a driller’s log or from a geologic cross-section based on subsurface investigations by federal or state agencies. Pumping rates may be obtained from the local water department. Many rates are measured by in-line, total-flow meters but many are design rates, which may be somewhat different from the measured rates.

The method based on hydrogeologic mapping combined with a hydrologic budget is used mainly for determining the boundary of a WHPA in the consolidated-rock terrane of the Interior Highlands. This method consists of two steps. The first includes mapping the surface-water and ground-water flow boundaries of the smallest drainage basin containing the well or wellfield. Mapping may be accomplished by the use of topographic maps and geologic maps. The second step includes the determination of a simplified hydrologic budget for the basin. The determination makes the assumptions (1) that the basin is a self-contained hydrologic unit, that is, precipitation equals or balances losses by evapotranspiration, and by outflow of runoff (ground water and surface water), and (2) that there is no long-term change of storage. If the basinal outflow is significantly larger than the inflow generated by precipitation, or if the well-discharge to runoff ratio is too large, it is concluded that the basin supplying the outflow is actually larger than the one initially mapped. In this case, the boundaries are subsequently changed to incorporate a larger basin in which inflow balances outflow, and runoff significantly exceeds well discharge. It should be noted that the numbers comprising this simplified budget are generally rough approximations so that rough approximate balances are all that are expected.

The mathematical flow equation used in Arkansas is the Theis nonequilibrium equation. This equation is commonly used in ground water flow problems and is discussed in textbooks and publications on ground-water hydraulics or on the theory of aquifer tests (Ferris et al., 1962; Lohman, 1972). This technique is used in the parts of Arkansas where the aquifers are in unconsolidated rocks, such as in the Coastal Plain. The Theis equation requires the determination of an aquifer’s hydraulic properties. These properties have been mainly determined by the hydrological interpretation of the driller’s well water-well performance test and the driller’s log because of the general lack of aquifer-test determined properties.

Conclusions

The purpose of the WHP program is to protect the ground-water resource from contamination, in contrast to cleaning up the water after contamination. The philosophy now is to do everything possible to protect this resource from contamination. Cleaning up contaminated ground water has been found to be extremely costly and in many cases not possible because of the nature of the contaminating substances. The upshot of the cleanup experience nationwide is that protection practices must be put in place to reduce the risk if not prevent contamination from occurring in the first place.

The U.S. Environmental Protection Agency says that the average cost of a Superfund Site cleanup is about $25 million nationally. In Arkansas, sites with state financial involvement are costing about $5 million to $18 million to remediate. The state’s involvement in developing the Wellhead Protection program, by comparison, is only about 1 percent of the smallest of these costs. Also, upfront initial costs of implementation of the program are nil or negligible. What better solution to protecting the ground-water resource than to adopt a penny-pincher’s delight like the Wellhead Protection program.

Acknowledgments.—We thank the Arkansas Department of Health for giving permission to present this paper.

Literature Cited

Morris, D.A. and A.I. Johnson. 1967. Summary of hydrologic and physical properties of rock and soil material, as analyzed by the Hydrologic Laboratory of the


**Spiders (Arthropoda: Aranea) From Deciduous Forest Litter of the Ouachita Highlands**

**Peggy Rae Dorris**  
Department of Biology  
Henderson State University  
Arkadelphia, AR 71999

**Henry W. Robison**  
Department of Biology  
Southern Arkansas University  
Magnolia, AR 71753

**Chris Carlton**  
Department of Biology  
Louisiana State University  
Baton Rouge, LA 70803

**Abstract**

One hundred two litter samples were collected from oak/hickory and maple/beech forests in the Ouachita Highlands of western Arkansas July 1991-June 1992. Berlese residues of these collections produced 17 families, 51 genera, and 56 species of spiders, and included 19 species previously unreported for the state of Arkansas.

**Introduction**

A series of Berlese samples was collected during the calendar year July 1991-June 1992 to assess the diversity and abundance of litter faunas of deciduous forest habitats in the Ouachita Highlands of western Arkansas. Moist deciduous valleys dominated by beech (*Fagus grandifolia*), maples (*Acer spp.*), and white oak (*Quercus alba*), and moist deciduous slopes dominated by white oak (*Quercus alba*), black oak (*Quercus velutina*), and various hickories (*Carya spp.*) were sampled. Our objectives were to assess species richness and abundance of a wide range of taxa that occur in forest litter habitats, identify new or previously unrecorded species, and determine seasonal patterns of some of the more abundant species.

Dorris and Burnside (1977) employed sifting methods and numerous other collecting techniques in the Ouachita Highlands, but detailed analysis of forest litter arthropods of this region are lacking. This research allows a more thorough understanding of spider diversity, seasonal utilization, and microhabitat distribution in upland regions of Arkansas.

**Materials and Methods**

The choice of deciduous forests in the Ouachita National Forest as a study area was based on recent documentation that suggest significant faunistic association with faunas in the southern Appalachian Mountains (Carlton and Cox, 1990, Gleason et. al., 1994, Mohlenbrock, 1993, Noble, 1993 and Babaei, 1992). Protected beech-maple valleys and north facing deciduous slopes were chosen because experience had suggested that they would yield the greatest diversity of any forest litter habitats in the Interior Highlands.

Site selection was based on dominant tree composition, ease of access, and past records of other interesting species. Primary sites were chosen during the first two weeks of the study (July 1991). Secondary sites were chosen throughout the project. Primary sites were sampled repeatedly throughout the study, secondary sites were sampled no more than twice.

Five study sites (Fig. 1) in the Ouachita National Forest where large areas of mature white oak or beech/maple forest occur were selected for regular sampling during this study. They are as follows:

1. Near the corners of Scott, Logan, and Yell Counties north of Blue Ball. White oak forest.
2. Polk County, on the east and northeast slope of Rich Mountain. White oak forest.
4. Polk County, in the vicinity of Shady Lake and Bard Springs recreation areas. Beech/maple forest.

These five areas circumscribe an area of approximately 1600 square miles in the Ouachita Mountain core region.

Litter samples were collected by sifting forest litter, including thoroughly rotted logs, leaf packs, root mats, and flood debris, through a 1/4 inch wire mesh sifter. The sifted sample was weighed and held in a cloth bag at room temperature until extraction. Organisms were extracted for 24 hours using Berlese funnels equipped with incandescent lights. Spiders and other organisms extracted from the samples were preserved in 70% ethanol. The spiders were later sorted and identified using a dissecting microscope. Sources used for identification of spiders included Kaston (1948, 1978), Comstock (1948), Heiss and Allen (1986), and Emerton (1902). Voucher specimens of identified taxa are deposited in the

**Proceedings Arkansas Academy of Science, Vol. 49, 1995**
Spiders (Arthropoda: Aranea) From Deciduous Forest Litter of the Ouachita Highlands

Henderson State University spider collection.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>County</th>
<th>Location</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaurobiidae</td>
<td>Polk</td>
<td>N. Slope Rich Mt.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Amaurobius ferox (Walckenaer)</td>
<td>Polk</td>
<td>Crystal Rec. Area</td>
<td>10/5/91</td>
</tr>
<tr>
<td>Araneidae</td>
<td>Polk</td>
<td>Rich Mt. Eagleton</td>
<td>1/9/92</td>
</tr>
<tr>
<td>Arenaeus cingulatus (Walckenaer)</td>
<td>Polk</td>
<td>E. Slope Rich Mt.</td>
<td>9/28/91</td>
</tr>
<tr>
<td>*Hyposigma pygmaea (Sundevall)</td>
<td>Polk</td>
<td>N. Slope Rich Mt.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Clubionidae</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Castianeira cingulata (L. Koch)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Clubiona obesa Hentz</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Clubionoides excepta (L. Koch)</td>
<td>Mont.</td>
<td>Crystal/Collier</td>
<td>7/7/91</td>
</tr>
<tr>
<td>Truchlas deceptus (Banks)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>10/4/91</td>
</tr>
<tr>
<td>Truchlas similis Cambridge</td>
<td>Polk</td>
<td>E. Slope Rich Mt.</td>
<td>9/28/91</td>
</tr>
<tr>
<td>Dictynidae</td>
<td>Scott</td>
<td>Mill Creek Rec.</td>
<td>2/11/92</td>
</tr>
<tr>
<td>*Dicytina stertosa (Hentz)</td>
<td>Mont.</td>
<td>Albert Pike</td>
<td>8/24/91</td>
</tr>
<tr>
<td>Gnaphosidae</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Drassodes neglectus (Keyserling)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>*Drassylus agilis (Bryant)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Drassylus coenensis Edline</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Gnaphosa sericata (L. Koch)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/19</td>
</tr>
<tr>
<td>*Haplodrassus signifer (L. Koch)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>*Orodrassus assimilis (Banks)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>*Poecilochroa ocellata</td>
<td>Yell</td>
<td>S. Blue Mt. Lake</td>
<td>3/24/92</td>
</tr>
<tr>
<td>(Walckenaer)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zelotes hentzi (Barrows)</td>
<td>Polk</td>
<td>N. Slope Rich Mt.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Linophilidae</td>
<td>Mont.</td>
<td>Crystal/Collier</td>
<td>7/7/91</td>
</tr>
<tr>
<td>*Eubathyphilus pallida (Banks)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>10/4/91</td>
</tr>
<tr>
<td>*Helophora insignis (Blankwall)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Lophophantes nebuloa (Sundevall)</td>
<td>Scott</td>
<td>Mill Creek Rec.</td>
<td>2/11/91</td>
</tr>
<tr>
<td>*Microneta violacea (Blackwall)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>10/4/91</td>
</tr>
<tr>
<td>Tennesellum fornicum (Emerton)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Nesticidae</td>
<td>Scott</td>
<td>Mill Creek Rec.</td>
<td>2/11/91</td>
</tr>
<tr>
<td>Edemanna pallida (Emerton)</td>
<td>Mont.</td>
<td>Crystal Rec.</td>
<td>10/5/91</td>
</tr>
<tr>
<td>Lycosidae</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Allocosa rubra (Hentz)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>9/28/91</td>
</tr>
<tr>
<td>Arctosa rubicunda (Keyserling)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Pardosa milvina (Hentz)</td>
<td>Polk</td>
<td>Rich Mt. Eagleton</td>
<td>1/9/92</td>
</tr>
<tr>
<td>Pinta minutus Emerton</td>
<td>Polk</td>
<td>Dry Creek</td>
<td>5/15/92</td>
</tr>
<tr>
<td>Pinta piratica (Clerck)</td>
<td>Scott</td>
<td>Dry Creek</td>
<td>5/15/92</td>
</tr>
<tr>
<td>Schizoca bilineata (Emerton)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Nesticidae</td>
<td>Mont.</td>
<td>Crystal Rec.</td>
<td>10/5/91</td>
</tr>
<tr>
<td>Oxyopidae</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>Oxyopes salticus Hentz</td>
<td>Mont.</td>
<td>Little Mo. Falls</td>
<td>8/15/91</td>
</tr>
<tr>
<td>Oxyopes salticus Hentz</td>
<td>Yell</td>
<td>S. Blue Mt. Lake</td>
<td>3/24/92</td>
</tr>
<tr>
<td>Pholcidae</td>
<td>Polk</td>
<td>Rich Mt. Eagleton</td>
<td>1/9/92</td>
</tr>
<tr>
<td>Spelphena meridonialis Hentzq</td>
<td>Yell</td>
<td>Blue Mt. Lake</td>
<td>3/24/92</td>
</tr>
<tr>
<td>Salticidae</td>
<td>Ballus youngi G. &amp; E. Peckham</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
</tr>
<tr>
<td>Evarcha hoyi (G. &amp; E. Peckham)</td>
<td>Mont.</td>
<td>Albert Pike</td>
<td>8/24/91</td>
</tr>
<tr>
<td>Habrocestum pulax (Hentz)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
</tr>
<tr>
<td>*Habronattus agilis (Banks)</td>
<td>Polk</td>
<td>Rich Mt. Eagleton</td>
<td>1/9/92</td>
</tr>
<tr>
<td>Habronattus decorus (Blackwall)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>10/4/91</td>
</tr>
<tr>
<td>Sitticus palustris G. &amp; E. Peckham Polk</td>
<td>Caney Creek Wild.</td>
<td>12/18/91</td>
<td></td>
</tr>
<tr>
<td>Segestridae</td>
<td>Arianida bicolore (Hentz)</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
</tr>
<tr>
<td>Therididae</td>
<td>*Achaearanea ripicola Emerton</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
</tr>
<tr>
<td>*Achaearanea ripicola Emerton</td>
<td>Polk</td>
<td>Caney Creek Wild.</td>
<td>10/4/91</td>
</tr>
<tr>
<td>Tegenaria domestic (Clerck)</td>
<td>Mont.</td>
<td>Little Mo. Falls</td>
<td>8/15/91</td>
</tr>
</tbody>
</table>

Results and Discussion

A total of 102 forest litter samples was collected from 14 localities, five primary and nine secondary as shown in Fig. 1. Seventeen families and 56 species among 51 genera of spiders were collected with 19 species having been previously unrecorded for the state (Dorris 1985, 1989). Below is a list of spider taxa and abbreviated locality information is provided. Species that are new for the state are indicated by an asterisk. More detailed locality data are available from HWR or CEC.

Fig. 1. Forest litter sample localities in the Ouachita Highlands during 1991 and 1992. Solid circles = primary sample sites. Open circles = secondary sample sites.
Dipoea nigra (Emerton) Polk N. Slope Rich Mt. 12/18/91
*Pholocoma hirsutum Emerton Polk Caney Creek Wild. 10/4/91
Polk Rich Mt. Eagleton 1/9/92
Mont. Crystal Rec. 10/5/91

*Theridion alabamense
Gert. & Archer

THERIDIOSOMATIDAE
Theridiosoma radiosa (McCook) Polk E. Slope Rich Mt. 9/28/91

THOMISIDAE
Mismenopus oblongus (Keyserling) Polk N. Slope Rich Mt. 12/18/91
*Oxyptila distans Dondale & Redner

Polk Caney Creek Wild. 12/18/91

Xysticus elegans Keyserling Polk N. Slope Rich Mt. 12/18/91
Xysticus locuples Keyserling Polk Caney Creek Wild. 12/18/91

ULOBORIDAE
Uloborus diversus Marx Polk Caney Creek Wild. 12/18/91

These identifications are based on examinations of 109 adult spiders. Generally, more spiders were collected during the colder months. This would be expected because protection in leaf litter, debris, and other objects is sought during the frigid months.

Eidmanella pallida was the most abundant species with specimens collected in nearly all counties sampled. Nesticidae is a small family of widely distributed spiders which build their webs under stones, leaves, and other dark places.

Previously unrecorded species were collected in small numbers usually one to four specimens; however, nearly every county in the study area produced at least one new species. Significant range extensions from oak/hickory slope habitats were seen in an extreme eastward move for Cybaeus reticulatus and Xysticus locuples and a westward move for Oxyptila distans.

Only six of the unrecorded species were collected from oak/hickory slope habitats. They are: Hyposinga pygmaea, Cybaeus reticulatus, Tegenaria domestica, Oxyptila distans, Xysticus locuples, and Pholocoma hirsutum. The remainder were collected in beech/maple valley forests.

Conclusions

The Ouachita National Forest litter collections representing Polk, Yell, Montgomery, and Scott Counties yielded 17 families, 51 genera, and 56 species of spiders. This number included 19 species not included in the Arkansas checklists reported by Dorris (1985, 1989).

Endemic faunas of the Magazine Mountain and the Ouachitas are classic examples of relict faunas, and are most closely related to the faunas of the Appalachians. Some aspects of this hypothesis are controversial, but the accumulating data supporting it are compelling according to Carlton and Cox (1990), Babaei and Stanton (1992), Mohlenbrock (1993), Noble (1993), and Gleason et. al. (1994). The discovery of an apparently disjunct population of Catamnaria cavifola (previously known only from Virginia south to Florida, west to Alabama, and Indiana) provides further evidence of this Appalachian relationship.

This research has contributed to our knowledge of spider diversity, seasonal utilization and microhabitat distribution of litter faunas in deciduous valleys and slopes of the Ouachita Highlands. The discovery of 19 species of spiders previously unrecorded for Arkansas from a single habitat in a limited area highlights the need for detailed arthropod diversity research in other inadequately studied habitats throughout the Interior Highlands.

Acknowledgments.—Fieldwork by HWR and CEC was supported by a Challenge/Cost Share Agreement with the U.S. Forest Service (USDA), Ouachita National Forest, Hot Springs, AR.

Identifications by PRD were made possible by a Henderson State University research grant.

Literature Cited


SCF-MO Conformational Analysis of Polycroconaine

T.E. Ezell and J.A. Darsey
Department of Chemistry
University of Arkansas at Little Rock
Little Rock, Arkansas 72204

Abstract

Ab initio calculations at the STO-3G basis set level using GAUSSIAN 92 were conducted on the monomer unit of polycroconaine, a conducting polymer with conductive properties similar to several metals, in order to determine the most probable conformation of the monomer. We also compared the energy difference between the highest occupied and lowest unoccupied molecular orbitals. Successive calculations were performed at dihedral angle intervals of 30° around the central bond of the monomer. Minimum energy was observed at 0° bond rotation, consistent with a theory that the polymer owes many of its conductive properties to a planar configuration in combination with extensive conjugation of the C-C double bonds in the structure.

Introduction

Polycroconaine is one of a series of recently prepared organic polymers that are more like metals in their intrinsic electrical properties than any previously known polymers. The polycroconaines and related polysquaraines are more metal-like because they have some of the smallest band gaps ever observed in organic polymers. The band gap of a metal is the amount of energy needed to promote an electron from the highest occupied energy level (the valence band) to the empty band immediately above it (the conductance band). This gap determines the intrinsic electronic and optical properties of a material since a smaller band gap corresponds to an increase in the material's electrical conductivity. Metals, which have zero band gap, are excellent electrical conductors because their electrons can readily be promoted to the conductance band. Insulators, on the other hand, have a very large band gap which greatly restricts the flow of electrons.

Conjugated organic polymers have currently found great interest with respect to their potential conductive properties. Several polymers have been prepared which conduct electricity when doped with an oxidizing or a reducing agent. The band gap in most of these doped polymers, which are semiconductors, generally ranges from 1.5 to 4 eV. In recent years research has been focused in preparing polymers with increasingly smaller energy gaps, so as to make an organic material with a band gap as close to zero as possible. These polymers would not need doping in order to conduct in a similar manner to metals.

A group of polymers whose band gap is as small as 0.5 eV has recently been synthesized (Havinga et al., 1992). These polymers, polycroconaine and polysquaraine, contain strong electron-donating and electron-accepting moieties in a regular alternating pattern. It is believed this close alternation causes a broadening of the energy bands which, in turn, leads to a smaller band gap. The electron donor in polycroconaine is a conjugated heterocyclic ring system containing nitrogen and sulfur atoms. The acceptor is croconic acid (4,5-dihydroxy-4-cyclopentene-1,2,3-trione) in the case of polycroconaine, or squaric acid (3,4-dihydroxy-3-cyclobutene-1,2-dione) for polysquaraine. These polymers are stable in air at room temperature and can be heated to 300°C in air without degradation. The smallest band gap exists for polycroconaine, measured at 0.5 eV (Havinga et al., 1993). Samples with this band gap were found to be up to seven times more conductive (10⁻⁵ Siemens/cm) than other undoped organic polymers, which are generally insulators. While this is still far less conductive than a metal such as copper (conductivity 10⁶ Siemens/cm), samples of polycroconaine which have been heavily doped with iodine show conductivities between 10⁻³ and 1 Siemens/cm, similar to that of undoped amorphous silicon (Havinga et al., 1993).

Materials and Methods

Because of the unique, semi-metallic electrical conductivity of polycroconaine, it would be useful to know if the polymer's properties are related to the extended conjugation offered by a planar structure for the monomer and possibly for extended sections of the polymer chain. Additionally, it would be useful to determine the energy differential between the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) and compare this value to the reported band gap for the polymer. In order to obtain these energy val-
ues, ab initio self-consistent field molecular orbital calculations were performed on the monomer or repeating unit of the polymer.

The segment of polycroconaine used for this research is the repeating unit shown in Fig. 1. Each end of the repeating unit was capped with a hydrogen atom in lieu of a representation of the remainder of the polymer chain. It was necessary to restrict this study to the single monomer unit because of the molecular size restrictions imposed by the ab initio program used. The procedure used was to optimize the geometry of the monomer unit using the GAUSSIAN 92 (Frisch et al., 1992) ab initio program, determine the potential energy function for rotation around the central bond of the monomer, and to determine the energy differential between the HOMO and the LUMO. These calculations were carried out on an IBM 3090 at the Cornell National Supercomputer Facility, a VAX 7000, and a 386DX/40 Microcomputer.

![Figure 1. Structure of polycroconaine with atomic labels used in calculations.](image)

The geometry of the polycroconaine monomer had to be optimized before other calculations could be performed. An internal coordinate data set was created in the Z-matrix format which included the three-dimensional orientation of the atoms, as well as bond lengths, bond angles, and dihedral angles with respect to the appropriate reference atoms (Hehre et al., 1986). The atomic labels, initial geometric parameters and structure are shown at Fig. 1. To insure the Z-matrix geometry was correct, the atomic coordinates derived from the matrix were used to plot the atoms in three dimensions and visually check the geometry. To optimize the initial geometry, GAUSSIAN 92 was used to optimize first all bond lengths, then all bond angles using the STO-3G basis set. Once optimization was completed, the geometry was again visually checked to insure the optimized parameters appeared reasonable.

The rotational potential energy function was created by rotating the croconic acid moiety around the central backbone of the monomer in 30° increments until the dihedral angle had been rotated through 360°. Again, each Z-matrix geometry was plotted and visually checked to insure a reasonable structure. These rotations were represented by a series of twelve rotation data sets used in the specific calculations. A point calculation (holding all parameters constant) was performed using GAUSSIAN 92 for each rotational increment. These calculations produced a set of 12 rotations with their corresponding energies listed in hartrees, or atomic units. These energies were converted to kilocalories per mole and plotted against the corresponding dihedral angle to generate the potential energy function.

A second point calculation was performed using GAUSSIAN 86 (Hout et al., 1986) to obtain a molecular orbital population analysis for the optimized molecule at the geometry with the lowest potential energy.

**Results and Discussion**

The results for the optimized geometry of the polycroconaine monomer are given in Table 1. All bond lengths are listed in Ångstroms; all bond angles are listed in degrees. It is interesting to note that these results predict that the two ring structures lie in the same plane, allowing maximum through-conjugation for the aromatic rings, the conjugated double bonds, and the nonbonding electron pairs from the hetero atoms in the structure.

Once the optimized geometry was determined, total energies were calculated at rotational intervals of 30° around the bond linking the heterocyclic ring to the croconic acid ring. The potential energy function created by this rotation is shown at Fig. 2. Energy minima are seen at 0° rotation with lesser local minima between 240° to 300°. Energy maxima occur between 30° to 90° rotation and again near 120° to 210°. Minimum energy is observed at 0° dihedral, where both rings lie in the same plane and the negatively-charged oxygen of the croconic acid ring is on the opposite side of the structure from the neighboring sulfur atom and its two nonbonding electron pairs. High rotational energies are observed between 30° and 90° and near 930°, likely because of repulsion between the electron pairs of the sulfur (S14) and the two neighboring oxygens on croconic acid. The bond length for the charged oxygen atom (C20-O34) is approximately 10% longer (1.360 Å) than the carbon-oxygen bond lengths for the carbonyl groups (C17-O32 and C18-O33; 1.215 Å), increasing the interaction between O34 and the sulfur electron pairs at these angles of rotation. Local minima are observed at 240° and 300° as the electron pairs on the oxygen rotate out of plane and away from the sulfur; however, some stability may also be lost due to loss of conjugation as the pi orbitals of the conjugated
double bonds move out of same plane. This is evidenced by the high energy observed at 270° where the croconic ring is at right angles to the heterocyclic ring. Finally, we calculated the energy differential between the HOMO and LUMO for the monomer unit to be 0.17896 hartrees, or atomic units. This is equivalent to 112.65 kcal/mol, or 4.869 eV.

Table 1. Optimized geometry of polycroconaine.

<table>
<thead>
<tr>
<th>Bond Lengths: (Angstroms)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N2-C1 = 1.49</td>
<td>S14-C15 = 1.74</td>
<td>H26-C7 = 1.08</td>
<td></td>
</tr>
<tr>
<td>C5-N2 = 1.34</td>
<td>C15-C16 = 1.32</td>
<td>H27-C10 = 1.08</td>
<td></td>
</tr>
<tr>
<td>S4-C3 = 1.61</td>
<td>C16-C17 = 1.48</td>
<td>H28-C12 = 1.09</td>
<td></td>
</tr>
<tr>
<td>C7-S4 = 1.61</td>
<td>C17-C18 = 1.49</td>
<td>H29-C12 = 1.09</td>
<td></td>
</tr>
<tr>
<td>C6-N2 = 1.56</td>
<td>C18-C17 = 1.49</td>
<td>H30-C12 = 1.09</td>
<td></td>
</tr>
<tr>
<td>C7-C6 = 1.38</td>
<td>C19-C18 = 1.49</td>
<td>H31-C15 = 1.09</td>
<td></td>
</tr>
<tr>
<td>C8-C7 = 1.38</td>
<td>C20-C19 = 1.53</td>
<td>O33-C17 = 1.22</td>
<td></td>
</tr>
<tr>
<td>C9-C8 = 1.38</td>
<td>C21-C19 = 1.32</td>
<td>O33-C18 = 1.22</td>
<td></td>
</tr>
<tr>
<td>C10-C5 = 1.38</td>
<td>H22-C3 = 1.08</td>
<td>O34-C20 = 1.36</td>
<td></td>
</tr>
<tr>
<td>N11-C9 = 1.52</td>
<td>H23-C1 = 1.09</td>
<td>H35-C21 = 1.08</td>
<td></td>
</tr>
<tr>
<td>C12-N11 = 1.49</td>
<td>H24-C1 = 1.09</td>
<td>H36-C21 = 1.08</td>
<td></td>
</tr>
<tr>
<td>C13-N11 = 1.52</td>
<td>H25-C1 = 1.09</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Interatomic Angles: (degrees)

| C1-N2-C3 = 109.0 | N2-N3-C4 = 109.0 | C3-S4-C5 = 109.0 |
| C1-N2-C6 = 141.0 | C5-N2-C2 = 110.0 | N2-C6-C7 = 126.9 |
| C6-C7-C8 = 120.0 | C7-C8-C9 = 120.0 | S4-C5-C10 = 141.0 |
| C8-C9-N11 = 108.0 | C9-N11-C12 = 109.0 | C9-N11-C13 = 109.0 |
| C12-N11-C13 = 142.0 | N11-C13-S14 = 109.0 | N11-C13-C15 = 125.0 |
| S14-C15-C16 = 126.0 | C15-C15-C16 = 125.5 | C15-C16-C17 = 110.0 |
| C16-C17-C18 = 105.0 | C17-C18-C19 = 110.0 | C18-C19-C20 = 105.0 |
| C18-C19-C21 = 123.5 | C20-C19-C21 = 131.5 | N2-C3-H22 = 131.5 |
| S4-C5-H22 = 119.5 | N2-C1-H25 = 109.5 | N2-C1-H24 = 109.5 |
| H24-C1-H25 = 109.4 | C6-C7-H26 = 116.0 | C8-C7-H26 = 124.0 |
| H29-C12-H30 = 109.4 | C13-C15-H31 = 119.5 | C16-C15-H31 = 117.0 |
| C16-C17-O32 = 121.0 | C18-C17-O32 = 82.5 | C17-C18-O35 = 121.0 |
| C19-C18-O35 = 79.8 | C19-C20-O34 = 129.6 | C19-C21-H35 = 119.0 |
| C19-C21-H36 = 119.0 | H35-C21-H36 = 122.0 |           |

ACKNOWLEDGMENTS.—The authors thank the Cornell National Supercomputer Facility, a resource of the Center for Theory and Simulation in Science and Engineering, which receives major funding from the National Science Foundation and IBM Corp., with additional support from the State of New York and members of the Corporate Research Institute. The authors additionally thank NASA for support in part of this research.

Literature Cited


Prediction of Leaf Area in Individual Leaves of Cherrybark Oak Seedlings (Quercus pagoda Raf.)

Yanfei Guo and Brian Lockhart
School of Forest Resources
University of Arkansas at Monticello
Monticello, AR 71656

John Hodges
Department of Forestry
Mississippi State University
Mississippi State, MS 39762

Abstract

The prediction of leaf area for cherrybark oak (Quercus pagoda Raf.) seedlings is important for studying the physiology of the species. Linear and polynomial models involving leaf length, width, fresh weight, dry weight, and internodal length were tested independently and collectively to predict leaf area. Twenty-nine cherrybark oak seedlings were grown in a greenhouse for one growing season and a total of 468 leaves were collected. Leaf area was polynomially related with leaf length or width, but linearly related with the cross product of length and width. Average leaf area for flush 3 was significantly greater than those of other flushes. However, variation in leaf area among flushes did not affect the models. Relationship between leaf area and length (or width) was consistent. Since leaf length is easy to measure and does not require destruction of leaves, it can be effectively used to predict leaf area in cherrybark oak seedlings.

Introduction

Leaf area is important in studying the physiology of trees. Most equipment to measure photosynthesis requires knowledge of leaf area to estimate photosynthetic rate and stomatal conductance. Although leaf size is usually large enough to fill leaf chambers of the equipment, leaf area must be estimated for smaller leaves. Similarly, to study the physiology of whole seedlings, leaf area for different sizes of leaves must be determined. Therefore, methods are needed to estimate leaf area quickly, accurately, and non-destructively.

Many methods to predict leaf area have been studied for various species. Although diameter, height, crown size, and root growth of trees have been related to leaf area (Bacon and Zedaker, 1986; Johnson et al., 1984), leaf length, width, and fresh or dry weight were most frequently used to predict individual leaf area (Farmer, 1980; Wargo, 1978; Persaud et al., 1993). Linear and polynomial models were generally used, applying the aforementioned factors as independent variables. For instance, Wargo (1978) related leaf length and width to leaf area and found that leaf area was closely related with the cross product of leaf length and width for black oak (Quercus velutina Lam.), white oak (Quercus alba L.), and sugar maple (Acer saccharum Marsh). Dry weight of leaves may also be used to estimate leaf area, but it may not be possible to preserve a foliage sample for drying. Therefore, fresh weight was suggested to replace dry weight of leaves (Larsen and Kershaw, 1991).

Another factor that may influence leaf area is the stage of seedling development. At stages of leaf expansion and flush lag, the interval between completion of one flush and the onset of the next, leaf morphology may vary (Hanson et al., 1986). Does the variation in leaf morphology affect the prediction of leaf area? Persaud et al. (1993) assumed that leaf blades of pearl millet (Pennisetum glaucum) have an invariant, genetically controlled shape and symmetry regardless of age and position on the plant. Can this assumption be applied to woody plant species?

Cherrybark oak (Quercus pagoda Raf.) is an important bottomland hardwood species in the southern United States, and research on the physiology of the species for successful natural regeneration has been conducted for many years (Hodges and Gardiner, 1993). One aspect of cherrybark oak ecophysiology research is to study the influence of shade on photosynthesis and stomatal conductance of cherrybark oak seedlings, which requires developing a method to predict leaf area of the species. The objective of this study was, therefore, to apply leaf length, width, fresh and dry leaf weight, and internodal length in linear and polynomial models and to find the best models for predicting leaf area of cherrybark oak.

Materials and Methods

In 1989, half-sib acorns of cherrybark oak located on the Noxubee National Wildlife Refuge, Mississippi were collected and sowed 2 cm deep in PVC pots (35-cm in length and 15-cm in diameter). The post were filled with a 50:50 (w/w) sphagnum peat:sand mixture and placed in a greenhouse located at Mississippi State University. Potting medium was limed to pH 5.3. No artificial light was used. Twenty-nine seedlings were used for the experiment. The
pots were irrigated 3-4 times per week with tapwater and once a week with a modified Hoagland's solution (Hanson et al., 1986; Hoagland and Arnon, 1939).

Once the first flush was completed, three seedlings were harvested. The same procedure was repeated for the next two flushes. A total of nine seedlings was harvested. Leaf area was measured by a Li-cor 3100 Leaf Area Meter. Length, width, and internode length for each leaf were measured to the nearest 0.1 cm. Length was measured from the tip of a blade to the connecting point of blade and petiole, and width was taken at the widest point. Leaf weight was recorded to the nearest 0.01 g and dry weight was measured after drying the leaves in an oven at 105° C for 48 hours. Upon termination of the study, the remaining 20 seedlings, all of which had completed at least three flushes of shoot growth, were harvested and measured similarly to the leaves mentioned above. A total of 468 leaves was used for the analysis. Data range and related statistics are listed in Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (cm)</td>
<td>7.85</td>
<td>3.29</td>
<td>0.30</td>
<td>16.7</td>
</tr>
<tr>
<td>Width (cm)</td>
<td>4.55</td>
<td>1.88</td>
<td>0.20</td>
<td>10.0</td>
</tr>
<tr>
<td>Fresh Weight (g)</td>
<td>0.46</td>
<td>0.36</td>
<td>0.01</td>
<td>2.69</td>
</tr>
<tr>
<td>Dry Weight (g)</td>
<td>0.16</td>
<td>0.41</td>
<td>0.00</td>
<td>0.26</td>
</tr>
<tr>
<td>Internode Length (cm)</td>
<td>2.92</td>
<td>3.69</td>
<td>0.26</td>
<td>33.3</td>
</tr>
</tbody>
</table>

In order to study the relationship between relative leaf position on the seedlings and leaf area, we determined relative leaf position of each flush by computing the median of actual leaf position, and relative leaf position was determined accordingly. Internodal length was also compared to relative leaf position to determine if a relationship existed.

Data were analyzed using SAS (SAS Institute Inc., 1990). The data were fitted to linear and polynomial regression models. Leaf length, width, length x width, fresh weight, dry weight, and subtending internodal length were regressed with leaf area independently and collectively. The data from the nine sample seedlings had similar regression parameters to those of the remaining seedlings, and all the data were then pooled together. Analysis of variance was conducted to study the influence of flushes on leaf area. Duncan's Multiple Range test was used to separate means (p=0.05).

**Results**

Generally, leaf area was greater for the leaves in the middle of a flush, but only the bottom leaf and/or the top leaf were significantly smaller than others for flush 1 and 2. For flush 3 and 4, there was no significant difference among the leaves, although leaf area was greater for the leaves growing in the middle of the flushes (Fig. 1).

![Fig. 1. Influence of relative leaf position on leaf area.](image)

Average leaf area among flushes was significantly different (Fig. 2). Flush 3 had the largest leaves and flush 1 the smallest. The smaller leaf area for flush 4 compared to that of flush 3 was probably due to the final harvest before some of the leaves were fully expanded.

Despite the difference in leaf area among the flushes, the relationship between leaf area and leaf length was consistent for all the flushes (Fig. 3) since the overall relationship between leaf area and length was very close. Similarly, leaf width was also highly related to leaf area (Table 2). Both relationships were polynomial, with greater increases in leaf area at greater length or width.

The relationship between leaf area and the cross product of length and width was linear (Table 2). The regression coefficient improved slightly compared to that for length, with a $r^2$ of 0.98.

Fresh and dry weight were linearly related to leaf area (Table 2), but the regression coefficients were relatively lower (0.79 and 0.86 respectively). Leaf area was not related to internodal length, although relative leaf position affected leaf area in flush 1 and flush 2. However, relative leaf position was closely related to internodal length, especially for flush 3 and 4 (Fig. 4).

Addition of fresh and dry weight to the models involving leaf length or width did not improve the fit. Multiple regression including leaf length, fresh weight,
and dry weight produced a model with a negligible improvement in $r^2$. Similar results were produced for the model involving width, fresh weight, and dry weight.

![Bar chart](chart1.png)

**Fig. 2.** Influence of flush on leaf area.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Equation</th>
<th>RMSE</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>Leaf area $= 2.56 + 1.00(Width^2)$</td>
<td>4.73</td>
<td>0.94</td>
</tr>
<tr>
<td>Length x Width</td>
<td>Leaf area $= 1.45 + 0.010(Length \times Width)$</td>
<td>2.65</td>
<td>0.98</td>
</tr>
<tr>
<td>Fresh weight</td>
<td>Leaf area $= 4.22 + 48.98(Fresh weight)$</td>
<td>8.81</td>
<td>0.79</td>
</tr>
<tr>
<td>Dry weight</td>
<td>Leaf area $= 1.53 + 19.15(Dry weight)$</td>
<td>7.30</td>
<td>0.86</td>
</tr>
</tbody>
</table>

**Table 2.** Equations and related statistics for leaf width, length x width, fresh, and dry weight.

![Graph](chart2.png)

**Fig. 3.** Relationship between leaf area and length.

![Graph](chart3.png)

**Fig. 4.** Influence of relative leaf position on internodal length of flush 3.
Discussion

 Apparently, leaf area for cherrybark oak was not affected by the development stage, position on the seedling, or the size of the leaves. Although the average leaf size for flush 3 was much greater than that for flush 1, the leaves from both flushes with similar length and width had similar leaf area. This fact seems to verify the assumption Persaud et al., (1993) indicated that leaves have invariant, genetically controlled shape and symmetry regardless of age and position.

For cherrybark oak seedlings, either length or width of the leaves can be used to predict leaf area, although length may provide a better estimate of the leaf area than width. Length was more closely related to leaf area and easier to measure than leaf width because of the shape of the cherrybark oak leaves.

The best estimate of leaf area was from the cross product of length and width. By combining the two independent variables, we increased the correlation between leaf area and leaf length x width. However, the improvement was slight compared to that between leaf area and length only. The improvement in $r^2$ was only 0.01. The difference between the two models is that one needs to measure both leaf length and width to gain that increase and therefore, it may not be worth the extra time required in actual studies.

Neither leaf fresh weight nor dry weight related to leaf area well. Leaf thickness may be a factor. However, measurement of leaf thickness has not been reported. Because collection of weight requires destruction of the leaves, leaf weight probably should not be used to predict leaf area of cherrybark oak seedlings since destruction of the leaves may affect seedlings' physiological activities.

It should be pointed out that the models developed in our study were based on the limited number of seedlings in a greenhouse condition. Caution should be taken in applying these models to field studies since leaf shape and thickness may be affected by sun and shade leaves. Under greenhouse condition, however, the models can be tested with samples and used appropriately.

In conclusion, leaf length seems to be the most appropriate variable to predict leaf area. Leaf width can also be used. The use of the cross product of length and width can produce a slightly better result, but requires measurement of both leaf length and width.

Acknowledgments.—The authors are grateful to the USDA Forest Service Southern Hardwood Research Laboratory at Stoneville, Mississippi for its partial funding of this study. The review and comments from the two anonymous reviewers are also greatly appreciated.

Literature Cited


Proforce Waves: The Effect of Current Behind the Shock Front on Wave Structure

Mostafa Hemmati and Steven Young
Department of Physical Science
Arkansas Tech University, Russellville, AR 72801

Abstract

Recently, the initial boundary conditions for proforce waves with a substantial current behind the shock front have been derived. Computer solutions of the Electron Fluid Dynamical equations meet the expected boundary conditions at the end of the sheath region. This paper will compare the wave structure for proforce waves with and without current behind the shock front.

Introduction

Electrical Breakdown waves in which electric field force on electrons is in the direction of wave propagation are referred to as proforce waves. Proforce current-bearing waves are proforce waves with a substantial current behind the shock front. Proforce current-bearing waves describe the natural phenomena "stepped leader" in lightning.

Breakdown waves consist of two distinct regions. Immediately following the front is the thin Debye layer which will be referred to as the sheath region. In this region the net electric field decreases to a nominal value and collisions with neutral particles cause the electrons to come to rest relative to heavy particles. Following the sheath region is a thicker region referred to as the quasi-neutral region. In this region, by further ionizing neutral particles, the electron gas cools. This paper is concerned with solutions of the Electron Fluid Dynamical equations within the sheath region.

A set of Electron Fluid Dynamical (EFD) equations for proforce waves has previously been formulated. Paxton and Fowler (1962) introduced a fluid approach to breakdown waves using a three-fluid, hydrodynamical model that is applied to a quasi-steady state three-component (electrons, neutral particles, and ions) system. Their set of equations consists of equations of conservation of mass, momentum, and energy. In their model they assumed that the heavy particles inside the wave only have a slight kinetic energy change during their interaction with the electron shock wave. The electron gas partial pressure was assumed to be much greater than that of other species, and the heat conduction and energy loss by electrons due to inelastic collisions were considered negligible. Later, Shelton and Fowler (1968) introduced modifications to Paxton and Fowler's equations. The use of Poisson's equation along with the introduction of dimensionless variables in the set of equations, and derivation of the initial boundary conditions allowed an approximate solution to the set of EFD equations.

For successful numerical integration of the set of EFD equations, the following major modifications were made by Fowler et al. (1984). First, they introduced the heat conduction term, which was considered negligible by Shelton and Fowler. Second, they allowed for temperature derivative discontinuity at the shock front and derived a new set of boundary conditions for variables such as electron temperature and velocity. Finally, they used an expression derived by Fowler (1985) to calculate the ionization rate throughout the zone where the electric field is present. Shelton and Fowler (1968) considered the ionization rate to be constant throughout the sheath region.

Model

The model introduced by Paxton and Fowler (1962), and later completed by Fowler et al. (1984), is a one-dimensional, steady profile, constant velocity Electron Fluid Dynamical wave. The wave propagates through a neutral gas from an electrode with a potential to the ground electrode regardless of the polarity of the applied potential. The set of EFD equations are equations of conservation of mass, momentum, and energy, coupled with Poisson's equation:

\[
\frac{d (v_n)}{dx} = \beta n, \quad (1)
\]

\[
\frac{d}{dx} \left\{ \frac{nnm(v-V)}{n_kT_e} \right\} = -enE \cdot \frac{K}{m}nV - V. \quad (2)
\]

\[
\frac{d}{dx} \left\{ \frac{nnm(v-V)^2 + nkT_e (v-V)}{nkT_e} \right\} = -\frac{5}{2} (nKv - V)^2 + 2 \epsilon nV \frac{d \epsilon}{d \epsilon} \frac{d T_e}{d \epsilon} \quad (3)
\]

\[
\frac{dE}{dx} = e \frac{\epsilon}{\epsilon_0} (n \cdot n). \quad (4)
\]
The variables are electron concentration \( n \), ion number density \( N_i \), electric field \( E \), electron velocity \( v \), electron mass \( m \), electron temperature \( T_e \), and position in the wave profile \( x \). \( \phi \) is the ionization potential of the gas; \( V \) is the wave velocity; \( M \) is the neutral particle mass; \( e \) is the electron charge. The dimensionless variables used are

\[
\begin{align*}
\eta &= \frac{E}{e_0}, \quad \psi = \frac{2e}{e_0} n, \quad \xi = \frac{v}{\sqrt{mV^2}}, \quad \alpha = \frac{2e}{mV}, \quad \beta = \frac{m}{eE_0}, \quad \omega = \frac{2m}{T}
\end{align*}
\]

where \( \eta \) is the electric field strength, \( \psi \) is the electron number density, \( \xi \) is the electron velocity, \( \theta \) is the electron gas temperature, \( \xi \) is the position within the sheath, \( \alpha \) and \( \kappa \) are wave parameters, \( \mu \) is the ionization rate, \( K \) is the elastic collision frequency, \( \beta \) is the ionization frequency, and \( E_0 \) is the electric field magnitude at the wave front. Introducing the dimensionless variables into equations 1-4, they reduce to:

\[
\begin{align*}
d\eta &= \frac{\eta \cdot \nu}{\eta \cdot \kappa} \cdot \kappa, \\
&= \left( \psi(\psi - 1) + \alpha \theta \right), \\
d\xi &= \frac{\psi(\psi - 1)^2 + \alpha \theta(\psi - 1) + \psi + \alpha \psi + \psi \cdot \frac{5e^2\psi^2}{\kappa} \frac{d \theta}{d \xi} }{C_0} = \psi \cdot (\psi - 1), \\
d\xi &= \frac{\psi(\psi - 1)}{\kappa}, \\
&= \frac{\psi(\psi - 1)}{\kappa}
\end{align*}
\]

The expression used to calculate the ionization rate, \( \mu \), is based on free trajectory theory that includes ionization from both random and directed electron motions

\[
\mu = \mu_0 \int_A \kappa^2 \hbar \cdot \kappa \cdot \hbar \cdot e^{-\mu} \cdot \kappa \cdot e^{-\mu} \cdot \hbar \cdot e^{-2\mu} \cdot \hbar \cdot e^{-\mu} \\
= \frac{1}{\sqrt{2\hbar}}, \quad B = \frac{(1 - \psi)}{\sqrt{2\hbar}}, \quad \text{and} \quad C = \kappa \sqrt{2a\hbar}
\]

Fowler et al. (1984) expanded the Momentum balance equation (6) and used other equations in the expanded form to solve for \( \frac{d \psi}{d \xi} \). The singularity inherent in the set of equations, therefore, appears in the denominator of the equation

\[
\begin{align*}
d\psi &= \frac{K(1 + \mu)(1 - \psi)\psi - \kappa \mu \theta \cdot \eta \psi - \alpha \psi \cdot \theta}{\kappa(1 - \psi - \alpha \theta)}
\end{align*}
\]

With a current, \( I \), behind the shock front, modifications must be made on the initial boundary conditions and Poisson's equation used by Fowler et al. (1984). According to Kirchoff's current law:

\[
eN_j - \eta v = I,
\]

where \( V \) is the ion velocity in the wave frame. Solving equation (11) for \( N_j \) and substituting it into equation (4) reduces the Poisson's equation to:

\[
d\psi = \frac{\psi}{\eta \cdot \kappa} \cdot \kappa \cdot \kappa.
\]

The change in ion velocity is negligible; therefore, \( V \) can be substituted for \( V \). Substituting the dimensionless variables and introducing \( t = \int \frac{d \psi}{\kappa} \) into equation (12), it becomes

\[
\frac{d \psi}{d \xi} = \frac{\psi}{\psi - 1} + \alpha \kappa.
\]

In order to derive the initial boundary condition, \( \theta_0 \), the global momentum equation

\[
\begin{align*}
\frac{d}{d \xi} \left( MNV^2 + M_0 N_j V^2 + m v^2 n k T_e + (N + N_i) k T_e \cdot \frac{eE_0^2}{2} \right) = 0
\end{align*}
\]

must be integrated, and the integration constant has to be evaluated using the values for the variables immediately ahead of the wave \( (n_0 = 0, N_{jo} = 0, V = V_0) \). Equation (14) then reduces to

\[
\begin{align*}
m \left( n_1 V_1^2 - \frac{L V_0}{e} \right) + n_1 k T_e = 0,
\end{align*}
\]

where \( n_1, v_1, I_1, \) and \( V_0 \) are the electron number density, electron velocity, current at the wave front, and wave velocity, respectively. By introducing the dimensionless variables into equation (15), the electron temperature at the wave front can be isolated as

\[
\theta_0 = \frac{-\psi(1 - \psi)}{\alpha \kappa} + \frac{\kappa}{\psi^2}.
\]

The major task in integrating the set of EFD equations is to pass through the singularity which presents
itself in the denominator of equation 10. When \((\psi^2 - \alpha \theta)\) approaches zero, \(\frac{\partial \psi}{\partial z}\) approaches infinity, indicating the presence of a shock. Since there can be no shock inside the sheath region, the denominator and numerator, therefore, must both approach zero at the same time. This allows one to choose a starting value for \(\psi_1\), for a given value of \(\kappa\), \(\alpha\), and \(v_1\), by trial and error.

Keeping the values of the numerator and denominator at the singularity constant allows one to pass through the singularity. After passing through the singularity and completing the integration, if the values of \(\psi\) and \(\eta\) do not satisfy the acceptable conditions at the end of the sheath, new values of \(v_1\) must be considered. This process must be repeated until one reaches the acceptable condition at the end of the sheath \((\psi_2 = 1)\).

Results

Uman and McLain (1970) derived expressions relating the stepped leader radiation field (electric field intensity or magnetic flux density) to the leader current. By measuring the radiation field from a distance, they were able to calculate the current by using the derived expressions. For the stepped leader, they calculated peak currents in the range of 800 to 5,000 amperes. These values correspond to a range of \(t\) of between 0.004 and 0.1. We have attempted to integrate the set of equations for a broader range of currents.

The solutions for a fast moving wave \((\alpha = 0.01)\) for current values of \(t = 0.001, 0.01, \text{ and } 0.1\) are available now. \(\alpha = 0.01\) represents a wave speed of \(3 \times 10^7\) meters per second. Figure 1 is a graph of electron velocity, \(\psi\), as a function of position, \(\xi\), with appropriate initial electron velocity \(\psi_1\), electron number density, \(v_1\), and wave constant, \(\kappa\), for the above mentioned values of current. (+)

\[ t = 0.001, \kappa = 1.18424, v_1 = 0.025, \psi_1 = 0.32, t = 0.01, \kappa = 1.24194, v_1 = 0.0221, \psi_1 = 0.3275 \text{ and } (\square) t = 0.1, \kappa = 1.01045, v_1 = 0.025, \psi_1 = 0.32. \]

Figure 2 is a graph of electric field \(\eta\) as a function of electron velocity \(\psi\) inside the sheath. The initial value of the electric field is equal to that of the applied field \((\eta_1 = 1)\); the net electric field (applied plus space charge field), however, approaches a minimal value at the end of the sheath.

Figure 3 contrasts the electric field \(\eta\) as a function of electron velocity \(\psi\) for proforce waves with \(t = 0.1\) and \(t = 0\). The electric field at the end of the sheath for proforce current bearing waves is not zero.

Figure 1 shows that, in general, higher currents increase the sheath thickness. With high values of current behind the shock front, the singularity becomes very sharp, making the passage through the singularity very difficult. There seems to be a cut-off point for current values greater than \(t = 0.25\). All attempts at integrating the set of equations for a current value of \(t = 0.5\) failed to pass through the singularity. In order to pass through the singularity at \(t = 0.25\), we had to resort to a higher order of approximation at the singularity. This was achieved by doubling the number of integration steps for which the numerator and denominator were held constant.
Conclusions

The Electron Fluid Dynamical equations and the boundary conditions at the wave front, modified for proforce current bearing waves, yield results for waves with a variety of current values behind the shock front. To complete the wave profile, further work must be done in order to integrate the set of equations for lower wave speeds.

Acknowledgments.—The authors would like to express their gratitude to the Scientific Information Liaison Office (SILO) for their financial support for this research.

Literature Cited


Critical Energy of Torus Knots

Fred Hickling & Wesley Davis
Department of Mathematics and Computer Science
Heather Woolerton
Department of Physics and Astronomy
University of Central Arkansas
Conway, AR 72035

Abstract

The energy of a smoothly parameterized knot \( \gamma(t) \) is defined as

\[
\int_0^{2\pi} \int_0^{2\pi} \left\{ \frac{1}{\|\gamma(s) - \gamma(t)\|^2} - \frac{1}{(D(\gamma(s), \gamma(t)))^2} \right\} \left\| \frac{d\gamma}{ds} \right\| \left\| \frac{d\gamma}{dt} \right\| dsdt
\]

where \( D(\gamma(s), \gamma(t)) \) is the arc length between the two points \( \gamma(s) \) and \( \gamma(t) \) on the curve. Simple calculus based arguments are used to locate critical values of the energy functional for torus knots. Explicitly the curves given parametrically by \( \sigma(a,b)(t) = \left( \frac{\cos(2atn)}{\sqrt{2}\sin(2bn)}, \frac{\sin(2atn)}{\sqrt{2}\sin(2bn)}, \frac{\cos(2bnt)}{\sqrt{2}\sin(2bn)} \right) \) are critical points of the energy functional whenever \( a \) and \( b \) are relatively prime.

Introduction

One of the earliest appearances of knots in physics occurred in 1867 when Lord Kelvin put forward the idea that atoms were vortex tubes. More recently, knot theory is being studied as a possible means of quantizing gravity (Baez and Munian 1994). An early attempt to define the energy of a knot was done by Fukuhara (1988). This was based on the usual \( \frac{1}{2} \) potential of electrostatics. Unfortunately, this potential doesn't give a finite energy when passing to a continuous charge distribution. It also isn't strong enough to prevent various parts of the knot from touching. More recently O'Hara (1991, 1992) has described a number of renormalized "energies" for knots. Freedman et al., have shown one of these energy functionals to be both scale and conformally invariant. They then used this to show that the least energy configuration over all knot types is the round circle. This energy functional for a smoothly parameterised knot \( \gamma(t) \) is defined as

\[
\int_0^{2\pi} \int_0^{2\pi} \left\{ \frac{1}{\|\gamma(s) - \gamma(t)\|^2} - \frac{1}{(D(\gamma(s), \gamma(t)))^2} \right\} \left\| \frac{d\gamma}{ds} \right\| \left\| \frac{d\gamma}{dt} \right\| dsdt
\]

where \( D(\gamma(s), \gamma(t)) \) is the arc length between the two points \( \gamma(s) \) and \( \gamma(t) \) on the curve. The terms \( \frac{d\gamma}{ds} \) and \( \frac{d\gamma}{dt} \) should be thought of as the charges in a small bit of arc length assuming there is a uniform charge distribution of one on the curve. The second term is the renormalization factor while the \( 2^{nd} \) power is used instead of the first to provide for a stronger potential.

The problem of minimizing the energy of various knot types is amenable to the basic calculus tools available to any good undergraduate. Most of the basic calculations in this paper were done by the second author during his senior year as part of a SILO undergraduate research grant. The simplest knots after the round circle are the torus knots. The first to study the energy of torus knots were Kim and Kusner (1993). In this paper we show that the \( (a, b) \)-torus knot given parametrically by \( \sigma(t) = \left( \frac{\cos(2atn)}{\sqrt{2}\sin(2bn)}, \frac{\sin(2atn)}{\sqrt{2}\sin(2bn)}, \frac{\cos(2bnt)}{\sqrt{2}\sin(2bn)} \right) \) is a critical point of the energy functional (1). This is done by recognizing that \( \sigma(t) \) is the stereographic projection of the curve \( \gamma(t) = (\cos(2atn), \sin(2atn), \cos(2bnt), \sin(2bnt)) \) in \( \mathbb{R}^4 \). This curve lies on \( S^3 \). Since the energy functional (1) is conformally invariant, if \( \gamma(t) \) is a critical point of (1) its stereographic projection \( \sigma(t) \) is a critical point of (1). \( \gamma(t) = (\cos(2atn), \sin(2atn), \cos(2bnt), \sin(2bnt)) \) is shown to be a critical point of the energy functional (1) by approximating it as a discrete set of charged points \( \{p_k\} = \{(\cos(2ak\pi/n), \sin(2b\pi/n)), (\cos(2b\pi/n)), (\cos(2b\pi/n))\} \) connected by straight line edges and then letting \( n \to \infty \). Since any \( C^1 \) curve can be approximated using a polygonal path, any \( C^1 \) curve near \( \gamma(t) \) can be approximated by perturbing the points \( p_k \). It is known that the energy functional (1) is continuous for \( C^1 \) curves (corollary 6.3, Freedman et al., 1994). This result can be extended to piecewise \( C^1 \) curves, which the various piecewise linear curves used in approximating \( \gamma(t) \) are, as is \( \gamma(t) \). Since all our curves have constant speed, to show that the first variation of the energy is zero at \( \gamma(t) \), it suffices to show that the gradient of the discrete model of the energy is zero in the limit as \( n \to \infty \).

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Calculations

In (1) the analytic potential assumes a uniform charge density of one. The analogue for the discrete case has the charge at each point equal to 1/2 of the sum of the lengths of the two edges which meet at that point. The energy in the discrete case is obtained as the double sum

\[ \sum_{k=1}^{n} q_k q_{k+1} \left( \frac{r_{k} q}{r_{k}^2} - \frac{r_{k+1} q}{r_{k+1}^2} \right) + \sum_{k=1}^{n-1} \left( \frac{r_{k+1} q}{r_{k+1}^2} - \frac{r_{k} q}{r_{k}^2} \right) \]

where \( p_i \) and \( p_j \) are the positions of two of the charged points, \( q_i \) and \( q_j \) their charges, and \( D(p_i, p_j) \) is the length of the shortest edge path between the two points \( p_i \) and \( p_j \).

Since the configuration of the points \( \{p_k\}_{k=1}^n \) is symmetric, if it can be shown that the four partials associated to varying the single point \( (1,0,1,0) \) are all zero in the limit as \( n \to \infty \), then all the partials associated to varying any point will also be zero in the limit, and so the gradient will be zero. Symmetry shows that the partials in the \( y = x_o \) and \( w = x_o \) directions are zero, since \( \sin \left( \frac{2n \pi}{n} \right) = \sin \left( \frac{2 \pi}{n} \right) \). The choice of the points \( p_k \) also shows that the calculation of the derivative in the \( z = x_o \) direction is identical to the calculation in the \( x = x_o \) direction with the roles of \( a \) and \( b \) reversed. To show that the gradient is zero in the limit as \( n \to \infty \), it suffices to vary only the point \( (1,0,1,0) \) in the \( x \)-direction and see that in the limit this partial goes to zero.

Note: for antipodal points on the circle there are two shortest connecting paths on the circle. So when modeling the circle by a discrete number of points, it is best to use an odd number of points to avoid having to choose a shortest path.

To begin the calculation of the energy for the discrete model the following simplifying notations are used

\( r_k \) is the distance between the points \((x,0,1,0)\) and \( p_k \) \((1 \leq k \leq n-1)\)

\( r_{k,j} \) is the distance from \( p_k \) and \( p_j \) \((1 \leq k \neq j \leq n-1)\)

\( q \) is the distance from two adjacent points if neither is \((x,0,1,0)\).

\( q \) is chosen for this last distance because the charge at all but the points \( p_1, p_{n-1} \), and \((x,0,1,0)\) is \( q \). The charge at \((x,0,1,0)\) is \( r_1 \) while the charge at both \( p_1 \), and \( p_{n-1} \) is \( r_1 \) + \( q \).

Since the charges are different at different points, the calculation of the energy is broken down into the following cases: the potential between the point \((x,0,1,0)\) and the points \( \{p_k\}_{k=1}^{n-2} \); the potential between \((x,0,1,0)\) and both \( p_1 \), and \( p_{n-1} \); the potential between both \( p_1 \), and \( p_{n-1} \); and finally the potential between pairs of the points \( \{p_k\}_{k=2}^{n-2} \). The various parts of the energy are given as follows. The part of the energy associated to the charges at the point \((x,0,1,0)\) and charges at the points \( \{p_k\}_{k=2}^{n-2} \) is given by

\[
2 \sum_{k=2}^{n-1} \left( \frac{r_{k} q}{r_{k}^2} - \frac{r_{k+1} q}{r_{k+1}^2} \right) + \sum_{k=1}^{n-2} \left( \frac{r_{k+1} q}{r_{k+1}^2} - \frac{r_{k} q}{r_{k}^2} \right).
\]

The 2 multiplying each of the sums is there because the sum in equation (2) has each pair of points appearing twice. Using the symmetry of \( p_1 \) and \( p_{n-1} \) this can be simplified further to

\[
\sum_{k=2}^{n-1} \left( \frac{r_{k} q}{r_{k}^2} - \frac{r_{k+1} q}{r_{k+1}^2} \right) + \frac{1}{2} \sum_{k=2}^{n-2} \left( \frac{r_{k} q}{r_{k}^2} - \frac{r_{k+1} q}{r_{k+1}^2} \right) + \frac{1}{2} \sum_{k=2}^{n-2} \left( \frac{r_{k+1} q}{r_{k+1}^2} - \frac{r_{k} q}{r_{k}^2} \right).
\]

The potential associated with adjacent points in the model does not contribute to the energy since the distance between adjacent points and the distance along the curve between them is the same, and thus the renormalization factor cancels the \( \frac{1}{2} \) potential. Because of this there is no contribution to the potential from the points \( p_1 \) and \( p_{n-1} \) with the point \((x,0,1,0)\).

Symmetry shows the potential between the points \( p_1 \) and \( p_{n-1} \) and the points \( \{p_k\}_{k=2}^{n-2} \) is twice that between the points \( p_1 \) and the points \( \{p_k\}_{k=2}^{n-2} \). The potential between the points \( p_1 \) and the points \( \{p_k\}_{k=2}^{n-2} \) breaks into two cases depending on whether the shortest arc length path goes through the point \((x,0,1,0)\) or not. It doesn’t for the points \( \{p_k\}_{k=2}^{n-2}\) and does for the points \( \{p_k\}_{k=(n+3)/2} \). So the potential associated with the points \( p_1 \) and \( p_{n-1} \) and the points \( \{p_k\}_{k=2}^{n-2} \)

\[
4 \left( \sum_{k=2}^{n-1} \left( \frac{1}{2} (r_{k} + q) \frac{q}{r_{k}} - \frac{1}{2} (r_{k+1} + q) \frac{q}{r_{k+1}} \right) + \frac{1}{2} (r_{k+1} + q) \frac{q}{r_{k+1}} - \frac{1}{2} (r_{k} + q) \frac{q}{r_{k}} \right).
\]

Here the sum starts at \( k = 3 \) because \( p_1 \) is adjacent to \( p_2 \) and the 4 appears because each pair of points is counted twice in sum (2) and then this is doubled to take into account the potential with the point \( p_{n-1} \).

The potential between \( p_1 \) and \( p_{n-1} \) is

\[
2 \left( \frac{1}{2} (r_{1} + q) \frac{q}{r_{1}} - \frac{1}{2} (r_{j} + q) \frac{q}{r_{j}} \right).
\]

Again the 2 appears to take into account that the pairs of points appear twice in equation (2).

The potential between a pair of the points \( \{p_k\}_{k=2}^{n-2} \) depends on whether the shortest length path goes through the point \((x,0,1,0)\) or not. Looking at only the points \( p_k, 2 \leq k \leq (n-1)/2 \), the points for which the shortest path doesn’t pass through \((x,0,1,0)\) are \( p_j \) for \( 2 \leq j \leq (n+1)/2 + k \) and \( p_{k} \) for the point \( p_k, 2 \leq k \leq (n-1)/2 \), the energy associated with it and the \( p_j, j \neq k, n-1 \) or \((x,0,1,0)\) is

\[
2 \sum_{k=1}^{n-1} \left( \frac{q^2}{r_{k,j}^2} - \frac{q^2}{(r_{k,j}+2q)^2} \right) + 2 \sum_{k=2}^{n-2} \left( \frac{q^2}{r_{k,j}^2} - \frac{q^2}{(2r_{k,j}+(k-j)q)^2} \right).
\]
When summing up over all the \( p_k, 2 \leq k \leq (n - 2) \), one must be careful not to double count the points. So in the case of the first sum above, one should restrict oneself to looking at only those \( j \) with \( k \leq j \leq \frac{2k+n}{2}+k \). Also the largest value of \( k \) for which there are points in the second sum is \( \frac{n-1}{2} \) (this is because all potentials with \((k,0,1,0)\) and \(p_{n-1}\) have already been taken into account). Summing the potential associated to the points \( p_k, 2 \leq k \leq (n - 1)/2 \) with the points \( p_k, 2 \leq k \leq (n - 2) \) gets all the potential between pairs of the points \( p_k, 2 \leq k \leq (n - 2) \), except for that associated with pairs of points in \((n + 1)/2 \leq k \leq (n - 2) \). Taking these into account and summarizing all of this gives

\[
2 \sum_{k=2}^{n-2} \sum_{j=k+1}^{\left\lfloor \frac{2k+n}{2}+k \right\rfloor} \left( \frac{q^2}{r_{r,j}^2} - \frac{q^2}{(j-k+1)^2} \right) + 2 \sum_{k=2}^{n-2} \sum_{j=k+1}^{\left\lfloor \frac{2k+n}{2}+k \right\rfloor} \left( \frac{q^2}{r_{r,j}^2} - \frac{q^2}{(j-k+1)^2} \right).
\]

Since \( x \) is only found in \( r_k \), the only terms for which the partial derivative of the energy with respect to \( x \) will be non-zero are

\[
4 \sum_{k=2}^{n-2} \left( \frac{q^2}{r_{r,k}^2} - \frac{1}{(r_k - (k-1))^2} \right) + 4 \sum_{k=3}^{n-1} \left( \frac{1}{r_{r,k}^2} - \frac{1}{(r_k - (k-1))^2} \right) + 4 \sum_{k=3}^{n-1} \left( \frac{1}{r_{r,k}^2} - \frac{1}{(r_k - (k-1))^2} \right) + 2 \sum_{k=2}^{n-2} \sum_{j=k+1}^{\left\lfloor \frac{2k+n}{2}+k \right\rfloor} \left( \frac{q^2}{r_{r,j}^2} - \frac{q^2}{(j-k+1)^2} \right).
\]

The derivative of this is

\[
\frac{dE}{dx} = 4q \sum_{k=2}^{n-2} \left( \frac{dr_k q^2}{r_k^2} - r_k q^2 \cdot 2dr_k \right) - \frac{1}{r_k^2} \cdot (r_k - (k-1))^2 \cdot dr_k - 2(r_k - (k-1))q \cdot dq \frac{dr_k}{r_k^2} + 2 \sum_{k=2}^{n-2} \sum_{j=k+1}^{\left\lfloor \frac{2k+n}{2}+k \right\rfloor} \left( \frac{q^2}{r_{r,j}^2} - \frac{q^2}{(j-k+1)^2} \right).
\]

Reorganizing this gives

\[
\frac{dE}{dx} = 4q \sum_{k=2}^{n-2} \left( \frac{dr_k q^2}{r_k^2} - r_k q^2 \cdot 2dr_k \right) + \frac{2}{r_k} \cdot (r_k - (k-1))^3 \cdot dr_k + 2 \sum_{k=2}^{n-2} \sum_{j=k+1}^{\left\lfloor \frac{2k+n}{2}+k \right\rfloor} \left( \frac{q^2}{r_{r,j}^2} - \frac{q^2}{(j-k+1)^2} \right) + 2q \sum_{k=2}^{n-2} \left( \frac{dr_k}{r_k^2} + \frac{4}{r_k} \cdot (r_k - (k-1))^2 \cdot dr_k \right) - \frac{dr_k}{(r_k - (k-1))^2} \cdot dq.
\]

When evaluating this derivative at \( x = 1 \), note that

(a) \( r_1 |_{x=1} = q \), and (b) \( r_{n-1} |_{x=1} = r_{n-1} \).

Using these to simplify (8) gives

\[
\frac{dE}{dx} = 4q \sum_{k=2}^{n-2} \left( \frac{dr_k q^2}{r_k^2} - r_k q^2 \cdot 2dr_k \right) + 2q \sum_{k=2}^{n-2} \left( \frac{dr_k}{r_k^2} + \frac{4}{r_k} \cdot (r_k - (k-1))^2 \cdot dr_k \right) - \frac{dr_k}{(r_k - (k-1))^2} \cdot dq + 2q \sum_{k=2}^{n-2} \left( \frac{dr_k}{r_k^2} + \frac{4}{r_k} \cdot (r_k - (k-1))^2 \cdot dr_k \right)
\]

The symmetry of the problem gives that

(c) \( r_{n-k} |_{x=1} = r_{n-k} \), and (d) \( r_{n-1} |_{x=1} = r_{n-1} \).

These can be used to reindex the sums giving

\[
\frac{dE}{dx} = 4q \sum_{k=2}^{n-2} \left( \frac{dr_k q^2}{r_k^2} - r_k q^2 \cdot 2dr_k \right) + 2q \sum_{k=2}^{n-2} \left( \frac{dr_k}{r_k^2} + \frac{4}{r_k} \cdot (r_k - (k-1))^2 \cdot dr_k \right) - \frac{dr_k}{(r_k - (k-1))^2} \cdot dq + 2q \sum_{k=2}^{n-2} \left( \frac{dr_k}{r_k^2} + \frac{4}{r_k} \cdot (r_k - (k-1))^2 \cdot dr_k \right)
\]

Recognizing that \( 8 \sum_{k=2}^{n-2} \sum_{j=k+2}^{n-2} \frac{dr_j}{k^3 q} = 8 \cdot \sum_{k=4}^{n-1} \frac{(k-3)dr_k}{k^3 q} \) and reorganizing to combine like terms gives

\[
\frac{dE}{dx} = 6q \sum_{k=2}^{n-2} \left( \frac{dr_k}{r_k^2} + \frac{2}{r_k} \cdot \frac{dr_k}{r_k^2} + 2q \sum_{k=3}^{n-2} \left( \frac{dr_k}{r_k^2} \right) - \frac{dr_k}{(k-3)^2 q} \right)
\]

which upon starting all the terms in the sums at the same place becomes

\[
\frac{dE}{dx} = 8q \sum_{k=2}^{n-2} \left( \frac{dr_k}{r_k^2} \right) - 8q^2 \sum_{k=2}^{n-2} \left( \frac{dr_k}{r_k^2} \right)
\]
\[-6 \frac{dr_1}{4q} - 8 \frac{dr_1}{9q} + \frac{dr_1}{2q} + 8 \frac{dr_1}{8q} + 24 \cdot \frac{dr_1}{27q}.
\]

This reduces to

\[
\frac{\partial E}{\partial x} = 8q \cdot \sum_{k=2}^{n/2} \left( \frac{r_k \cdot dr_1 - q \cdot dr_k}{r_k^3} \right).
\]

Evaluating at \(x = 1\) and using

\[
r_k|_{k=1} = \sqrt{\left( \cos \left( \frac{2 \pi k}{n} \right) - 1 \right)^2 + \sin^2 \left( \frac{2 \pi k}{n} \right) + \left( \cos \left( \frac{2 \pi k}{n} \right) - 1 \right)^2 + \sin^2 \left( \frac{2 \pi k}{n} \right)},
\]

\[
\left. dr_k \right|_{k=1} = \frac{2 \sin \left( \frac{\pi k}{n} \right)}{r_k},
\]

\[
r_1|_{k=1} = q
\]

(13) becomes

\[
\frac{\partial E}{\partial x} = 4 \sum_{k=2}^{n/2-1} \left( \frac{\sin^2 \left( \frac{\pi k}{n} \right) \cdot \sin \left( \frac{\pi k}{n} \right) - \sin^2 \left( \frac{\pi k}{n} \right) \cdot \sin^2 \left( \frac{\pi k}{n} \right)}{\sin^2 \left( \frac{\pi k}{n} \right) + \sin^2 \left( \frac{\pi k}{n} \right)} \right).
\]

It remains to show in the limit as \(n \to \infty\) that this is zero. This is done by breaking the sum (14) into two parts. If \(a < b\) split the sum for \(k \leq n/2b\) and \(k > n/2b\), if \(a > b\) split the sum between \(k \leq n/2b\) and \(k > n/2a\).

Assuming \(a < b\), and since \(\sin(x) > 2x/\pi\) for \(0 < x < \pi/2\), we have that

\[
\sum_{k=2}^{\lfloor n/2b \rfloor} \sin^2 \left( \frac{\pi k}{n} \right) \sin \left( \frac{\pi k}{n} \right) - \sin^2 \left( \frac{\pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right) < \sum_{k=2}^{\lfloor n/2b \rfloor} \left( \left( \frac{2 \pi k}{n} \right)^2 - \left( \frac{2 \pi k}{n} \right)^4 \right) \sin^2 \left( \frac{\pi k}{n} \right) +\sin^2 \left( \frac{\pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right) * (a^2 + b^4)k^4.
\]

Using the Taylor expansion for \(\sin(x)\) in (15) gives

\[
\sum_{k=2}^{\lfloor n/2b \rfloor} \frac{\left( \frac{2 \pi k}{n} - \frac{1}{2} \left( \frac{2 \pi k}{n} \right)^2 \left( \frac{2 \pi k}{n} \right)^3 + \ldots \right)^2}{k^4} = \frac{n^4}{16 \cdot (a^2 + b^4) k^4} \sum_{k=2}^{\lfloor n/2b \rfloor} \left( \frac{2 \pi k}{n} - \frac{1}{2} \left( \frac{2 \pi k}{n} \right)^2 \left( \frac{2 \pi k}{n} \right)^3 + \ldots \right)^2.
\]

Since the terms inside the sum are all bounded, the sum itself is on the order of \(n/2b\), so (16) is of order \(1/n\), thus its limit is zero, that is

\[
\lim_{n \to \infty} \sum_{k=2}^{\lfloor n/2b \rfloor} \frac{\sin^2 \left( \frac{2 \pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right) - \sin^2 \left( \frac{\pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right)}{\sin^2 \left( \frac{\pi k}{n} \right) + \sin^2 \left( \frac{\pi k}{n} \right)} = 0.
\]

For \(k > n/2b\), since \(a\) and \(b\) are relatively prime, the denominator for

\[
\sum_{k=\lfloor n/2b \rfloor + 1}^{\lfloor n/2b \rfloor} \frac{\sin^2 \left( \frac{2 \pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right) - \sin^2 \left( \frac{\pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right)}{\sin^2 \left( \frac{\pi k}{n} \right) + \sin^2 \left( \frac{\pi k}{n} \right)}
\]

is bounded away from zero, so

\[
\lim_{n \to \infty} \sum_{k=\lfloor n/2b \rfloor + 1}^{\lfloor n/2b \rfloor} \frac{\sin^2 \left( \frac{2 \pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right) - \sin^2 \left( \frac{\pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right)}{\sin^2 \left( \frac{\pi k}{n} \right) + \sin^2 \left( \frac{\pi k}{n} \right)} = 0.
\]

Similarly

\[
\sum_{k=\lfloor n/2b \rfloor + 1}^{\lfloor n/2b \rfloor} \frac{\sin^2 \left( \frac{\pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right) - \sin^2 \left( \frac{\pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right)}{\sin^2 \left( \frac{\pi k}{n} \right) + \sin^2 \left( \frac{\pi k}{n} \right)} = 0.
\]

(17) and (21) combine to give

\[
\lim_{n \to \infty} \sum_{k=\lfloor n/2b \rfloor + 1}^{\lfloor n/2b \rfloor} \frac{\sin^2 \left( \frac{2 \pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right) - \sin^2 \left( \frac{\pi k}{n} \right) \sin^2 \left( \frac{\pi k}{n} \right)}{\sin^2 \left( \frac{\pi k}{n} \right) + \sin^2 \left( \frac{\pi k}{n} \right)} = 0.
\]

(22) together with the symmetry of our discrete

\[
\sum_{k=2}^{\lfloor n/2b \rfloor} \frac{\left( a^2 k^2 b^4 + a^3 k^3 b^7 - b^2 k^2 a^4 - b^4 k^4 a^2 \right)}{k^4}
\]

Proceedings Arkansas Academy of Science, Vol. 49, 1995
model shows, in the limit as the number of points in the model goes to infinity, that all the partials of the energy for this configuration are zero. Since the energy functional is continuous at \( \gamma(t) \), the first variation of the energy for the curve \( \gamma(t) = (\cos(2at\pi), \sin(2at\pi), \cos(2bt\pi), \sin(2bt\pi)) \) is zero. Thus this curve is a critical point of the energy. Projecting this curve to \( R^3 \) gives the curve

\[
\sigma(t) = \left( \frac{\cos(2at\pi)}{\sqrt{2}\sin(2bt\pi)}, \frac{\sin(2at\pi)}{\sqrt{2}\sin(2bt\pi)}, \frac{\cos(2bt\pi)}{\sqrt{2}\sin(2bt\pi)} \right)
\]

Using the conformal property of the energy functional (1) shows that the curve \( \sigma(t) \) is a critical point of the energy.

**Literature Cited**


Influence of Pine Silvicultural Systems on Spider Population Diversity in Drew County, Arkansas

Holly Hill and Peggy Rae Dorris
Department of Biology
Henderson State University
Arkadelphia, AR 71999-0001

Lynne C. Thompson
School of Forest Resources
U. of A. at Monticello
Monticello, AR 71656-3468

Abstract

Spiders were collected by pit-trapping in southeastern Arkansas in 1984. Collection areas included two pine silvicultural treatments, clear-cutting and selection cutting; and control stands, where no cutting occurred. Spider populations decreased with increased disturbance.

Introduction

A preliminary study of spiders collected by pit-traps in Drew and Bradley counties, Arkansas was published by Dorris (1986). Since that time many more species have been identified, and experience shows that as succession occurs in a forest stand, populations of organisms change with respect to numbers and species. Mounting evidence indicates that the population density, behavior, and population dynamics of spiders are such that these predators are collectively an important stabilizing agent of terrestrial arthropod population (Bremeyer, 1966; Moulder and Reichle, 1972; Enders, 1975; Coyle, 1981) and thus, spiders may be an important factor in total ecosystem stability. Tanner et. al., (1994) discussed species coexistence, keystone species, and succession. Numerous authors have noted changing predator-prey relationships as succession occurs in disturbed areas: Carlson (1994), Tallis (1994), Moore (1993). Spiders are among the dominant predators in many terrestrial communities (Gertsch, 1979).

Spiders were collected by pit-traps in Drew County in 1984 in a replicated experiment that included two silvicultural treatments and a control area. Nine different forestry stands were employed in an effort to determine how spider population decreases with increased disturbance.

Materials and Methods

This study was initiated in the West Gulf Coastal Plain in southeastern Arkansas, near Monticello in Drew County. One set of three stands was designated as the undisturbed control and the remaining six stands were managed using two pine silvicultural systems: selection cutting and clearcutting, each consisting of three stands.

In clear-cut stands all merchantable trees were harvested and the remaining vegetation and logging debris was sheared, raked and windrowed. Site preparation began in mid-September, 1981, and was completed within two weeks; windrows were burned approximately ten days after completion. The clear-cuts were planted in December, 1981, with genetically improved loblolly (Pinus taeda) pine seedlings in a 2.4m x 3.0m spacing.

Stands designated for selection management were prescribed burned and selectively harvested to remove some pines (including all pines with a diameter at breast height (d.b.h.) > 53cm) and all merchantable hardwoods; the remaining hardwoods (d.b.h.) > 2.5cm were injected with the herbicide 2,4- D + picloram. Harvesting began in July, 1981 and was completed by mid-August, 1982. The goal of selection management is to produce a stand with an overall structure grading from many seedlings and saplings to a few large trees; however, most of the stand basal area ( a measure of stand density expressing the total cross-sectional area at d.b.h. of all trees in a unit of land) is in sawtimber-sized trees (d.b.h. > 25cm).

Generally, in clear-cut areas ground vegetation was dominated by blackberry (Rubus spp.) Japanese honeysuckle (Lonicera japonica), and hardwood vegetation. The many open areas in selection stands produced thickets of blackberry, Japanese honeysuckle, hardwood, and pine saplings. By contrast, the ground vegetation of the control stands was sparse because of its dense overstory.

Spiders were collected using pit-traps. Each trap consisted of a cylinder made from a tin 1-quart oil can with both ends removed. The cylinder was buried vertically (with one open end up) and level with the ground surface. A 16-ounce clear plastic drinking cup was placed in the cylinder and filled about one-third full with preserving fluid, a 1:1 mixture of anti-freeze (ethylene glycol) and water. To simplify content removal, a strainer (made from another plastic cup and aluminum window screen) was placed into the bottom of each drinking cup. A 1-ft sq. plywood rain lid, held about two inches over the cup using three large nails as legs, reduced the amount of
Influence of Pine Silvicultural Systems on Spider Population Diversity in Drew County, Arkansas

...water entering each trap. Traps were serviced weekly, from May 5, 1984 to November 21, 1984.

Spiders were picked from the arthropods collected in each trap and stored in glass vials in 70% ethanol. Spiders were identified using the keys of Kaston (1948, 1978), Comstock (1965) and Heiss and Allen (1986).

Data collected were stored in a database system. The statistical program, SPSS (Norusis, 1990), was used for analysis. The three replicates for each treatment were pooled to produce the total for that treatment.

Results and Discussion

Pitfall trapping is not a good measure of absolute abundance because trap catches are influenced by the activity of each species and by differences in their susceptibility to trapping. Pitfall traps are typically used in ecological studies because they give reasonable estimates of spider relative abundance and are easy to use.

A total of 68 genera, more than 70 species and 10,856 total spiders was identified. The control stands produced 52%, selection stands 25% and clear-cuts 23% of the spiders (Fig. 1).

Total Spiders Identified in Each Station

![Graph](image)

Fig. 1. Total spiders in each station.

![Graph](image)

Fig. 2. Abundance of *Agelenopsis* in different study areas.

![Graph](image)

Fig. 3. Abundance of *Castianeira* in different study areas.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
The following genera were most affected by clearcutting with a reduction in abundance: *Agelenopsis, Castianeira, Drassyllus, Gnaphosa, Lycosa, Misumemops, Oxyptila, Pirata, Rachodrassus, Schizocosa, Zelotes* (Figs. 2-12). Some genera did not occur in clear-cuts but occurred in the other stands.

The genera most affected by clearcutting were typical-ly ground dwelling spiders. These spiders have high trap susceptibility and are more frequently collected in pittraps than other spiders. Some species were extremely affected by disturbance such as *Rachodrassus exilae* (Fig. 10), *Gnaphosa sericata* (Fig. 5) and *Misumemops asperatus* (Fig. 7). These species followed the writers' expected pattern of decreased numbers usually occurring with disturbance. A study done by Coyle (1981) on the effects of
clearcutting in southern Appalachian forests indicated that clearcutting reduced the total spider population.

Not all species followed the predicted pattern. Zelotes hentzi (Fig. 12), Zealotes duplex (Fig. 12) and Lycosa gulosa (Fig. 6) occurred in greater numbers in the selection stands. These species may respond differently to disturbance and to different food supplies.

Schizocosa avida, Schizocosa billineata (Fig. 11), Lycosa avida (Fig. 6) and Lycosa rabida (Fig. 6) occurred in large numbers in the clear-cuts. The growth of ground vegetation in clear-cut areas attracts insects which in turn attracts spiders such as these wolf spiders that hunt prey rather than building webs. The ability of hunting spiders to successfully adjust to clearcutting is not surprising in view of the abundant evidence that many hunting spiders are remarkably well adapted to open and climatically harsh environments (Lowrie, 1948; Almquist, 1973; Gertsch and Riechert, 1976). Two factors contributed to the success of hunting spiders in such environments.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Holly Hill, Peggy Rae Dorris and Lynne C. Thompson

First, many hunting spiders live on or near the ground where the climate is relatively stable (Geiger, 1950). Secondly, their ability to move readily to patches with more favorable climate and resource values (Almquist, 1973; Kronk and Riechert, 1979) may be especially important by allowing them to cope with the large amount of spatial and temporal variation in microclimate that exists in a clear-cut habitat.

The overall effect on spider populations followed the expected pattern with a decrease in numbers from control, to selection, to clear-cuts. The pattern can be seen in Table 1.

Table 1. Abundance of genera of spiders in different areas.

<table>
<thead>
<tr>
<th>GENUS</th>
<th>CONTROL</th>
<th>CLEARCUT</th>
<th>SELECTION</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agelenidae</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Agelenopis</td>
<td>27</td>
<td>17</td>
<td>24</td>
<td>68</td>
</tr>
<tr>
<td>Allocosa</td>
<td>5</td>
<td>10</td>
<td>17</td>
<td>32</td>
</tr>
<tr>
<td>Antrodiaetus</td>
<td>37</td>
<td>3</td>
<td>6</td>
<td>46</td>
</tr>
<tr>
<td>Anyphaena</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Araneae</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Arctosa</td>
<td>5</td>
<td>9</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>Arctura</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Callilepis</td>
<td>71</td>
<td>91</td>
<td>0</td>
<td>162</td>
</tr>
<tr>
<td>Castaneinae</td>
<td>295</td>
<td>47</td>
<td>57</td>
<td>399</td>
</tr>
<tr>
<td>Ctenidae</td>
<td>19</td>
<td>4</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Chalcidion</td>
<td>10</td>
<td>4</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Chelifer</td>
<td>0</td>
<td>8</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Ctenidion</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ctenicus</td>
<td>25</td>
<td>5</td>
<td>13</td>
<td>43</td>
</tr>
<tr>
<td>Dicranidae</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Dryasodes</td>
<td>357</td>
<td>11</td>
<td>10</td>
<td>56</td>
</tr>
<tr>
<td>Dryasylus</td>
<td>482</td>
<td>297</td>
<td>140</td>
<td>919</td>
</tr>
<tr>
<td>Eris</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Eutaita</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Gnaphosa</td>
<td>471</td>
<td>101</td>
<td>209</td>
<td>781</td>
</tr>
<tr>
<td>Heronactis</td>
<td>23</td>
<td>3</td>
<td>6</td>
<td>32</td>
</tr>
<tr>
<td>Heronatus</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Haplodrassus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Herpyllus</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Hoherinae</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Latrodectus</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Linyphiulus</td>
<td>27</td>
<td>0</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>Lycomus</td>
<td>1580</td>
<td>1091</td>
<td>657</td>
<td>3328</td>
</tr>
<tr>
<td>M. rosea</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Mecina</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Marcellina</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Marmosia</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Metaptychus</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Micaria</td>
<td>16</td>
<td>3</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>Micrathaena</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Micromerist</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Misumena</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Misumipops</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Misumoechus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Misuminephra</td>
<td>441</td>
<td>26</td>
<td>67</td>
<td>534</td>
</tr>
<tr>
<td>Myrmelechalis</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Neocurias</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>N. sinensis</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>N. sp.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Neomarina</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Neoscona</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Oxyopidae</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Orthosia</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Or피phila</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Paradiasus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phidippus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phlegra</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Palarotopus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pinatia50</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Pleophilius</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Pneoctonius</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Pneoctonius</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pseudosoma</td>
<td>405</td>
<td>9</td>
<td>214</td>
<td>628</td>
</tr>
<tr>
<td>Schizocosa</td>
<td>721</td>
<td>307</td>
<td>226</td>
<td>1254</td>
</tr>
<tr>
<td>Sericulus</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Sesiella</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Scytodes</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Streptacanthus</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Symphyta</td>
<td>29</td>
<td>35</td>
<td>24</td>
<td>88</td>
</tr>
<tr>
<td>Symmea</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trinetrona</td>
<td>10</td>
<td>15</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>Tricosia</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Trechona</td>
<td>15</td>
<td>5</td>
<td>13</td>
<td>33</td>
</tr>
<tr>
<td>Xysticus</td>
<td>158</td>
<td>3</td>
<td>7</td>
<td>168</td>
</tr>
<tr>
<td>Zelotes</td>
<td>474</td>
<td>343</td>
<td>772</td>
<td>1589</td>
</tr>
<tr>
<td>Zora</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5695</td>
<td>2468</td>
<td>2702</td>
<td>10856</td>
</tr>
</tbody>
</table>

Fig. 11. Abundance of Schizocosa in different study areas.

Fig. 12. Abundance of Zelotes in different study areas.
Conclusions

Pit-traps assess relative abundance of spiders. Numbers collected show highest density in the controls followed by the selection stands and slightly less in clear-cuts. The three stand types reflect increasing disturbance intensity. Data have shown that the greater the disturbance the more adversely the spiders are affected.

Large numbers of Lycosidae and Gnaphosidae were found than other spider families. These families are primarily ground spiders or hunting spiders that catch prey without the aid of a web and, therefore are more likely to fall into pit-traps.

Acknowledgments.—Appreciation is extended to Mr. and Mrs. Sam Hill, Matt Largen and Craig Watson for computer and statistical assistance and for other support. Others who contributed to this paper are Lisa Parker, a fellow sufferer through long hours of spider identification, and Jim Parker, a student at the University of Arkansas at Monticello, who aided in pit-trap collections and arthropod sorting.

Literature Cited


Proceedings Arkansas Academy of Science, Vol. 49, 1995
Dytiscidae (Coleoptera) of Jackson County, Arkansas

Anthony Holt and George L. Harp
Department of Biological Sciences
Arkansas State University
State University, AR 72467

Abstract

Dytiscid beetles were surveyed to establish a baseline list for this county, which lies primarily in the Mississippi Alluvial Plain. This list was then compared with that for an Ozark county, which had been surveyed in a previous study. Eighteen sites were surveyed by Turtox Indestructible™ dip net and funnel traps. Literature records were also searched. Twenty-one taxa were collected, with temporary pools and oxbow/cypress swamps supporting the greatest diversity. These are the least disturbed sites in Jackson County. Most species collected are generally widely distributed and prefer either shaded ponds/pools with some leaf litter, or shallow areas of ponds, lakes and slow streams. To the contrary, Randolph County, on the Ozark Plateau, has more taxa (31), with many typifying Ozark streams. More specifically, *Hydroporus* was represented by seven species in Jackson County, but 13 species were found in Randolph County. The difference was the presence in Randolph County of the subgenus *Heterosternuta*, found invariably along the gravelly margins of clear streams.

Introduction

A survey of Jackson County was conducted to establish a record of the dytiscids. Jackson County lies almost exclusively within the Mississippi Alluvial Plain in northeastern Arkansas with the exception of approximately 10 square kilometers that are within the Ozark Plateau. A secondary purpose was to compare this record with that of Pippenger and Harp (1985) in Randolph County, which lies primarily on the Ozark Plateau.

Materials and Methods

Eighteen sites were sampled to represent the major habitat types within the study area. Organisms in this study were collected by two principle methods. Most of the specimens were collected with a Turtox Indestructible™ dip net. Funnel traps were also utilized. One trap was constructed with the design by Hilsenhoff (1987), using a wide-mouth 0.95 l jar and a funnel made from the top of a 2.0 l soda bottle. Another trap was a variation of the above with the funnel having a diameter approximately twice that of the 2.0 l trap. A plastic minnow trap was also used to obtain some samples. All samples were preserved in 70% ethanol. A search of the Arkansas State University Museum of Zoology (ASUMZ) Aquatic Macroinvertebrate Collection provided specimens from five additional sites, which were also presumably collected by Turtox Indestructible™ dip net. Final identification of most organisms was made by G. William Wolfe at Reinhardt College, Waleska, GA. Paul Spangler of the Smithsonian Institution identified *Dytiscus carolinus*. Voucher specimens are housed in the ASUMZ Aquatic Macroinvertebrate Collection.

Site locations and a brief description of each are as follows:

1. Tupelo Brake. T12N R1W S7 & R2W S12.
   Tupelo/Cypress swamp adjacent to Village Creek.
   Road crossing at a disturbed site, somewhat lotic in nature due to a narrowing of the stream width by approximately two-thirds.
   Permanent water in a large woodlot (approximately 12 ha) with sandy soil.
   Oxbow/scar lake of Black River. Cypress trees numerous on the shores with water very turbid.
5. T14N R2W S16.
   Temporary pool (puddle) adjacent to #4.
6. T14N R2W S22.
   Rice field.
   Effluent of a rice field being drained. Samples collected in traps 4 days.
   Roadside ditch which retains water almost continually.
   Rice field.
    Temporary pond approximately 1 ha in surface area.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Borrow ditch along the Jackson/Independence County Line. No dytiscids collected.

   A 2nd order Ozark stream.
   A 1st order Ozark stream. No Coleoptera collected.
   Cypress Swamp.
   Deltaic stream/cypress swamp.
   Temporary pool in recently bulldozed right-of-way.
17. T14N R2W S15.
   Top of a 209 1 (55-gallon) steel drum (water approx. 1 cm deep) under a mercury-switch controlled light.
   Temporary pond.
   A 2nd order Deltaic stream.
20. Temporary pond in a woodlot. Location unknown.
22. T14N R2W S22.
   Permanent fish pond. Approximately 8 ha in surface area.
   *Sites 19-23 are specimens from the museum collection - collection method unknown.

Results and Discussion

Twenty-one taxa represented by 402 individuals (361 from the present study and 41 from the ASUMZ) were collected in this study (Table 1). Sites one and 10 yielded the greatest number of species, while no dytiscids were collected at sites 11 and 13.

Eight different major habitat "types" were examined in this study (Table 2). Species richness was greatest in temporary ponds (13 taxa) and oxbows/cypress swamps (11 taxa). The habitat type with the fewest dytiscids present was that of Ozark streams with only one taxon, Hydroporus Neoptorus carolinus, collected.

In Arkansas one would ordinarily expect the greatest diversity of aquatic insects, including some dytiscid groups (Matta and Wolfe, 1981; Harp, 1989), to be in an Ozark stream because of the diversity of habitats found with respect to water depth, current speed and substrate particle size. Buffering provided by the limestone substrate further contributes to species richness (Cather and Harp, 1975). Temporary pools would have little diversity because of the limitation imposed by periodic absence of water. The opposite was found to be the case in Jackson County for several reasons. Most of this county lies in the Mississippi Alluvial Plain and is intensely cultivated. As a consequence, surface waters are heavily impacted by pesticide and fertilizer applications, channelization of streams in the interest of flood control and other agriculturally related practices (Holt and Harp, 1993). A major hinderance to current agricultural practices in the Mississippi Alluvial Plain is the occurrence of scattered wetlands, particularly shallow depressions that retain water for a significant part of the growing season. These wetlands, often in the form of temporary pools or oxbow/cypress swamps, are today the least disturbed sites to be found, and they, therefore, support the greatest diversity of dytiscids.

The reversal of habitats with greatest/least diversity seen in Jackson County is accentuated in that the Ozark Plateau rarely reaches into Jackson County. Thus the two Ozark streams sampled were very small (1st and 2nd order), subject to periodic drying, and with unusually homogenous substrates of gravel-pebble.

As a whole, those taxa of dytiscids collected in this study are generally widespread in distribution (Merritt and Cummins, 1984), and it is of no surprise that they were found in the habitat types covered by this study. In a similar study of Randolph County, also in northeastern Arkansas, Pippenger and Harp (1985) collected 31 taxa (Table 3). They sampled more sites (32 vs. 23) than were sampled in this study. More importantly, however, Randolph County encompasses parts of both the Ozark Plateau (80%) and Mississippi Alluvial Plain (20%). This provides that county with much more diversity of habitat types and thus a greater diversity of aquatic insects. Indeed, the greatest difference in the species lists for the two counties is the relative lack of Hydroporus spp. in Jackson County, 7 vs. 12. Most of those reported by Pippenger and Harp (1985) were of the Heterosternuta subgenus, invariably collected along gravelly stream margins or in bedrock substrate in fissures where gravel and algae have accumulated. Agabus semiwittatus is apparently a form characteristic of springs (Pippenger and Harp, 1985). Conversely, those species collected by us, but not in Randolph County, are most often collected in shaded ponds and pools having some leaf litter (e.g., Aciilius frater- nus, Michael and Matta, 1977) or shallow areas of ponds, lakes, slow streams or longer-lasting temporary sloughs (e.g., Dytiscus spp., Larson, 1975). These habitats are similar to the temporary ponds and oxbow/cypress swamps sampled in the present study.
Table 1. Dytiscids of Jackson County, Arkansas.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Taxon</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acilius fraternus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agabus disintegratus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coptotomus loticis</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coptotomus venustus</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cybister fimbriolatus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dytiscus carolinus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydaticus bimarginatus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Hygrotrus nubilus</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>47</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydroporus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrourus rufulabris</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus carolinus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus clypealis</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus hybridus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus undulatus</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Neoporus venustus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus vittatipennis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Laccophilus fasciatus rufus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Laccophilus proximus proximus</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>10</td>
<td>20</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neobidessus pullus pullus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermonectus basilaris</td>
<td>3</td>
<td></td>
<td></td>
<td>20</td>
<td>25</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermonectus ornaticollis</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>22</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uvarus lacustris</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total taxa</td>
<td>8</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>4</td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total individuals</td>
<td>42</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>16</td>
<td>49</td>
<td>118</td>
<td>7</td>
<td>15</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sites</th>
<th>Taxon</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acilius fraternus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agabus disintegratus</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coptotomus loticis</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coptotomus venustus</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cybister fimbriolatus</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dytiscus carolinus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydaticus bimarginatus</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Hygrotrus nubilus</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Hydroporus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrourus rufulabris</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Neoporus carolinus</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus clypealis</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>23</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus hybridus</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus undulatus</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td>2</td>
<td>1</td>
<td></td>
<td>1</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus venustus</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neoporus vittatipennis</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Laccophilus fasciatus rufus</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>8</td>
<td></td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Laccophilus proximus proximus</td>
<td>21</td>
<td>9</td>
<td>78</td>
<td>9</td>
<td>78</td>
<td>16</td>
<td>16</td>
<td>19</td>
<td>16</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neobidessus pullus pullus</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td>2</td>
<td>1</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermonectus basilaris</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermonectus ornaticollis</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uvarus lacustris</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total taxa</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Total individuals</td>
<td>20</td>
<td>1</td>
<td>39</td>
<td>7</td>
<td>3</td>
<td>11</td>
<td>1</td>
<td>26</td>
<td>2</td>
<td>14</td>
<td>402</td>
</tr>
</tbody>
</table>
Table 2. Major habitat types.

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>Sites</th>
<th>No. Taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary pond (including ricefields)</td>
<td>5,6,7,9,10</td>
<td>13</td>
</tr>
<tr>
<td>Deltaic stream (3-5th order)</td>
<td>16,18,20,23</td>
<td></td>
</tr>
<tr>
<td>Deltaic stream (1st order)</td>
<td>2,15,21</td>
<td>6</td>
</tr>
<tr>
<td>Ozark stream (1-2nd order)</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>Artificial container</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Permanent road ditch</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Oxbow/cypress swamp</td>
<td>1,4,14</td>
<td>11</td>
</tr>
<tr>
<td>Permanent pond</td>
<td>3,11,22</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3. A comparison of dytisci species reported for Jackson and Randolph Counties, Arkansas. Randolph Co. data modified from Pippenger and Harp (1985).

<table>
<thead>
<tr>
<th>Species</th>
<th>Jackson</th>
<th>Randolph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acilius fraternus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Agabus confusus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>A. disintegratus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>A. semivittatus</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Birdassonotus inconspicuous</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Celina hubelli</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Coptotomus lenticus</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>C. loticus</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>C. venustus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Cybister fimbriolatus</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Dytsicus carolinus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Graphoderus perplexus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Hydaticus himarginatus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Hydroporus carolinus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. chyenei</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. demidiatius*</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. hybridus</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>H. lynceus*</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>H. oblitus*</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>H. ouachitus</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>H. pulcher</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>H. rufilabriss</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. shermani</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. somnus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. undulatus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. venustus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. vittatipennis</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H. wickhami</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Hydroyxus pastulatus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Hygrothus rubilus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Ibyius oblitus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Laccophilus fasciatus rufus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>L. maculosus maculosus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>L. proximus proximus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Neobidessus pullus pullus</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

*H. lobatus should be assigned to the lynceus complex, H. solitarious was H. demidiatius, and H. tigrinus was H. oblitus (Matta, pers. comm.).

Literature Cited


Optimizing Tracking Software for
a Time Projection Chamber

Wilson H. Howe, Christine A. Byrd, Amber D. Climer, W.J. Braithwaite
Department of Physics and Astronomy
University of Arkansas at Little Rock
Little Rock, Ar 72204
Jeffrey T. Mitchell
Brookhaven National Laboratory
Upton, NY 11973

Abstract

International research collaborations will be using accelerators in the U.S. and Europe to produce and detect the phase transition in high-density nuclear matter called the Quark-Gluon Plasma, formed in collisions between pairs of A=200 nuclei, for projectiles with kinetic energies large compared to their rest mass energies. Each collaboration will use time projection chambers (TPC) to track thousands of secondary charged particles formed in the aftermath of each central primary collision. Creating and optimizing TPC tracking software is difficult in such a high multiplicity environment, particularly for particles with a low momentum (below 300 MeV/C). At high momenta, energy loss is low enough for particle-tracking to use unchanging helix parameters. However, at low momenta, tracking requires changing helix parameters as energy is lost along the path. Tracking software, written for particles of high momenta, may identify the track of a single low momentum particle as two or three separate tracks. This tracking problem was corrected by changing the main tracking algorithm to merge together these two-or-three fragmented, low-momentum particle tracks. Event displays were found exceedingly helpful in diagnosing the problems and optimizing the algorithms.

Introduction

Within the first microsecond after the big bang, the Standard Model predicts that mass-energy densities were so high, the dominant form of matter in the universe was the quark-gluon plasma or QGP (Schukraft, 1993). QGP is a state in which quarks and gluons move freely at a much higher mass-energy density than that of nuclear matter. At lower mass-energy density, quarks and gluons are usually bound together in particles such as protons, neutrons, pions, etc. Except, possibly, in the cores of neutron stars, densities and temperatures do not rise high enough to permit quarks and gluons to break free from protons and neutrons, so QGP is not readily observed in nature (Schukraft, 1993). Attempts to produce QGP have been made using the SPS (Super Proton Synchrotron) at CERN and using the AGS (Alternating Gradient Synchrotron) at Brookhaven National Laboratory. In each case relativistic nuclei collide with stationary nuclei in fixed targets. None of these experiments have reported the detection of the QGP (Schmidt, 1993).

Two distinct attempts are now being made to produce the phase transition from normal matter to QGP, using relativistic beams of heavy nuclei. One effort, which is underway, uses the SPS at CERN to provide lead (Pb) beams on a fixed lead target. The second effort is planned at Brookhaven National Laboratory using RHIC (the Relativistic Heavy Ion Collider), where heavy nuclei will collide in pairs. RHIC and its detectors are on schedule for completion by the end of the century (Schukraft, 1993).

RHIC is expected to provide the energy necessary to produce the QGP by colliding gold nuclei, where each is moving within 1 part in 20,000 light speed. At such speeds, the kinetic energy of each colliding gold nucleus is over 100 times its rest mass energy. The Standard Model predicts the QGP will be formed at these high energy densities, so even if the QGP is not formed, these efforts will provide a significant test of the Standard Model.

At RHIC, the effort to observe the QGP will be carried out by analyzing the particles emerging from the aftermath of central collisions between relativistic pairs of gold nuclei. Thousands of charged secondary particles, produced in each primary collision, will be used to investigate the physics of the primary collision. Detectors at RHIC are being built to track charged particles generated in the aftermath of each central primary collision. Several thousand charged secondary particles (called a high multiplicity environment) make tracking a difficult experi-
The Solenoidal Tracker (STAR) is one of two large instruments located at RHIC at one of its six colliding-beam crossover points. Secondary charged particles produced at RHIC are observed using different sub-detectors of STAR, which is made up of a solenoidal magnet containing these sub-detectors. The solenoidal magnet surrounds the beam pipe of RHIC, creating a magnetic field (0.5 T) along the beam line. Charged particles will bend in this B-field, and the charge and momentum of these particles will be determined by measuring the curvature of their tracks. The STAR sub-detectors are being built to determine pixel-by-pixel coordinates of each particle's trajectory, so all can be tracked simultaneously.

The main sub-detector in STAR is the Time Projection Chamber (TPC), which measures the trajectories of charged particles in three spatial dimensions. The TPC is complemented by several other detectors; these include: a tracker near the collider vertex responsible for measuring all charged particle tracks, especially those with low transverse momentum (below 150 MeV / c) or short half-lives; trigger detectors for measuring when and where each gold on gold event occurs; and an Electromagnetic Calorimeter used to measure particle energies (STAR, 1992).

The TPC is a coaxial cylinder, 4.2 meters long, with an outside diameter of 4 meters and an inside diameter of 2 meters. The cylinder is located within the Solenoidal Magnet and around the vertex tracking detector. Particles with momenta greater than 125 MeV / c can make it through the TPC geometry, but tracking lower-momentum particles is left to the vertex detector. The TPC misses some high momentum particles due to its geometry, but overall it tracks about 50% of the secondary charged particles created in each central collider event (STAR, 1992). The TPC cylinder is divided in half by a high voltage membrane which creates an electric field (130 V / cm). The endcaps are made up of rows of pads at low potential (1265 V), where the signals for tracking particles are induced. The track density is great near the vertex; thus, pads close to the vertex are small (2.85 x 11.5 mm) providing good track separation. TPC pads farther from the vertex are larger (6.2 x 19.5 mm), providing better particle identification (STAR, 1992).

The TPC is designed to detect charged particles, identify them, and obtain the momentum and charge of each. The TPC can be viewed as electronically "taking a three-dimensional picture of the particle trajectories" as the particles ionize its gas, as seen in Fig. 1. The electric field causes the ionization electrons to drift toward the

---

**Fig. 1.** Ionization electrons are shown drifting toward the endcaps of a Time Projection Chamber. The size of the beam pipe is exaggerated.
ends of the TPC chamber. There the signal from each electron is amplified at a thin anode wire; a signal is then induced on a pad under the wire. The placement of the signal on the pad gives two coordinates of the track, and the drift time gives the third coordinate. Up to 45 \((x,y,z)\) pixel coordinates may be associated with a single track; tracking software groups these three-dimensional coordinates into particle tracks.

Measuring charged particle tracks is important because these tracks can be used to infer fundamental information about the primary central collision which created them. The curvature of each track can be used to calculate the charge and momentum of the particle, and the energy loss of a particle can be calculated by measuring the track density of ionized electrons as a function of this measured momentum. This energy loss may be used to determine the particle type. Measurements of what happens after each central gold on gold event are important to understanding the physical processes of these collisions.

Thousands of charged particles are created by each central gold on gold event. With such a large multiplicity, tracking is difficult (see Fig. 2). Particles decay as they leave the vertex creating other particles which must be tracked. These created particles make tracking even more difficult since their tracks can start anywhere in the TPC instead of starting at the vertex. All particle tracks do have common characteristics, and these characteristics are used in designing tracking software. For instance, charged particles follow helical paths in magnetic fields, so the tracking algorithm uses a helix to link hits into particle tracks.

The tracking algorithm starts by making groups out of all the hits on the outside of the TPC. Because of the lower track density, this algorithm begins with the outermost hit and moves inward toward the vertex. When working on a given hit, nearby, unused hits which successfully form a helix fragment with the given hit are found. Then the possible groups for that hit are evaluated, and the group which most closely resembles a helix fragment is kept. The hits from this group are removed from the pool of unused hits, and the next unused hit is grouped (Mitchell and Sakrejda, 1994).

After all the initial groups are found, they are linked into longer tracks. Starting with a given group, all other unused groups with similar helix parameters to that of the first group are compared. The groups making the best helix are joined together into track segments. A single helix is then fit to the entire track segment, and any hits falling too far outside these helix parameters are removed from the track (Mitchell and Sakrejda, 1994).

These track segments are then extended. Starting with the longest track segment, all hits which fall within the helix parameters are added to this long segment. Smaller segments can be destroyed in this process. After the track segments have been extended, most of the tracks are complete. Tracks of particles with low transverse momenta (below 300 MeV/c) often do not get completed in this process.

Particles with low transverse momenta (pt) lose energy more quickly than particles with a higher pt. Energy losses due to interactions of these particles with the gas causes their helix parameters to change as they proceed through the TPC. The normal tracking algorithm breaks these tracks into two or three pieces interpreting each piece as a separate track. Since this track fragmentation is an error, the last step of the algorithm was changed to merge these broken tracks together, by joining low pt tracks with similar helix parameters.

Materials and Methods

Because the detector is not yet built, a simulation software package called GEANT is being used to provide test data to be used by tracking software (GEANT, 1994). GEANT is a Monte Carlo Program which provides data for simulating events expected to occur within the TPC. Pixel data made identical to data which will be produced.

---

Fig. 2. Hits from a simulated Au+Au event in the Time Projection Chamber of STAR. The dots represent the coordinates of points along the particle trajectories for one gold on gold event. This display shows over 80% of the recorded points for a gold on gold event.
by the TPC is constructed from the GEANT simulation. This pixel data is analyzed using a software package called the Physical Analysis Workstation (Paw, 1994), and the software which tracks each helix was written at the Lawrence Berkeley Laboratory (Mitchell and Sakrejda, 1994) for use with the TPC Analysis Shell.

GEANT provides all the information about each simulated particle, which then is used to test whether the tracking software correctly reconstructs each particle's type, speed and momentum. Thus, the efficiency of the tracking software is measured using known input data (Jones, 1994). Improvements in the tracking algorithm can be obtained by looking at the tracking efficiency of the software and by using event displays.

An 8% improvement in efficiency was made for tracking low transverse momentum particles, i.e., particles having a transverse momentum around 150 MeV/c (see Fig. 4). This increase in tracking efficiency greatly improves the probability the TPC will successfully measure the trajectories of particles with a low transverse momentum.

**Fig. 3.** Broken tracks from a simulated event containing only negative pions. The information from this display was used to optimize tracking software so that broken tracks occurred less often.

**Fig. 4.** The efficiency of tracking software as a function of transverse momentum. The dashed lines represent the efficiency before the software was optimized, and the solid lines represent efficiency after it was optimized.

**Results and Discussion**

Given the difficulty of associating low pt particles with fixed helix parameters, tracking efficiency drops at these lower pt values. Since particles of pt less than 125 MeV/c do not often make it into the TPC, efficiency drops dramatically at this low pt. Tracking efficiency is defined as the number of generated tracks in which all hits end up on one track divided by the total number of tracks. Partially or completely unrecorded tracks, broken tracks, and tracks with hits on two or more reconstructed tracks lowers tracking efficiency.

From the event displays, problems were found with the tracking code which lowered the tracking efficiency (see Fig. 3). Problems were solved by changing the algorithm which compared the helix parameters of the broken tracks.

An 8% improvement in efficiency was made for tracking low transverse momentum particles, i.e., particles having a transverse momentum around 150 MeV/c (see Fig. 4). This increase in tracking efficiency greatly improves the probability the TPC will successfully measure the trajectories of particles with a low transverse momentum.
Excellence in Education.

**Literature Cited**

GEANT. 1994. GEANT user's guide: Detector Description and Simulation Tool, CERN Program Library Internal document, CERN Data Division, Geneva, CH.


PAW. 1994 PAW user's guide: Physics Analysis Workstation (PAW manual), CERN Program Library Internal document, CERN Data Division, Geneva, CH.


Recent Establishment of the Asian Tiger Mosquito
(Aedes albopictus) in Independence County, Arkansas

David H. Jamieson
ASU-Beebe (Newport Campus)
Biology Department
7648 Victory Blvd.
Newport, AR 72112

Larry A. Olson
Arkansas State University
Department of Biological Science
State University, AR 72467

Abstract

Three adult Aedes albopictus were collected on 10 August 1993 within the city limits of Batesville, Arkansas. This is the first known report of this species from Independence County. Subsequent investigation revealed the presence of at least three well established populations in the county, two of which were monitored on a monthly basis from April to September of 1994. Peak A. albopictus numbers were recorded in July and August when the population levels were sufficient to make this mosquito a significant pest in Batesville. Our observations suggest that the Asian tiger mosquito will likely colonize other similar communities in Arkansas.

Introduction

On 2 August 1985, the Harris County Mosquito Control District in Houston, Texas discovered the first breeding population of Aedes albopictus (Skuse) in the United States (Moore et al., 1988). This species, commonly known as the Asian tiger mosquito, has been described as potentially one of the most important arbovirus vectors in the western hemisphere (Centers for Disease Control, 1987). A. albopictus historically has occurred from Madagascar eastward through southern Asia to Japan, Korea, and China (Hawley, 1988). Since its arrival in Texas, it has spread rapidly and is now known to inhabit several large cities in the southeastern and midwestern United States (Moore et al., 1991). The interstate shipment of automobile tires is believed to be responsible for its rapid dispersal. A. albopictus originally was described as a woodland species in southeastern Asia where it commonly selects treeholes for its larval habitat. However, this species has quickly adapted to breeding in artificial containers, particularly automobile tires, that may periodically be flooded by rainfall. In the United States, A. albopictus can most frequently be encountered in the urban environment where an abundant supply of suitable artificial containers is available.

On 10 August 1993, three biting female A. albopictus were collected by the senior author in the city limits of Batesville, Arkansas. Until this, the only known published collections of A. albopictus in the state were from Grant County in central Arkansas (Moore et al., 1988), Jefferson County in southeastern Arkansas (Savage et al., 1994), and Craighead County in northeastern Arkansas (Jamieson et al., 1994). An intensive investigation to determine the source of these individuals followed. Three breeding sites were discovered: Site 1, a tire dump at the intersection of State Hwy. 69 and Main Street in downtown Batesville; Site 2, a tire dealership 4 km north of Batesville on State Hwy. 69; Site 3, a tire dealership 1 km south of Batesville on State Hwy. 25.

Larval collections were made at Sites 1 and 3 on a monthly basis from April to October of 1994. Samples were taken in a systematic and uniform manner in order to provide data as to comparative abundance. Ten tires were selected at each site and two dips were taken from each tire using a standard 350 ml mosquito dipper. Larval and adult A. albopictus were distinguished from other North American Aedes using the keys of Darsie (1986). In this study, Aedes albopictus larvae frequently were collected in association with larvae of Culex resuans(Theobald), C. salinarius (Coq.), Culiseta inornata (Coq.) and Orthopodomyia signifera (Osten Sacken). Aedes albopictus larval populations peaked at Site 1 during July (Fig. 1) and at Site 3 during August (Fig. 2). Apparently, there is continuous production of A. albopictus during summer months if sufficient rainfall occurs to inundate eggs. The absence of larvae in September at both sites, despite the presence of water, suggests that females may have laid diapause eggs in response to shorter day lengths. However, according to Hawley (1988), larval production may be influenced by several other factors including water temperature, the number of floods required to hatch eggs, and the oxygen content of the hatching medium. Hawley (1988) also reported one of the most important evolutionary aspects of A. albopictus has been its development of
photoperiodic egg diapause which has allowed it to permanently inhabit cooler temperate regions. It is interesting to note that the yellow fever mosquito (Aedes aegypti), an animal similar to A. albopictus in that it has effectively extended its range by utilizing artificial containers as larval production sites, has not developed a diapause egg and is thus more limited by cold temperatures.

![Graph 1](image1)

**Fig. 1.** Monthly larval collections of *Aedes albopictus* at old tire dump (site 1) in Batesville, Arkansas.

![Graph 2](image2)

**Fig. 2.** Monthly larval collections of *Aedes albopictus* at tire dealership (site 3) 1 km south of Batesville, Arkansas.

Although no quantitative data were recorded, biting adult female *A. albopictus* were encountered at both sites during the entire study period. Adult populations were high enough in July, August, and September to make larval sampling almost impossible. Additional biting collections made at several locations within the Batesville city limits revealed the presence of adults several kilometers from any known production site. Although adult *A. albopictus* are known to be weak fliers with a short flight range (Hawley, 1988), we observed this species readily dispersed in the city by utilizing a variety of artificial-container habitats. In addition to automobile tires, we collected larvae from house gutters, flower pots, bird baths, barbecue grills, and a Christmas tree stand.

In Batesville, population levels of *A. albopictus* were sufficient to restrict human outdoor activities in some neighborhoods from June to September. According to several local residents, Batesville has been transformed from a city with virtually no mosquito problem to one with a serious mosquito control dilemma.

Our observations suggest that the Asian tiger mosquito likely will become established in other Arkansas communities, especially those that do not regularly engage in mosquito control activities.

**ACKNOWLEDGMENTS.**—The authors express thanks to Twyliah Mitchell and Janna Kegley for assistance in preparation of the manuscript.

**Literature Cited**


Recreational and Angler Survey of the Buffalo National River, Arkansas

James E. Johnson
National Biological Service
Arkansas Cooperative Fish and Wildlife Research Unit
Department of Biological Sciences
University of Arkansas
Fayetteville, AR 72701

Abstract

The Buffalo River in northern Arkansas was surveyed for recreator and angler use in 1991 and 1992. The river was divided into three reaches and numbers of boats, recreators, anglers, and catches were compiled by creel clerks at nine selected take-out points. Outfitter rental receipts were used to estimate rental boats, and the proportion of rental to private boats creeled was used to correct for private boats not counted on the rental receipts. A total of 1,656 boats containing 8,071 recreators was contracted by the creel clerks during 1991 and 1992; 9.2% of the recreators were anglers. Expansion of the creel data indicates an estimated 192,348 people floated the river during 1991 and 1992, resulting in annual averages of 116 and 73 boats/ha, 214 and 135 recreators/ha, and 20 and 12 hours of angling/ha on the river during those two years. Smallmouth bass was the principal game fish and accounted for a harvest of 4.6 and 1.3 fish/ha and a catch rate of 0.08 and 0.03 fish/hr. However, catch and release, estimated at 1.0 fish/hr, may have biased harvest and catch rates. Smallmouth bass harvest was low when compared to other waters and is not likely impacting the population.

Introduction

The Buffalo River in northern Arkansas is one of the last free-flowing rivers in the Arkansas Ozarks. It originates in the Boston Mountains, Newton Co., in the Upper Buffalo River Wilderness Area on the Ozark National Forest and flows eastward for 238 km before joining the White River (Whisenant and Maughan, 1989). Approximately 90% of the Buffalo River mainstream is within National Park Service (NPS) boundaries; it was the first National River to be designated by Congress (1972, PL 92-237). There are 22 NPS maintained access points on the mainstream Buffalo River and perhaps four times that many informal access points used infrequently by local anglers and recreators. Water quality of the Buffalo River is high, especially in the upper reach, and the substrate is gravel, boulder, and rock. Pools are long and deep, and the riffles short. It is the most popular floating stream in Arkansas (Arkansas Game and Fish Commission, 1992).

Boating on the Buffalo River increased dramatically after it received national recognition as the Nation's first National River. In 1963, NPS estimated 5,500 canoes floated the river. By 1981, that number had increased by an order of magnitude, to 51,000 canoes (Whisenant and Maughan, 1989). There are presently 25 outfitters on the Buffalo River that arrange float trips of a few hours to several days, depending upon distances floated. In an attempt to regulate recreators on the Buffalo National River, NPS placed limits on the number of boats (1,250 canoes, 110 jonboats, 56 rafts/day) outfitters could rent to the public; nothing limits the number of private boats that float the river.

Angling on the Buffalo River is principally for smallmouth bass (Micropterus dolomieu), with sunfishes including Ozark bass (Ambloplites constellatus) and longear sunfish (Lepomis megalotis) and catfishes including flathead catfish (Pylodictis olivaris) and channel catfish (Ictalurus punctatus) accounting for less than 20% of the catch (Whisenant and Maughan, 1989). The overall fish community is rich, with Cashner and Brown (1977) recording 59 species. Channel catfish no longer maintain a viable population in the Buffalo River due to the lack of a spring spawning migration from the cold, hypolimnetic waters of the White River (Siegwarth and Johnson, 1994). Sometime prior to 1977, NPS estimated total annual use of the Buffalo River at 27,380 anglers/yr (calculated from NPS, 1977), and in their River Use Management Plan (NPS, 1983) suggested 33,000 anglers used the river in 1981. The purpose of this study was to determine recreational use and angling harvest on the Buffalo River in 1991 and 1992.

Materials and Methods

A stratified random design was used by the creel clerks to interview recreators as they came off the Buffalo
River at selected access points. Nine stations were chosen from NPS access points in order to best represent the overall traffic on the river (Fig. 1). Data collection design utilized both access point and roving creel clerk techniques, similar to the “bus-stop” survey suggested by Jones and Robson (1991) for fisheries with many well-defined access sites. Each month the clerks gathered information for 8 days (4 week days, 4 weekend days), spending two hours/station and sampling three stations/day. Which eight days of each month to sample and which stations to begin sampling were selected by blindly choosing numbered markers. Sampling then continued downstream. The survey began on March 1, 1991, and ended December 31, 1992.

![Map of Buffalo River, Arkansas, showing divisions of the river.](image)

Only 202 km of the Buffalo River below Ponca, AR are normally floated or fished by boat. The stream above Ponca is usually intermittent and may be floated only at the highest water levels; any fishing in that uppermost reach is usually from the bank. I divided the 202 km of the Buffalo River into three reaches (Fig. 1) with three sampling stations in each reach. The upper reach from Ponca to Carver (56.2 km) is one of the most popular canoe streams in Arkansas during high water in the spring, but becomes intermittent during summer and autumn months. The middle reach extended from Carver to Maumee (77.6 km) and is floatable except during the driest years when its upper portion may become intermittent. The lower reach extended from Maumee to Buffalo City (68.4 km) at the confluence of the White River; this reach is always floatable and consists mainly of long pools and few riffles. Gradients in the river are: upper reach 2.5 m/km, middle reach 1.0 m/km, lower reach 0.6 m/km (NPS, 1977).

Boat rental data on the Buffalo River were obtained from NPS, which required outfitters to maintain rental receipts that included data and location of departure and pickup and number of individuals per boat. The creel clerks counted private and rental boat landings at each station during their two hour period, as well as number of people per boat. This provided a proportion of private to rental boats on the river. If recreators possessed fishing gear, clerks asked if they fished, if their catch could be identified and measured, and how many hours/day they spent fishing (line in the water). During 1992, anglers were also asked how many fish they captured and released. These latter two estimates are biased as they are dependent upon memory, but provide the only method of calculating number of fish caught and the time needed to catch a fish. The total number of boats per reach per year was calculated by determining the proportion of private to rental boats creelled and expanding the number of rental boats as determined from outfitter receipts.

### Results

Table 1 provides numbers of boats, recreators, and anglers contacted on the Buffalo River in 1991 and 1992. An ANOVA test failed to find differences for numbers of boats ($P = 0.49$), recreators ($P = 0.90$), and anglers ($P = 0.71$) between 1991 and 1992, so those data were combined. The creel clerks sampled 375 stations during those two years and contacted 1,656 boats containing 3,071 recreators, for an average of $1.85 \pm 0.28$ (mean $\pm 2$ SE) people per boat. During that same period, 283 recreators stated that they fished at least once during their trip, indicating $9.2\% \pm 0.05$ of the people floating the Buffalo River engaged in fishing.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Stations Contacted</th>
<th>Total Stations</th>
<th>Recreators Contacted</th>
<th>Anglers Contacted</th>
<th>Percent Anglers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>48/41</td>
<td>468/128</td>
<td>525/529</td>
<td>18/22</td>
<td>3.4/8.4</td>
</tr>
<tr>
<td>Middle</td>
<td>75/73</td>
<td>253/246</td>
<td>354/331</td>
<td>46/28</td>
<td>8.3/5.3</td>
</tr>
<tr>
<td>Lower</td>
<td>61/78</td>
<td>262/359</td>
<td>474/215</td>
<td>94/75</td>
<td>19.8/10.5</td>
</tr>
<tr>
<td>Subtotals</td>
<td>184/192</td>
<td>923/733</td>
<td>1963/1508</td>
<td>158/125</td>
<td>10.1/8.3</td>
</tr>
<tr>
<td>TOTALS</td>
<td>376</td>
<td>1656</td>
<td>3071</td>
<td>285</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Using the observed proportion of rental to private boats on each reach for each year (Table 2), a calculated number of private boats was added to the known number of rental boats to provide annual boat traffic on the river (Table 3). Data for 1991 and 1992 were not combined, as significant differences existed between years on several data sets. April, May, and June were the principal use months in the upper reach for both 1991 and 1992, as
Recreational and Angler Survey of the Buffalo National River, Arkansas

Table 2. Numbers of rental and private boats surveyed in 1991/1992 on the Buffalo River and numbers of boats recorded as being rented by outfitters by reach.

<table>
<thead>
<tr>
<th>MONTH</th>
<th>CREEL</th>
<th>PRIVATE</th>
<th>OUTFITTER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rental</td>
<td>Private</td>
<td></td>
</tr>
<tr>
<td>Jan</td>
<td>*/0</td>
<td>*/0</td>
<td>*/10</td>
</tr>
<tr>
<td>Feb</td>
<td>*/4</td>
<td>*/0</td>
<td>*/19</td>
</tr>
<tr>
<td>Mar</td>
<td>24/11</td>
<td>35/1</td>
<td>*/890</td>
</tr>
<tr>
<td>Apr</td>
<td>39/7</td>
<td>9/7</td>
<td>4751/1648</td>
</tr>
<tr>
<td>May</td>
<td>129/2</td>
<td>153/1</td>
<td>284/4168</td>
</tr>
<tr>
<td>Jun</td>
<td>50/68</td>
<td>11/19</td>
<td>5005/3187</td>
</tr>
<tr>
<td>Jul</td>
<td>a/8</td>
<td>a/0</td>
<td>313/1041</td>
</tr>
<tr>
<td>Aug</td>
<td>a</td>
<td>a/451</td>
<td></td>
</tr>
<tr>
<td>Sep</td>
<td>a</td>
<td>a/73</td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>a</td>
<td>a/27</td>
<td></td>
</tr>
<tr>
<td>Nov</td>
<td>0/a</td>
<td>0/a</td>
<td>20/37</td>
</tr>
<tr>
<td>Dec</td>
<td>0/a</td>
<td>0/a</td>
<td>12/32</td>
</tr>
<tr>
<td>TOTALS</td>
<td>222/100</td>
<td>186/28</td>
<td>12,975/11,398</td>
</tr>
</tbody>
</table>

a Data not available. Upper reach is usually intermittent except during spring months.
*Data not available. Project began collecting data March 1, 1991.

Anglers accounted for 9.2% of the recreators contacted by the creel clerks (Table 1). Expanding this proportion to the estimated number of recreators using each reach of the river each year, the upper reach of the Buffalo River supported a mean of 2,790 anglers during 1991 and 1992; the middle reach 2,639 anglers, and the lower reach 3,420 anglers.

Thirty of the 158 anglers (19%) interviewed in 1991 caught and retained 156 fish for consumption, including 29 smallmouth bass, numerous shadow bass and longear sunfish; no catfishes were creelred during the study. Mean length of the smallmouth bass was 29.6 cm and mean weight was 397 g. In 1992, only 10 of 125 anglers (8%) interviewed had fish in their possession, and 13 of the 15 fish creeld were smallmouth bass. Mean length of smallmouth bass was 28.2 cm and mean weight 354 g. In 1992, 120 of the 125 anglers surveyed (96%) reported having caught and released fish. Combining both years of catch, 64% of the harvested fish came from the lower reach, as did 54% of the released catch in 1992. The middle reach accounted for 30% of the harvested fish and the upper reach only 6%. However the upper reach accounted for 29% of the released catch.

Fishing pressure can be compared between reaches and streams by calculating the number of anglers/surface area of stream (anglers/ha) or the number of angling hours/surface area of the stream (hr/ha). Anglers found it very difficult to estimate the number of hours spent angling, as many trips were overnight and much time on the river was taken up by non-angling activities. However, in 1991 anglers estimated they spent 2.3 hours with their
lines in the water/day and 2.9 hours/day in 1992, for an average of 2.6 hours of fishing/day. Surface areas for the three reaches of the Buffalo River were calculated by measuring widths at 10 points along each of the three reaches to determine a mean width. Reach lengths were obtained from NPS maps. The upper reach averaged 14.9 m wide and was 56.2 km long (83.7 ha), the middle reach averaged 31.5 m wide and was 77.6 km long (244.4 ha), and the lower reach averaged 33.0 m wide and 68.4 km long (225.7 ha). The mean width for the Buffalo River was 27.2 m and its length 202.2 km for a total surface area of 550 ha. Table 4 estimates the anglers/hectare and angling hours/hectare for the Buffalo River for 1991 and 1992.

During the two years of the study, the upper reach of the Buffalo River received more intense recreational pressure (boats, recreators, anglers, hours) per hectare than did the rest of the river combined (Table 4). In part, this is due to the reduced area of the river in the upper reach, which is less than half as wide as the middle and lower reaches. However, it should also be remembered that the pressure was concentrated into the months March through June due to intermittent flows. Mean number of recreators on the entire river over the two years of the study, weighted by area, was 174.9/ha/yr and mean number of anglers was 16.1/ha/yr. Expanding this by 2.9 hours/angler indicates 46.7 hr/ha/yr of fishing pressure was expended on the Buffalo River.

Fish harvest rate for the Buffalo River in 1991 was 19.4 fish/ha for all fishes and 4.6 smallmouth bass/ha; it took anglers 12.5 hours to harvest one smallmouth bass (0.08 smallmouth bass/hour) during that year. In 1992, harvest fell to 1.5 fish/ha, 1.3 smallmouth bass/ha, and 0.03 smallmouth bass/hour. However, in 1992, over 40 fish/ha were caught and released.

### Discussion

Recreational pressure on the Buffalo River has not increased since the 1981 figure of 51,000 boats/year, with the present study estimating almost 52,000 boats/year in 1991 and 1992. NPS efforts to control boating pressure on the river appear to be working. Mean number of recreators in boats exceeded 96,000 people each year in 1991-1992. The proportion of recreators that were fishing (9.4%) is slightly lower than an earlier estimate of 12.5% by Ditton (1979). However, the average annual number of anglers on the Buffalo River in 1991/1992 (8,848) is greatly reduced from the 27,380 to 33,000 anglers/yr estimated by NPS (1977, 1983) in 1977 and 1981.

Angling pressure on the Buffalo River was 19.7 anglers/hr and 45.4 hr/ha in 1991 and fell to 12.4 anglers/ha and 36.1 hr/ha in 1992. This can be compared to 150 to 275 anglers/ha (considered heavy pressure) and 17 anglers/ha (considered light pressure) on the Housatonic River in Connecticut (Barry, 1991). Sample and Hubert (in Reed, et al., 1981) considered 77 hr/ha on the Tennessee River in Alabama to be moderate angling pressure. Arkansas Game and Fish Commission (1992) estimated 73 anglers/ha and 300 hr/ha on Crooked Creek, AR, a slightly smaller stream just north of the Buffalo River that flows parallel to it. Funk and Fleener (1975) found 130 to 275 hr/ha finishing pressure on Big Piney River in Missouri and suggested the quality of the smallmouth bass fishery would decline under continued fishing pressure of >250 hr/ha. It appears angling pressure on the Buffalo River was light to moderate during 1991 and 1992.

Harvest of smallmouth bass on the Buffalo River was

---

**Table 4. Boating pressure, recreation pressure, angling pressure, catch per unit effort, and smallmouth bass (SMB) catch per unit effort on the Buffalo River in 1991 and 1992. Weighted means calculated from totals and total surface area of river (550 ha).**

<table>
<thead>
<tr>
<th>Year</th>
<th>Reach</th>
<th>Boats/ha</th>
<th>Recreators/ha</th>
<th>Anglers/ha</th>
<th>Angling Hours/ha</th>
<th>SMB Harvest/ha</th>
<th>SMB Harvest/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1991</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td></td>
<td>225.7</td>
<td>417.5</td>
<td>38.4</td>
<td>88.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td>77.5</td>
<td>143.3</td>
<td>13.2</td>
<td>30.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td></td>
<td>114.8</td>
<td>212.5</td>
<td>19.5</td>
<td>44.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEIGHTED MEANS</td>
<td></td>
<td>115.9</td>
<td>214.4</td>
<td>19.7</td>
<td>45.4</td>
<td>4.6</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>1992</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td></td>
<td>166.0</td>
<td>307.0</td>
<td>28.2</td>
<td>81.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td>49.4</td>
<td>91.4</td>
<td>8.4</td>
<td>24.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td></td>
<td>63.2</td>
<td>116.9</td>
<td>10.8</td>
<td>31.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEIGHTED MEANS</td>
<td></td>
<td>73.1</td>
<td>155.3</td>
<td>12.4</td>
<td>36.1</td>
<td>1.3</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Recreational and Angler Survey of the Buffalo National River, Arkansas

4.6/ha and 0.08/hr in 1991, and 1.3/ha and 0.03/hr in 1992. Reed et al. (1991) summarized harvest of smallmouth bass for 12 streams and found a range of from 0.05 fish/hr in the Maquoketa River, Iowa, to 1.3 fish/hr in the New River, Virginia. Arkansas Game and Fish Commission (1992) estimated catch (almost all of which was harvest) of 50.6 smallmouth bass/ha and 0.16 fish/hr from Crooked Creek. Coble (1975) considered a harvest rate of 1.0 smallmouth bass/hr to be good, and Barry (1991) found smallmouth bass harvest rates of 0.42 to 2.8 fish/hr on the Housatonic River and considered the higher levels to be very good. Paragamian and Coble (1975) found harvest rates of smallmouth bass in many locations often were less than 0.1 fish/hr. Whisenant and Maughan (1989) reported on angler harvest on the Buffalo River in 1981 and 1982. They surveyed 343 anglers and found a harvest rate of 0.29 smallmouth bass/hr. My summed results of interviewing 283 anglers found a harvest rate of 0.06 smallmouth bass/hr, 20% of the harvest rate of only a decade ago on the Buffalo River.

Compared to these reports, harvest rate of smallmouth bass on the Buffalo River appears to be low and to have declined over the past decade. However, the high rate of catch and release noted in this study (96%) may strongly influence harvest data. Clark (1983) suggested high release rates could bias catch statistics and invalidate comparisons with historic data.

Fewer anglers are floating the river and fewer fish are being harvested by those that recreate on the Buffalo River. Ditton (1979) asked recreators on the Buffalo River to categorize their reasons for being on the river and found that of 36 possible categories including viewing scenery, change from daily routine, and peace and calm, that fishing came in second to the last, only above testing equipment. With recreation remaining constant and harvest of fishes declining on the Buffalo River, NPS and Arkansas Game and Fish Commission may consider catch-and-release or on-the-spot consumption of fish as practical management options for our first National River.

ACKNOWLEDGMENTS.—Arkansas Game and Fish Commission funded this study. Buffalo National River (NPS) provided assistance and information. A special thanks to creel clerks Ron Horton and George Imrie who gathered much of this data.

Literature Cited


Barry, T.J. 1991. Assessment of trout management regula-


Diagnostics of CdTe Electrodeposition by Rest Potential Voltammetry

Brandon Kemp, Robert Engelken, Arif Raza, Arees Siddiqui and Omer Mustafa  
Optoelectronic Materials Research Laboratory  
Department of Engineering  
Arkansas State University  
P.O. Box 1740  
State University, AR 72467

Abstract

Due to the extreme sensitivity of the partial elemental currents (i.e., \( i_{\text{Cd}} \), \( i_{\text{Te}} \)) and, hence, stoichiometry to deposition voltage, temperature, mass transport, and ambient light intensity during electrodeposition of semiconductor films, it is important to implement \emph{in situ} methods for monitoring the stoichiometry and related semiconductor efficacy of the growing film. We report investigation of open circuit rest potential (\( E_{\text{oc}} \)) voltammetry as one such method during electrodeposition of CdTe from aprotic electrolytes such as ethylene glycol. Plots of transient open circuit potential versus sweep voltage exhibit distinct transition and plateau structures corresponding to Te, CdTe, and Cd phases and correlating with the appearance/disappearance of photocurrent, x-ray diffraction evidence of the three phases, and optical absorption spectroscopy. In particular, the \( E_{\text{oc}} \) plateau corresponding to deposition of near-stoichiometric CdTe can be used to monitor and control the deposition process.

Introduction

Cadmium telluride (and sister compounds Hg\(_{1-x}\)Cd\(_x\)Te, Cd\(_{1-x}\)Zn\(_x\)Te, and Cd\(_{1-x}\)Mn\(_x\)Te) has become one of the most valuable and most investigated semiconductor compounds because of its potential application in a variety of systems and devices, for example, photovoltaic energy conversion and light detection. Electrodeposition has emerged as one of the more interesting methods for depositing compound semiconductor thin films because of obvious advantages, including low chemical and equipment costs, low temperature and atmosphere pressure operation, potential to be scaled up to large areas, and convenient monitoring and control through its electrical nature. However, a better understanding of the chemistry/electrochemistry is needed for more precise control of this process.

Experimental results have been reported describing the electrochemical deposition and subsequent material characteristics of CdTe (Sella et al., 1986), (Verbrugge and Tobias, 1987), (Von Windheim and Cocivera, 1991) and its sister compounds such as Hg\(_{1-x}\)Cd\(_x\)Te (Mori et al., 1990) and CdSe (Ham et al., 1991). Photovoltaic properties of CdTe-based devices also continue to be investigated (Kim et al., 1994). Still, theoretical models (Engelken and Van Doren, 1985), (Engelken, 1987), (Engelken, 1988) describing solution electrochemistry provide an understanding of the CdTe codeposition process.

The quasi-rest potential (QRP) has been defined as the open circuit potential established immediately after current interruption and before there has been any relaxation of nonequilibrium ion concentrations at the cathode surface due to diffusion effects (Engelken, 1987). \( E_{\text{oc}} \) is heavily dependent upon ion concentrations, cathode surface stoichiometry, and temperature, as governed by the mixed reversible potential dictated by zero total current. It is determined, ideally in the absence of other interfering species such as H\(^+\), by the voltages which makes the partial tellurium and cadmium currents negatives of each other in the Butler-Volmer/Tafel current-potential characteristics for each ion. Eventually, ion relaxation and changes in the CdTe surface to Te-richness due to exchange of Te(IV) for Cd(II) will transform the QRP to the equilibrium rest potential described by equating the Nernst Potentials for both Te and Cd:

\[
E_{\text{oc}} = E^0 + \left( \frac{RT}{nF} \right) \ln \left[ \frac{a_{M}(+)a_{M}(n)}{a_{M}(+)a_{M}(n)} \right]
\]  

where \( E^0 \) is the standard reduction potential, \( R \) the universal gas constant, \( n \) the ionic charge, \( F \) Faraday's constant, \( T \) the Kelvin temperature, \( a_M \) the elemental activity, and \( a_{M}(+)a_{M}(n) \) the activity of the ions in solution for a pure elemental electrode in a solution of its positive-valent ions. In an intermetallic compound, such as CdTe, modeled by

\[
\text{Cd}(\text{s}) + \text{Te}(\text{s}) \rightarrow \text{CdTe}(\text{s})
\]

the activities of the constituent elements are reduced to the bonding between the atoms according to the equilibrium constant expression
of CdTe Electrodeposition by Rest Potential Voltammetry

\[ \frac{a_{\text{CdTe}}}{a_{\text{Cd}}} = \exp(-\Delta G^0/(RT)) \]  

(3)

where \( \Delta G^0 \) is the Gibb's free energy for CdTe formation (Engelken, 1988).

The described work focused on characterization of organic solutions used for CdTe electrodeposition in search of convenient and low cost monitoring of thin film stoichiometry. It is hoped that measurements of open circuit potential \( E_{oc} \) will provide information on the electrochemical nature of the solution as well as composition of growing films. This paper will present data relating the open circuit potential of electrodeposited CdTe thin films to some of the controlling variables such as Cd(IV) concentration, deposition voltage, and illumination.

Materials and Methods

The equipment used in film deposition and to measure \( E_{oc} \) included 1 cm\(^2\) indium-tin oxide (ITO) coated glass cathodes (Balzers and Donnelly) held by a Poco graphite cathode clamp utilizing Teflon bolts and nuts. A Fisher Ag/AgCl reference electrode was utilized. A Poco graphite anode was used with 3 cm\(^2\) submerged. The \( E_{oc} \) versus \( E_{sweep} \) plots were obtained using an EG&G Princeton Applied Research Model 862 scanning potentiostat and a Hewlett Packard 7046-B x-y recorder. Other items in solution were a Teflon covered stirring bar and a Fisher Hg-filled thermometer.

The Alfa/Johnson Matthey ethylene glycol (99\%) solutions contained 0.05 M Aldrich reagent grade CdCl\(_2\) and 10\(^{-4}\) to 10\(^{-3}\) M Alfa/Johnson Matthey 99.9\% TeCl\(_4\). The solvents were quickly dissolved by heating the solution to 40\(^\circ\)C.

A Rigaku D-MAX x-ray diffractometer (XRD) and a Perkin-Elmer Lambda 19 UV/VIS/NIR optical spectrophotometer were used in film characterization.

The ITO glass substrates were cleaned using Comet cleanser and tap water. This was followed by distilled water rinsing and drying under an air stream.

The solution was heated to 100\(^\circ\)C. The \( E_{oc} \) versus \( E_{sweep} \) plots were then obtained at a sweep rate of 1 mv/s or 2 mv/s for sweeps accompanied by pulsed illumination. The on/off current times were controlled at 3-4 s by an in-house built pulser circuit. Current (I) versus \( E_{sweep} \) plots were obtained at a sweep rate of 5 mv/s. Pulsed illumination accompanied I versus \( E_{sweep} \) plots with equal on/off times of about 2.5 s. Longer on/off times (i.e. about 15 s each) were used for illuminated potential sweeps to compensate for the slower sweep rate. Film depositions were then performed using fresh ITO glass substrates. The films were rinsed in hot ethylene glycol followed by hot distilled water. The films were then placed in an air stream to dry, prior to XRD and spectrophotometer characterization.

Results and Discussion

As predicted, a direct correlation between \( E_{oc} \) and deposition voltage was observed in the potential plots. Three distinct plateau structures were seen in \( E_{oc} \) versus \( E_{sweep} \) plots indicating different \( E_{oc} \) values corresponding to Te, CdTe, and Cd.

Figure 1 exhibits the \( E_{oc} \) versus \( E_{sweep} \) plot for a solution containing 3 \( \cdot \) 10\(^{-4}\) M TeCl\(_4\). Notice the transition from the first structure (A) corresponding to deposition of elemental tellurium to the middle plateau region at a sweep potential of about -0.20 V. This level plateau (B) corresponds to the regions in which CdTe is plated and in which photocurrents were observed on the corresponding photovoltammogram (Fig. 2). Another transition region (C), observed at about -0.70 V, corresponds to Cd plating on the I versus \( E_{sweep} \) plot. Figure 3 shows XRD data for a film deposited at -0.60 V from this solution. Strong diffraction peaks match the vertical CdTe powder diffraction file lines. Figure 4 is a plot of optical absorbance versus wavelength for the same film. Notice the deflection (absorption edge) near 800 nm. This is consistent with the 1.45 eV direct bandgap of CdTe. The "hump" centered near 1300 nm is an interference ripple caused by interference in the film as wavelength is varied.

The next data set reveals results of pulsed illumination on an \( E_{oc} \) versus \( E_{sweep} \) plot (Fig. 5) for a similar solution containing 4 \( \cdot \) 10\(^{-4}\) M TeCl\(_4\). The photovoltages occur in the same sweep voltage range (i.e. from -0.30 V to -0.70 V) as the photocurrents on the forward sweep of the corresponding cyclic voltammogram (Fig. 6). Figure 7 presents XRD data for a film deposited at -0.65 V from this solution. Strong diffraction peaks match CdTe file peak locations, an indication of polycrystalline CdTe deposition. Figure 8 shows spectrophotometer data for the same film. Again, a deflection of the curve occurs as a wavelength near 800 nm. However, a narrow tail preceding this deflection could indicate slight Cd - richness in film composition. This is consistent with the open circuit curve which shows a region of transition to the \( E_{oc} \) of metallic Cd just negative of the "knee" at the -0.65 V deposition voltage.

Figure 9 is an \( E_{oc} \) versus \( E_{sweep} \) plot for a solution with a TeCl\(_4\) concentration of 7 \( \cdot \) 10\(^{-4}\) M. The plateau structures persist for this high [Te(IV)] solution, but are shifted negative with respect to similar structures for lower [Te(IV)] solutions. The I versus \( E_{sweep} \) voltammetric structures, plotted in Fig. 10, are also shifted negative. A film, deposited at a more negative voltage than those previously discussed (i.e. at -0.85 V), produced XRD and spectrophotometer data exhibited in Fig. 11 and Fig. 12.
Brandon Kemp, Robert Engelken, Arif Raza, Arees Siddiqui and Omer Mustafa

Fig. 1. $E_{oc}$ vs. $E_{sweep}$ curve for a solution containing $3 \cdot 10^4$ M TeCl$_4$ and 0.05 M CdCl$_2$ in ethylene glycol at 100°C. Note the three structures, A, B, and C, corresponding to elemental Te, CdTe, and Cd metal, respectively.

Fig. 2. Forward sweep of a voltammogram (current-voltage curve) for an ethylene glycol solution the same as with Fig. 1. Note the cathodic photocurrent pulses centered at -0.5 V.

Fig. 3. X-ray diffraction pattern for a film deposited at -0.6 V from the solution described by Fig. 1 and Fig. 2. Note the matches with peak locations for CdTe powder; (i.e., File 15-770).

Fig. 4. Optical absorbance vs. wavelength curve for the same film as with Fig. 3. Note the absorption edge near 800 nm.

respectively, consistent with previous data presented for polycrystalline CdTe. The absorbance "tail" tapering down toward wavelengths greater than 800 nm could reflect slight Te-richness. This shows that the correlation of $E_{oc}$ versus $E_{sweep}$ plots with CdTe deposition voltage remains for a change in [Te(IV)].

The last data set presented reveals a change in phase correlating with the corresponding $E_{oc}$ change. Figure 13 is a photovoltammogram for a solution containing $1 \cdot 10^4$ M TeCl$_4$. The Te plating currents are relatively small for this lower concentration solution. Figure 14 is an $E_{oc}$ versus $E_{sweep}$ plot for the solution. Low currents cause the Te plating rate to be slow and the $E_{oc}$ "plateau" for elemental Te is not at all level. This is a direct result of the fact that the Te current is nearly diffusion-limited and the Te(IV) concentration steadily decreases toward zero at the cath-
Fig. 5. $E_{oc}$ vs. $E_{sweep}$ curve for an ethylene glycol solution containing $5 \cdot 10^{-4}$ M TeCl$_4$ and 0.05 M CdCl$_2$ at 100°C. Note the cathodic photovoltage pulses centered at -0.05 V.

Fig. 6. Cyclic voltammogram for the same solution as in Fig. 5. Note the cathodic photocurrent pulses centered at -0.5 V on the forward sweep.

Fig. 7. X-ray diffraction pattern for a film deposited at -0.65 V from the solution described in Fig. 5 and Fig. 6. Note the matches with the peak locations for CdTe powder; (i.e.; File 15-770).

Fig. 8. Optical absorbance vs. wavelength spectrum for the same film as in Fig. 7. Note the absorption edge near 800 nm.

The most positive plateau structure on the potential plot occurs at an $E_{sweep}$ value (i.e. about -0.20 V) corresponding to a sharp rise in current on the cyclic voltammogram. Photocurrents are not observed, however, until the $E_{sweep}$ value is negative of -0.58 V. At this voltage, a small transition is observed on the $E_{oc}$ versus $E_{sweep}$ plot. A film was deposited at a deposition voltage (i.e. at -0.55 V) just positive of this value.

Figure 15 exhibits XRD data for this film. Notice that the CdTe diffraction peaks are weaker than strong Te diffraction peaks. Figure 16 is a plot of XRD data for a film deposited at -0.65 V which corresponds to the region negative of the transition at -0.58 V. This data reveals a strong diffraction pattern corresponding to CdTe. The absence of Te diffraction peaks indicates that the small
Fig. 9. $E_{oc}$ vs. $E_{sweep}$ for an ethylene glycol solution containing $7 \times 10^{-4}$ M TeCl$_4$ and 0.05 M CdCl$_2$ at 100°C. Note the negative shift of the second "plateau" structure (i.e. CdTe plateau) in comparison to Fig. 1 and Fig. 5.

Fig. 10. Cyclic voltammogram for the same solution as in Fig. 9. Note the negative shift of the forward sweep cathodic photocurrent pulses as compared with Fig. 2 and Fig. 6.

transition region observed on the $E_{oc}$ versus $E_{sweep}$ plot again corresponds to a change in deposited phase with respect to deposition voltage.

Fig. 11. X-ray diffraction pattern for a film deposited at -0.85 V from the solution described by Fig. 9 and Fig. 10. Note the matches with peak locations for CdTe powder; (i.e., File 15-770).

Fig. 12. Optical absorbance vs. wavelength for the same film as in Fig. 11. Note the absorption edge near 800 nm and the tail toward longer wavelengths.

Conclusions

Open circuit potential voltammetry has been used successfully in characterizing organic electrolytes used for CdTe electrodeposition. The results presented in this paper clearly support initial predictions that the open circuit potential can be used to monitor electrodeposited film phase as a function of deposition voltage. Photovoltages observed with rest potential voltammetry correspond to photocurrents on photovoltammograms, and, thus, correlate with the range in which semiconducting material is being plated. Also, spectrophotometer and XRD data for films deposited from the baths demonstrate the potential of this technique for controlling semi-
Ig. 13. Cyclic voltammogram for a solution containing $1 \times 10^{-4}$ M TeCl$_4$ and 0.05 M CdCl$_2$ at 100°C. Note the forward sweep cathodic photocurrents centered near -0.58 V.

Fig. 13. Cyclic voltammogram for the solution containing $1 \times 10^{-4}$ M TeCl$_4$ and 0.05 M CdCl$_2$ at 100°C. Note the forward sweep cathodic photocurrents centered near -0.58 V.

Fig. 15. X-ray diffraction for a film deposited at -0.55 V from the solution described by Fig. 13 and Fig. 14. Note the matches with peak locations for CdTe powder; (i.e., File 15-770) and Te; (i.e., File 36-1452).

Fig. 16. X-ray diffraction for a film deposited at -0.65 V from the solution described by Fig. 13 and Fig. 14. Note the matches with peak locations for CdTe powder; (i.e., File 15-770).

Fig. 14. $E_{oc}$ vs. $E_{sweep}$ for the same solution as in Fig. 13. Note the small transition centered near -0.58 V which corresponds to the onset of forward sweep cathodic photocurrents in Fig. 13.

conductor efficacy. Thus, rest potential voltammetry has emerged as a sensitive *in-situ* monitoring technique for use in electrodeposition of semiconductor thin films.

Future work will involve open circuit potential voltammetry for related II-VI compounds such as ZnSe, Hg$_{1-x}$Cd$_x$Te, and Hg$_{1-x}$Zn$_x$Te. The application of open circuit potential voltammetry to ternary compounds introduces an intriguing scientific challenge due to the possible existence of multiple compound phases (and, hence, multiple $E_{oc}$ plateau structures) in addition to the pure
elements. Also, future plans include a more quantitative investigation of the relationship between $E_{oc}$ and open circuit time period.

Acknowledgments.—The described work is being jointly funded by the NASA JOint VEnture (JOVE) and NASA ESPECoR programs. Dr. Robert D. Engelken’s work involves electrochemical preparation and rest potential characterization of compound semiconductors, primarily metal tellurides, which are of interest to NASA for fundamental material studies and device applications.

Dr. Engelken is working under the JOVE Program in conjunction with Dr. Frank Szofran of the Electronic and Photonic Materials, Branch, Microgravity Division, Space Sciences Laboratory, NASA Marshall Space Flight Center in Huntsville, Alabama. The program is designed to bring together University professors and NASA personnel for work on projects of mutual interest.

The Arkansas NASA EPSCoR Project includes the Advanced Photovoltaic Materials Research Cluster. The Cluster, of which Dr. Engelken is a participant along with faculty from the University of Arkansas - Fayetteville and the University of Arkansas Little Rock, is investigating photovoltaic materials, configurations and processes.

The Arkansas Science and Technology Authority is also thanked for previous grants that paved the way for the current work.

Literature Cited


Timber Felling Time, Costs, and Productivity in Arkansas

R. Kluender, D. Lortz and W. McCoy
School of Forest Resources
University of Arkansas at Monticello
Monticello, AR 71656

B. Stokes and J. Klepac
USDA Forest Service
Southern Forest Experiment Station
Devall Drive
Auburn University, AL 36849

Abstract

Sixteen stands were harvested by either clearcut, shelterwood, group selection, or single-tree selection methods. Harvest productivity was evaluated in four consecutive years (1991 through 1994). Three of the stands had uneven-aged structure, the other 13 were typical, mature, even-aged stands. Harvest intensity (proportion of basal area removed) ranged from 0.27 to 1.00. Logging contractors used one to three sawyers with production chain saws to fell trees on all 16 tracts. There was no statistical difference in production rate between sawyers on the same stand. Harvested sites were similar in slope, average diameter at breast height (DBH) and pre-harvest number of stems by two inch diameter class. Total felling time (including walk, acquire, fell, and limb-top times) was inversely related to harvesting intensity and directly related to stem DBH. Factors affecting total felling time (in decreasing order of importance) were DBH of harvested stems, intertree distance, and harvest intensity. Felling productivity (100 cubic feet/hour) was found to be highest under high intensity harvests of large trees and lowest under low intensity harvests of small trees. Productivity was more sensitive to stem diameter than harvest intensity. Felling cost was shown to have an inverse relationship with felling productivity.

Introduction

Comparisons of even-aged and uneven-aged forest management have recently attracted increased attention. One aspect of research includes comparisons of the time required to perform various timber harvesting operations under differing management regimes. Manual tree felling is the most labor intensive component of all harvesting operations, and frequently represents a “bottle neck” in production. Previous studies often addressed only a single harvest method, (i.e., clear cutting or single-tree selection) (Kellog et al., 1991; Miller and Sarles, 1986) with differences among stands or harvesting crews and equipment confounded with treatment effects (Bell, 1989; Miller and Smith, 1991; Sloan, 1991). Studies have been needed which cover both even-aged and uneven-aged silviculture and contain a large enough data set to identify trends common to all manual felling operations. The results of felling time studies conducted over four years are presented here.

Materials and Methods

Treatment of the Stands.—A wide range of harvest intensities were examined. Clearcutting and single-tree selection methods represented extremes in harvest intensity, while shelterwood and group selection harvests represented intermediate treatments. Table 1 shows the method of harvest, harvest date, and harvest intensity.

The proportion of basal area removed was used as an index of harvesting intensity for each stand. Basal area removed was chosen because it is sensitive to both number of trees removed from the stand and average tree size. Stands were located in western Arkansas (13 on the Ouachita National Forest and three on land owned by Deltic Farm and Timber Corporation).

Table 1. Descriptive information of the 16 stands studied.

<table>
<thead>
<tr>
<th>Stand (year-#)</th>
<th>Harvest Method</th>
<th>Proportion of BA Removed</th>
<th>Avg. DBH Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>91-01</td>
<td>Clearcut</td>
<td>1.00</td>
<td>11.4</td>
</tr>
<tr>
<td>91-02</td>
<td>Shelterwood</td>
<td>0.57</td>
<td>10.4</td>
</tr>
<tr>
<td>91-03</td>
<td>Single-tree</td>
<td>0.31</td>
<td>10.7</td>
</tr>
<tr>
<td>91-04</td>
<td>Clearcut</td>
<td>1.00</td>
<td>10.4</td>
</tr>
<tr>
<td>91-05</td>
<td>Shelterwood</td>
<td>0.71</td>
<td>10.6</td>
</tr>
<tr>
<td>91-06</td>
<td>Single-tree</td>
<td>0.43</td>
<td>13.7</td>
</tr>
<tr>
<td>91-07</td>
<td>Group</td>
<td>0.48</td>
<td>11.7</td>
</tr>
<tr>
<td>91-08</td>
<td>Group</td>
<td>0.62</td>
<td>10.9</td>
</tr>
<tr>
<td>91-09</td>
<td>Single-tree</td>
<td>0.45</td>
<td>13.5</td>
</tr>
<tr>
<td>91-10</td>
<td>Single-tree</td>
<td>0.52</td>
<td>13.9</td>
</tr>
<tr>
<td>91-11</td>
<td>Single-tree</td>
<td>0.31</td>
<td>11.8</td>
</tr>
<tr>
<td>91-12</td>
<td>Single-tree</td>
<td>0.30</td>
<td>12.2</td>
</tr>
<tr>
<td>91-13</td>
<td>Single-tree</td>
<td>0.27</td>
<td>12.5</td>
</tr>
<tr>
<td>91-14</td>
<td>Single-tree</td>
<td>0.36</td>
<td>15.5</td>
</tr>
<tr>
<td>91-15</td>
<td>Single-tree</td>
<td>0.32</td>
<td>15.5</td>
</tr>
<tr>
<td>91-16</td>
<td>Single-tree</td>
<td>0.27</td>
<td>16.0</td>
</tr>
</tbody>
</table>

The stands were composed primarily of shortleaf pine (Pinus echinata Mill.) and loblolly pine (Pinus taeda

Proceedings Arkansas Academy of Science, Vol. 49, 1995
L.). There was a small hardwood component in all stands. The stands harvested in 1994 were of uneven-aged structure, while the other 13 were even-aged.

All stands were cruised before and after harvest to determine the harvest intensities. Diameter distributions from pre harvest cruises were compared using a Kolmogorov-Smirnov distribution test (Wilkinson, 1990) to determine whether they were from the same parent distribution.

The sawyers felled all marked trees within the stand boundaries according to felling ease and safety. Directional felling to optimize skidding was not a consideration, nor was it practiced. Hung trees occurred in all stands. When trees were hung, the sawyer stopped work while the skidder was used to pull or push the tree to the ground or the sawyer moved to a new area until the hung tree was brought to the ground by the skidder operator. Trees were processed into tree-length stems by limbing and topping immediately after felling.

A felling observation was defined as the time required for the sawyer to walk to a tree (walk), clear the brush for a safe exit path and plumb the tree (acquire), fell the tree (fell), and limb and top the tree (limb and top). Not every felling cycle was observed. Observed felling cycles were randomly chosen as work progressed through the stand. Field research team members timed and recorded each event in the cycle. When a tree was limbed and topped so it was safe to approach, researchers measured the diameter at breast height (DBH) and merchantable length (5-inch top) of the felled tree. Individual tree volumes were calculated by a formula developed by Clark and Saucier (1990). Total time per tree (excluding delays) was calculated for each observation. Means for walk-time, acquire-time, cut, limb and top-time, and delay-time were computed by tract and the overall study. Differences in mean times by sawyer and harvest year were detected by Tukey’s HSD pair-wise comparison test at the 0.05 level. Adjusted (by mean tree diameter and intertree distance) total-time-per-tree was calculated for each stand. A linear regression model was estimated for total felling time with the proportion basal area harvested, DBH and intertree distance as independent variables. Two additional nonlinear models were developed to predict productivity (CCF/hour) and cost ($)/CCF using just harvest intensity and DBH. The cost estimation incorporated machine rate calculations. (Miyata, 1980) and productivity estimates.

Results

Stands.—The pre harvest diameter distributions were compared using a Kolmogorov-Smirnov distribution test which showed that they were from the same parent distribution. The diameter distribution for the three uneven-aged stands harvested in 1994, while not statistically different from the parent population, were approaching a “reverse-j” distribution indicative of uneven-aged stands. The average harvested stem DBH was larger in these stands. This is a function of the uneven-aged management prescription where the harvested trees are concentrated in the larger DBH classes. In the seven even-aged stands harvested by single-tree selection, the distribution of removed stems was similar to a mixed thinning with cutting in the 6-10 inch classes (low thinning) and in the 14-18 inch classes (thinning from above). The goal of this thinning was to move these stands toward uneven-aged structure.

Felling.—Each phase of the felling operation was fit to an exponential equation (Y=aX^b) using DBH as the independent variable. This was done to determine whether or not the results of the current study were consistent with classic relationships defined in the literature. Intertree distance was inversely related to harvesting intensity. The sawyer had to walk further to find marked trees in the single-tree selection stands than in the clearcut stands where he could move directly to the next nearest tree; walk-time decreased as harvesting intensity increased. The number of trees marked on a per-acre basis was influenced by the size of the trees. The distance between trees may be approximated by the square root of the area per tree. Thus, a square root relationship between walk time and DBH as found (the exponent coefficient approaching 0.5) is consistent with the expected relationship.

Walk Time = 0.076 x DBH^{0.591}

There was no identifiable trend in acquire-time. The amount of time to plan the fall and to clear brush from around a ten inch tree would be about the same as that of a twenty inch tree. Only in the extreme diameter classes would DBH have an influence on acquire time. The low power coefficient shows that in the observed cycles this value was essentially constant. An exponent of zero would mean that acquire time is constant and independent of the size of the tree.

Acquire Time = 0.080 x DBH^{0.200}

Fell time approached a linear relationship with the DBH (the exponent coefficient approaching one). This is consistent with studies evaluating production chainsaws (Lanford et al., 1972).

Fell Time = 0.047 x DBH^{0.887}

Limb and top time was a function of crown size. The ratio of crown diameter to stem diameter is essentially
constant; therefore stem volume may be estimated as a function of crown diameter (Avery and Burkahart, 1983). It is reasonable that the time to remove the limbs and top (a function of crown size) would be estimated using the best single proxy for stem volume, which is DBH². Limb and top time constituted the largest portion of the felling operation.

\[
\text{Limb and Top Time} = 0.06 \cdot \text{DBH}^{2.129}
\]

Figure 1 shows total felling time broken into each component. The vertical distance between the lines is the average time required for the identified activity. The top line is the average total felling time based solely on DBH.

\[
\text{Total Time} = 0.069 \cdot \text{DBH}^{1.879}
\quad R^2 = 0.49 \quad n = 1150
\]

Tree diameter proved to be the most significant variable when estimating felling time of a tree independent of stand characteristics and harvesting prescription. When estimating the felling time of a tree within a stand, the distance from the previous felled tree (DIST) and the proportion of basal area removed (INTENSITY) also provided to be significant at the .01 level.

![Graph showing predicted felling time by operation for a tree based on diameter at breast height.](image)

**Fig. 1.** Predicted felling time by operation for a tree based on diameter at breast height.

\[
\text{Total Time} = 1.049 + 0.009 \cdot \text{DBH}^2 + 0.006 \cdot \text{DIST} - 0.850 \cdot \text{INTENSITY}
\quad R^2 = 0.55 \quad n = 1145
\]

Table 2 gives the range of values for harvest intensity, intertree distance, and DBH which were the significant independent variables. Other variables were tested as possible independent variables but were not significant.

<table>
<thead>
<tr>
<th>Variable</th>
<th>max.</th>
<th>min.</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity (% basal area)</td>
<td>1.00</td>
<td>0.27</td>
<td>0.49</td>
</tr>
<tr>
<td>DBH Removed (inches)</td>
<td>26.1</td>
<td>5.2</td>
<td>13.7</td>
</tr>
<tr>
<td>Intertree distance (feet)</td>
<td>408</td>
<td>1.1</td>
<td>45.2</td>
</tr>
</tbody>
</table>

Table 2. Summary of the felling data variables used in the stand level felling regression equation based on 1154 observation.

Application of the total time regression equation is straightforward. For example, a 15-inch tree would take 1.125 minutes longer to process (all other conditions being the same) than a 10-inch tree. The sensitivity of the time estimate to each independent variable was evaluated through the use of standardized coefficients. These coefficients have been adjusted to remove differences in scale by using means and standard deviations. Examination of the standardized coefficients in the structural regression equation indicated the most important factors influencing total felling time (in decreasing order of importance) were DBH, intertree distance, and harvest intensity. The expected total times per tree for each stand are plotted in Fig. 2 using individual stand averages for DBH, intertree distance and measured harvest intensity (points). The line in Fig. 2 shows the expected total felling time across all harvest intensities using global averages (all stands combined) for DBH and intertree distance.

![Graph showing predicted felling times for trees within a stand.](image)

**Fig. 2.** Predicted felling times for trees within a stand.

Productivity in hundred cubic feet (CCF) per hour was calculated using measured total time and estimated stem volume. An estimator for productivity was derived using a nonlinear model with DBH and harvest intensity as the independent variables.

\[
\text{CCF/HR} = 1.627 \cdot \text{DBH}^{0.626} \cdot \text{INTENS}^{0.209}
\]

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Figure 3 shows the response surface produced by this model. Removal intensity had less influence on productivity than DBH.

![Graph showing response surface produced by model](image)

**Fig. 3.** Gelling productivity by harvest intensity and diameter at breast height.

Felling cost per unit volume varied inversely with productivity. An hourly fixed cost of $0.80, a variable cost of $0.70 per productive hour, and a labor cost of $7.98 per hour were used in calculations. The adjusted (50 percent availability) (Miyata, 1980) hourly operating cost under these assumptions was $17.56 per hour. The response surface for the relationships between cost, DBH and harvest intensity (Fig. 4) was the inverse of the productivity surface with the differences in slope being influenced by the machine rate estimate. (Note that the DBH axis is reversed in the cost surface to facilitate viewing of the graph.) The cost of harvesting small trees was more sensitive to the harvest intensity than the cost of harvesting large trees.

![Graph showing felling cost per 100 cubic feet by harvest intensity and diameter at breast height](image)

**Fig. 4.** Felling cost per 100 cubic feet by harvest intensity and diameter at breast height.

**Discussion**

The most important factors in felling time per tree were DBH, intertree distance and harvest intensity. In the analysis of co-variance and the structural regression analysis, intensity acted as a harvest variable to collect variation in felling time caused by harvesting prescription. The extra time spent finding marked trees, planning the cut, and working around residual stand components slowed production for the partial harvest methods.

Individual tree size had the greatest influence on felling productivity. The felling operation was most productive and least expensive (per unit of volume) in stands where large trees were being removed under high harvest intensities. The average DBH removed from the uneven-aged stands tended to be lower than those from the uneven-aged stands. The even-aged stands were characterized by a normal bell shaped distribution of tree size. Trees removed from these stands tended toward the stand average tree size. In the uneven-aged stands, the tree size distributions approached a "reversej" with many more stems in the smaller diameter classes than in the larger classes. At harvest, only the larger diameter classes were removed (this is typical of uneven-aged forest management). This had the effect of increasing productivity (CCF/hour) and reducing costs ($/CCF) even at the observed lower harvesting intensities.

Light thinnings of small trees were the most expensive per CCF harvested. Harvesting large trees even at lower intensity produced a lower $/CCF than when smaller trees were harvested. For example, stand 93-19 had an average DBH harvested of 11.5 inches and an intensity of 0.27 proportion of basal area removed, while in stand 94-16 the average DBH removed was 16.23 inches at the same intensity (0.27). The response surface indicates that it would be less expensive per CCF to harvest stand 94-16.

The controversy between even-aged versus uneven-aged management and their associated silvicultural methods will continue, especially for public land management. For many proponents of uneven-aged management, harvesting cost and economic efficiency are a distant third consideration after maintaining stand visual quality and minimizing individual stand disturbance. Even-aged management advocates focus on harvesting and capital efficiency as preeminent concerns. An extension of this analysis will be to identify profitability of felling operations given different values of logs at the mill. The stand conditions and harvest prescription at which an operation is economically feasible need to be shown.
Literature Cited


Proceedings Arkansas Academy of Science, Vol. 49, 1995
Construction Resource Allocation Using a Genetic Algorithm

Siripong Malasri and Jennifer R. Martin
Department of Civil Engineering
Christian Brothers University
Memphis, TN 38104

Abstract

A proper allocation of limited resources (men, machines, materials, and money) is critical in a construction project. Traditionally, resource allocation problems have been solved using methods in operations research (OR), such as mathematical programming. In recent years, genetic algorithms (GA) have emerged as an effective optimization methodology. One major advantage of the GA approach over the OR approach is that the GA approach is universal for various types of optimization problems, unlike the OR approach which varies depending on the types of problems at hand. This paper shows an application of GA to a resource allocation problem in the construction industry in which a contractor tries to maximize profit by properly allocating various pieces of heavy equipment to various ongoing construction projects. This type of problem has customarily been solved by the linear programming method. GA has proved to be quite an attractive alternate to the OR method. Since the GA method is more universal than the OR method, the program can be easily modified to solve other types of problems. A description of a computer program written in Visual Basic is also presented.

Introduction

Resource allocation has been a challenging problem for many organizations. At present the construction industry is highly competitive. A proper allocation of limited resources (men, machines, materials, and money) is critical to their success. The profit margin has been shrinking and heavy equipment is expensive. Therefore, due to the multi-project nature of the industry, it is preferable to properly manage fewer pieces of equipment than it is to acquire more pieces of equipment.

Traditionally, resource allocation problems have been solved using methods in operations research (OR), such as mathematical programming (Hillier and Lieberman, 1974). In recent years, genetic algorithms (GA) have emerged as an effective optimization methodology (Michalewicz, 1992). One major advantage of the GA approach over the OR approach is that the GA approach is universal for various types of optimization problems, unlike the OR approach which varies depending on the types of problems at hand. This paper shows an application of GA to a resource allocation problem in the construction industry in which a contractor tries to maximize the profit by properly allocating various pieces of heavy equipment to various ongoing construction projects.

Materials and Methods

Genetic algorithms (GA) are based on the natural selection process. The process starts with a randomly created first generation of population. The population is usually kept at a constant size for the entire evolution to simplify the process. Every individual in a generation represents one solution. An individual consists of one chromosome with a number of genes. Each chromosome is then evaluated for its fitness - how well it accomplishes the set goal. More fit chromosomes have a better chance to get to the next generation. Genes are exchanged through the crossover process and diversity is added into the population by the mutation process. The process is repeated over several generations and the overall best solution is used. The general procedure is very similar to previous work (Malasri et al., 1994) with differences in the details of each step. The following sections describe the details of this process in the context of resource allocation optimization.

Problem Statement.—Generally, the objective of the resource allocation problem is to maximize a function $P$ of $n$ variables under $m$ constraints:

$$P = P(X_1, X_2, X_3, \ldots, X_n)$$

under the following constraints:

$$f_1(X_1, X_2, X_3, \ldots, X_n) \leq 0$$
$$f_2(X_1, X_2, X_3, \ldots, X_n) \leq 0$$
$$f_3(X_1, X_2, X_3, \ldots, X_n) \leq 0$$
$$\ldots$$
$$f_m(X_1, X_2, X_3, \ldots, X_n) \leq 0$$

As an example, a problem previously solved by linear programming (Pilcher, 1976) is used: "A contractor has one mechanical excavator and one bulldozer which are available for work on either of two adjacent sites. On one site clay overburden is being excavated for a ballast pit owner and on the other, ballast is being removed under..."
subcontract to another client. The contractor's experience leads him to believe that he can make £50 profit for every 1000 m$^3$ of clay overburden and £60 profit for every 1000 m$^3$ of ballast he removes. A comprehensive work study assesses the resources required to remove 1000 m$^3$ of clay to be 8 hours' use of the excavator, 4 hours' use of the bulldozer and 50 man-hours of laborers' time. In the case of the excavation of 1000 m$^3$ of ballast, the resources are required for 4 hours, 5 hours and 13 man-hours respectively. The contractor's employees work a 40-hour week. The mechanical equipment is also available for a 40-hour week. In addition to the mechanical equipment, 5 laborers are available for up to 40 hours each in any one week in order to assist with the work. When not employed on the excavation, use can be made of the laborers elsewhere. Question: how should the contractor use his resources in order to maximize his profit during one working week?

If $X_1$ and $X_2$ represent the units of 1000 m$^3$ of clay and ballast excavated, respectively (both are positive value), the problem can be rewritten as:

Maximize $P(X_1, X_2) = 50X_1 + 60X_2$

subject to the following constraints:

$f_1 = 8X_1 + 4X_2 - 40 \leq 0$
$f_2 = 4X_1 + 5X_2 - 40 \leq 0$
$f_3 = 50X_1 + 13X_2 - 200 \leq 0$

**Chromosome Formulation.**—The first part of a chromosome contains the binary representation of the first variable ($X_1$) while the second part represents the second variable ($X_2$). Let $a_i$ and $b_i$ be the lower and upper bound of the $i$-th variable. The range of the $i$-th variable ($r_i$) becomes ($b_i - a_i$). If $d$ is the number of decimal places on each variable, then the number of genes required for the binary representation of the $i$-th variable ($g_i$) is:

$$g_i = \ln(r_i^*10^d) / \ln(2)$$

The derivation of the above equation for $g_i$ can be found in a textbook example (Michalewicz, 1992). The chromosome consists of a total of ($g_1 + g_2$) genes, since there are only two variables ($X_1$ and $X_2$).

**The First Generation.**—The first generation is randomly created by filling all gene slots with 0 or 1. For each gene slot, a random number (between zero and one) is generated. If this number is less than 0.5, the value 0 is entered into the gene slot, otherwise the value 1 is entered. To ensure that the random number does not always start from the same point in the random number sequence, the program uses the minute part of the computer clock to seed the starting location in the random number sequence.

**Fitness Evaluation.**—Each chromosome is evaluated for its fitness in order to determine the chance of being selected into the next generation. From each chromosome, the binary representation (base 2) of each variable is converted into a corresponding real number (base 10). These real numbers, after divided by $10^d$, are then entered into the objective function to determine the value of the function $P$. Each constraint condition is then evaluated. Initially, the fitness is set equal to the value of function $P$. Thus, the higher the value of the function $P$, the higher the fitness. For each violation of constraint conditions (i.e., the value of $f_i$ is greater than zero), the fitness is reduced by dividing the fitness by the user-specified extra penalty. It also could occur that the value of $X_i$ turns out to be greater than the user-specified upper limit. If this happens, the fitness for that chromosome is also reduced by dividing the fitness by the same extra penalty.

**Population Selection, Cross Over, and Mutation.**—Chromosomes are selected into the next generation based on their fitness. The process is similar to creating a spinner in which a chromosome with a larger fitness occupies a larger area on the spinner. When the spinner is spun, it would have a greater chance to stop on a larger area. The spinner is then spun for the number of population to select a group of potential parents. These potential parents then go through the process of crossing over (in which genes are exchanged) and the process of mutation (in which genes are altered). The details of these procedures can be found in a recent work (Malasri et al., 1994).

**Results and Discussion**

The method described above was implemented in a computer program using Microsoft Visual Basic programming language which operates under the Windows 3.1 environment. Figure 1 shows the evolution screen. The left and upper parts of the screen are the user input area for both problem-specific input and genetic parameters. In the middle of the screen are the results of the evolution. The program displays the best solution for the current generation as well as the overall best solution from the first generation to the current generation. A graph is also displayed to show the distribution of all solutions in each generation where each dot represents a possible solution. In the first generation, the possible solutions (chromosomes) are created randomly. Thus the dots are spread over the entire graph area. As generations pass, these dots are concentrated only in a few areas of the graph which shows that most solutions converge to the location of the maximum function.

The program was executed for 40 runs consecutively with varied parameter values. For comparison, the best
Fig. 1. Evolution screen.

Table 1. Results from 40 consecutive runs.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>$X_{1\text{max}}$</th>
<th>$X_{2\text{max}}$</th>
<th>Dec. Pls.</th>
<th>Pop. Size</th>
<th>No. of Gen.</th>
<th>Ext. Penalty</th>
<th>Gen.</th>
<th>$X_1$</th>
<th>$X_2$</th>
<th>P</th>
<th>Error*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>10</td>
<td>50</td>
<td>2</td>
<td>42</td>
<td>2.40</td>
<td>4.56</td>
<td>393.6</td>
<td>-18.56</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>10</td>
<td>50</td>
<td>2</td>
<td>44</td>
<td>2.31</td>
<td>4.98</td>
<td>414.3</td>
<td>-14.28</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>25</td>
<td>50</td>
<td>2</td>
<td>42</td>
<td>2.39</td>
<td>5.04</td>
<td>421.9</td>
<td>-12.71</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>25</td>
<td>50</td>
<td>2</td>
<td>13</td>
<td>0.79</td>
<td>7.31</td>
<td>478.1</td>
<td>-1.08</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>50</td>
<td>50</td>
<td>2</td>
<td>36</td>
<td>0.88</td>
<td>7.29</td>
<td>481.4</td>
<td>-0.40</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>50</td>
<td>50</td>
<td>2</td>
<td>24</td>
<td>0.78</td>
<td>7.37</td>
<td>481.2</td>
<td>-0.44</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>100</td>
<td>50</td>
<td>2</td>
<td>45</td>
<td>1.51</td>
<td>6.78</td>
<td>482.3</td>
<td>-0.21</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>100</td>
<td>50</td>
<td>2</td>
<td>4</td>
<td>1.57</td>
<td>6.73</td>
<td>482.3</td>
<td>-0.21</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>50</td>
<td>100</td>
<td>2</td>
<td>3</td>
<td>1.02</td>
<td>7.14</td>
<td>479.4</td>
<td>-0.81</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>50</td>
<td>100</td>
<td>2</td>
<td>59</td>
<td>2.44</td>
<td>5.11</td>
<td>428.6</td>
<td>-11.32</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>50</td>
<td>200</td>
<td>2</td>
<td>175</td>
<td>0.44</td>
<td>7.56</td>
<td>475.6</td>
<td>-1.60</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>50</td>
<td>200</td>
<td>2</td>
<td>32</td>
<td>1.45</td>
<td>6.81</td>
<td>481.1</td>
<td>-0.46</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>100</td>
<td>100</td>
<td>2</td>
<td>94</td>
<td>2.58</td>
<td>4.83</td>
<td>418.8</td>
<td>-13.35</td>
</tr>
<tr>
<td>14</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>100</td>
<td>100</td>
<td>2</td>
<td>50</td>
<td>1.61</td>
<td>6.71</td>
<td>483.1</td>
<td>-0.05</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>100</td>
<td>200</td>
<td>2</td>
<td>101</td>
<td>0.58</td>
<td>7.50</td>
<td>479.0</td>
<td>-0.90</td>
</tr>
<tr>
<td>16</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>100</td>
<td>200</td>
<td>2</td>
<td>7</td>
<td>1.12</td>
<td>7.09</td>
<td>481.4</td>
<td>-0.40</td>
</tr>
<tr>
<td>17</td>
<td>20</td>
<td>20</td>
<td>2</td>
<td>50</td>
<td>100</td>
<td>2</td>
<td>65</td>
<td>1.48</td>
<td>6.75</td>
<td>479.0</td>
<td>-0.90</td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>20</td>
<td>2</td>
<td>50</td>
<td>100</td>
<td>2</td>
<td>16</td>
<td>1.06</td>
<td>7.15</td>
<td>482.0</td>
<td>-0.28</td>
</tr>
</tbody>
</table>
Construction Resource Allocation Using a Genetic Algorithm

Table 2. Evolution from an initial random solution to the final solution.

<table>
<thead>
<tr>
<th>Generation</th>
<th>X1</th>
<th>X2</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.40</td>
<td>6.36</td>
<td>451.6</td>
</tr>
<tr>
<td>2</td>
<td>1.56</td>
<td>6.36</td>
<td>459.6</td>
</tr>
<tr>
<td>3</td>
<td>0.69</td>
<td>7.26</td>
<td>470.1</td>
</tr>
<tr>
<td>7</td>
<td>1.40</td>
<td>6.86</td>
<td>481.6</td>
</tr>
<tr>
<td>48</td>
<td>1.56</td>
<td>6.75</td>
<td>483.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Input Data: Crossover Probability</th>
<th>Mutation Probability</th>
<th>X1max</th>
<th>X2max</th>
<th>Decimal Places</th>
<th>Population Size</th>
<th>Number of Generations</th>
<th>Extra Penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 0.3</td>
<td>= 0.1</td>
<td>= 10</td>
<td>= 10</td>
<td>= 2</td>
<td>= 100</td>
<td>= 100</td>
<td>= 2</td>
</tr>
</tbody>
</table>

Evolution Progress:

<table>
<thead>
<tr>
<th>Number of Generations</th>
<th>X1</th>
<th>X2</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10.0</td>
<td>10.0</td>
<td>31.0</td>
</tr>
<tr>
<td>50</td>
<td>2.73</td>
<td>4.53</td>
<td>408.3</td>
</tr>
<tr>
<td>100</td>
<td>2.47</td>
<td>5.06</td>
<td>427.1</td>
</tr>
<tr>
<td>100</td>
<td>1.25</td>
<td>6.99</td>
<td>418.9</td>
</tr>
<tr>
<td>100</td>
<td>1.58</td>
<td>6.50</td>
<td>469.0</td>
</tr>
<tr>
<td>100</td>
<td>3.85</td>
<td>0.56</td>
<td>226.1</td>
</tr>
<tr>
<td>100</td>
<td>2.99</td>
<td>3.88</td>
<td>379.3</td>
</tr>
<tr>
<td>100</td>
<td>1.7</td>
<td>6.6</td>
<td>481</td>
</tr>
<tr>
<td>100</td>
<td>8.0</td>
<td>7.2</td>
<td>482</td>
</tr>
<tr>
<td>100</td>
<td>1.25</td>
<td>7.0</td>
<td>482.7</td>
</tr>
<tr>
<td>100</td>
<td>1.12</td>
<td>7.09</td>
<td>481.4</td>
</tr>
<tr>
<td>100</td>
<td>1.667</td>
<td>6.659</td>
<td>482.89</td>
</tr>
<tr>
<td>100</td>
<td>2.938</td>
<td>4.077</td>
<td>391.52</td>
</tr>
<tr>
<td>100</td>
<td>1.108</td>
<td>7.09</td>
<td>480.58</td>
</tr>
<tr>
<td>100</td>
<td>1.2228</td>
<td>7.0033</td>
<td>481.33</td>
</tr>
</tbody>
</table>

*Best solution from linear programming method is 483.33

The results from the genetic algorithm program are summarized in Table 1. Sixty-five percent of the total runs yield the results within 1% error. The percentage increases to 75% and 95% for error within 5% and 20% respectively. The best profit, resulting from run number 14, is 483.1 as compared to 483.33. All runs took less than two minutes (with most within one minute) on a 486 DX2-66 computer. Runs with larger populations size tend to converge very early. A larger population size means a larger search space, which increases the number of candidate solutions. However, earlier convergence is not necessarily better, since computation time increases with population size. An extra run was made and the evolution results were recorded and summarized in Table 2. In this particular run, the solution started with the 1st generation's best solution of 451.6, evolved, and converged to a solution of 483 in the 48th generation.

Conclusions

Genetic algorithms work well with the resource allocation problems as shown in this paper. The major advantage of the GA method over the traditional OR methods is its applicability to a wide range of problems with very few modifications to the computer program. For example, the same computer program can be easily modified to solve non-linear programming problems or to solve problems with more than two variables. The GA method, however, does not guarantee the optimum solution. It is the user's responsibility to make several runs with different parameter values and then choose the best solution.
Literature Cited


Proceedings Arkansas Academy of Science, Vol. 49, 1995
Energy-Loss Particle Identification in 2-D Silicon Drift Detectors

G. Douglas Mauldin, A. A. Rollefson and W. J. Braithwaite
Department of Physics and Astronomy
University of Arkansas at Little Rock
Little Rock, AR 72204

Abstract

A relatively new type of transducer known as the Silicon Drift Detector (SDD) has been fabricated onto thin silicon wafers. SDD operates like a miniature, high-resolution, 2-D Time-projection chamber. One of these devices can detect two dimensions of an ionizing particle's position, and its integrated electrical charge output level is proportional to the particle's energy loss through the silicon. An array of SDD's, arranged in three coaxial cylinders, is being considered as part of an instrument surrounding the beam pipe of a highly-relativistic colliding beam facility, where it would be used to simultaneously track individual paths of thousands of charged particles emerging from each primary collision. Energy-loss data from the (x,y) pixels of each track allow individual particle identification as an electron, pion, kaon or proton. CERN's Monte Carlo modeling program, GEANT, is being used to predict energy loss at high statistical accuracy to account for high-energy tailing of the more prevalent pions. GEANT has been installed on a Linux workstation in Little Rock. Speeding up the modeling process is being investigated using parallel virtual memory techniques and groupings of Linux workstations.

Introduction

The Silicon Drift Detector (SDD) is a solid-state device proposed for obtaining trajectory and energy-loss data from ionizing particles such as those emerging from the collision vertex of a high-energy nuclear physics experiment as proposed by the STAR Collaboration (1992) for use at the Relativistic Heavy Ion Collider. The sensitive volume of an SDD detector is a wafer of silicon, and it employs the phenomenon of electron drift through the silicon.

The SDD represents a new detector technology intended as a solid-state version of the well-known time-projection chamber or TPC (Marx and Nygren, 1978). Although not seen as a replacement for the TPC, the SDD could offer greater resolution over a smaller region of space for applications such as precise location of central collision vertices in a collider experiment.

To place the evolution of the SDD in proper perspective, a brief description of the TPC follows. A TPC is an electronically-instrumented ionization chamber. It is essentially a box filled with a gas mixture at atmospheric pressure that is chosen for its ionization characteristics. An electric field is produced along two opposite walls of the chamber between parallel conductive planes. An ionizing particle traversing the gas volume leaves a trail of free electrons, which drift toward the positively-charged side of the chamber, quickly reaching a terminal velocity in the presence of the gas. Some secondary electron emission occurs along the way to the positive plane, which is a matrix of isolated and individually-instrumented plates called pads. The coordinates of the pads provide two spatial dimensions, and analysis algorithms use drift time to infer the third spatial dimension of the track. Typically, energy loss in the TPC is only a fraction of a radiation length, so traversing the TPC has little effect on particle tracks, except at the lowest momenta.

Unlike the TPC, the SDD is a slab of solid silicon. Thin metallic electrodes deposited onto the surfaces of this slab are used for biasing, focusing, and signal readout. Applied bias voltages deplete the silicon of mobile charge carriers. A charged particle passing through the slab will promote atomic electrons of the semiconductor material into its conduction band, thereby creating electron-hole pairs along the path of the particle. The holes are swept away by the focusing electrodes and the electrons drift along a potential channel in the silicon, until they are collected by a segmented readout electrode at one end of the silicon slab and detected by the readout electronics.

To keep this detector from causing appreciable changes to the particles' momenta, the SDD is made very thin, essentially planar, and only two spatial dimensions are measured. A line of pads is used instead of a plane, and time-projection is used to obtain one more dimension. In a practical detector design, an array of SDD's would be used to obtain multiple points to define the helical trajectory of a particle.

In addition to position information, the semiconductor-solid-silicon SDD detector can measure statistically-significant energy loss by a particle traversing its sensitive volume. This measurement can be used to identify parti-
cle types (electrons, pions, kaons, protons) for a range of momenta, with the main difficulty in identifying being the statistical fluctuation in energy losses for individual particles about the mean value and the likelihood that the energy loss value of a particle could lie in a region characteristic of a different particle type. Obtaining a physically realistic picture of the distribution of energy loss values (traversing silicon) for pions, the predominant particle type anticipated in high-energy collider experiments, is essential for the construction of a suitable identification algorithm which is the focus of future work.

Methods

The passage of charged particles such as pions through matter is governed primarily by atomic physics. Most of the energy loss and scattering effects that occur are due to the particle's Coulomb interactions with bound atomic electrons of the matter in its path. Being much heavier than an electron, a pion suffers a small energy loss and undergoes a small deflection in an interaction with and electron. The electron is excited or ionized by the energy transferred to it in the collision.

Consider a well-collimated beam of pions passing through a slab of silicon. Each pion interacts with a great number of electrons along it path, the small energy losses and deflections add statistically, such that as the beam emerges from the slab, it is no longer monoenergetic and has an angular spread. The energy losses of these particles are distributed about a mean energy loss value.

If the silicon slab is sufficiently thick, some of the pions are stopped. The thickness required to stop a particle is its range in the material. At a thickness \( R_m \), called the mean range, half of the particles are stopped, and at some greater thickness essentially all the particles are stopped. The fluctuation in range is called straggling. Sometimes straggling is used to refer to the fluctuation in energy loss.

Since one of the design goals of a vertex tracking device using SDD detectors is to have minimal effect on the trajectories of the particles it tracks, the energy-thick-ness of the silicon slabs are chosen to be a fraction of a radiation length for pions, and, thus, well below that which would cause a significant number of pions to be stopped. Thus, pions and other particles can pass through the SDD detectors on their way to other detectors like TPC's which they would minimally affect.

The mean energy loss of a beam of particles traversing an absorber can be expressed as \(-dE/dx\), where \(-dE\) is the energy lost over a distance \(dx\) in the absorber. An approximate value for \(-dE/dx\) can be obtained using the Bethe-Bloch equation. The energy loss is proportional to the electron density of the absorber and the square of the particle charge. The Bethe-Bloch equation breaks down below the energy for which the particle's velocity is less than that of the atomic electrons in the absorber (Frauenfelder and Henley, 1991).

Different statistical distributions of \(-dE/dx\) are predicted for different particles and energy regimes. These include the Landau Distribution, The Vavilov Distribution and the (generic) Gaussian Distribution. Fig. 1 shows predictions for two different types of Landau distribution, one (flawed) Vavilov distribution, and a Gaussian distribution, using the Center for European Nuclear Research (CERN) detector modeling program GEANT (GEANT, 1994). These plots were generated using an earlier version of GEANT (version 3.15) in which the distribution could be selected via the IMODE variable. This variable is not recognized by the newer versions of GEANT (e.g., version 3.21).

![Pion Energy Loss in Slab Silicon (Channel No.)](image)

Fig. 1. Energy loss predictions for two different types of Landau distributions, one (flawed) Vavilov distribution, and a Gaussian distribution, using an early version of the CERN detector modeling program (GEANT, 1994).

To simulate the statistical fluctuations in energy loss suffered by particles traversing matter, CERN's program GEANT uses a Monte Carlo method. Monte Carlo refers to a numerical technique that accounts for randomness in a physical process through the use of random numbers, and is named for the well-known casino resort city where the element of chance plays a key role.

In a Monte Carlo program, random numbers are passed through a modeling algorithm to produce simula-
ed data. These values can then be analyzed as if they were produced by the physical system being modeled. For example, they can be arranged into an occurrence distribution and graphed as a histogram. The extent to which such a simulation represents the modeled system is affected both by the validity of the algorithm chosen and the quality of the random number supply.

In practice, detector modeling programs are complicated, but well-connected researchers need not write their simulation software entirely from scratch. The management of CERN, the European Organization for Nuclear Research, makes it software library, known as Cernlib, available for use to members of the High Energy Physics (HEP) community. The Cernlib subroutines for detector descriptions are found in a Cernlib package known a GEANT, whose name is said to be a contraction of “geometry and tracking.” Perhaps not by happenstance, GEANT is also the French word for “giant.” These and other subroutines in Cernlib, along with various necessary user-generated subroutines, can be used to handle the many aspects of a practical detector simulation, including particle tracking, physics processes, histogram booking, and other functions. Strictly speaking, GEANT comprises only the parts of a simulation that deal with detector description, but it is common to speak of the entire program as a “GEANT simulation.”

Cernlib software consists primarily of libraries of subroutines but also includes some complete programs, most notably the Physics Analysis Workstation (PAW, 1994) for data manipulation and presentation. Cernlib is made available for a variety of platforms ranging from mainframe computers to workstations, including PClone systems running Linux, which is a clone of the UNIX operating system (Johnson, 1994). Such a system can be assembled for a fraction of the cost of other kinds of platforms used for this purpose. The emergence of this no-cost UNIX that runs on low-cost hardware prompted a group of physics researchers in the former Soviet Union to “port” (move to a different computing platform) a version of GEANT and other essential Cernlib subroutines and programs to run on this kind of system. GEANT programs under Linux are functionally equivalent to those on other platforms, including mainframes and supercomputers. Being well received by the worldwide high-energy physics community, the Linux port is now an officially-sanctioned part of the CERN Program Library.

Most of the simulation work presented was performed on a Linux system constructed and administered by the first author. The choice to use a personal system instead of a University-owned computer involved a trade-off of computing speed for control. Being the administrator of one’s own system enables one to quickly make needed changes that would be at best time-consuming and difficult if not impossible to obtain on a system administered by others. Furthermore, a personal computer with one user can devote essentially all its resources to the one simulation program. Dedicating a Linux system to one task effectively narrows the real-time performance gap between the Linux system, and they can be slower, depending on the load imposed by other users. Since total control over the system could be had for an acceptable sacrifice in performance, the choice of a Linux system for this project was clear.

The computer system used for this work was assembled from components chosen for optimal performance under Linux. The Intel 80486DX-50 microprocessor was chosen over the only high-speed alternative at the time, the 80486DX2-66, due to reports by other Linux users that its overall performance is better. For Linux use, the faster CPU of the DX2-66 is more than offset by the slower 33-MHz bus rate when compared with the DX-50 which runs at 50 MHz both internally and on its bus. The Pentium was not considered because no compiler optimized for it had been developed for use under Linux. Primary storage consists of eight megabytes of random-access memory (RAM) and a 256-Kilobyte memory cache. Secondary storage is provided by a 1080-megabyte Western Digital fixed-disk drive. A Colorado Memory Systems tape drive in QIC (quarter-inch cassette) format is used for off-line storage and backup. A local-bus video board with two megabytes of video RAM drives a 14-inch color display with resolution of 1024 by 768 pixels which is adequate for the graphics requirements of CERN’s Physics Analysis Workstation software.

There have been recent developments in parallel processing techniques using clusters of UNIX workstations. One implementation of this is called Parallel Virtual Machine, or PVM (Beguelin, et al., 1993). This consists of a suite of functions that can be called from FORTRAN or C programs and is portable to a number of platforms including Linux. Since our GEANT simulation consists of many independent iterations of the algorithm, it appears to be a good candidate for a parallel processing method such as PVM. We have begun to implement this by preparing a second Linux machine and an Ethernet link to connect the two and acquiring the needed additional software, but a final version of a PVM system had not been implemented at the time of this writing. We intend to pursue this enhancement in the future.

One part of learning to write GEANT programs is understanding the complex flow of control among the many subroutines. The “main” program, supplied by the user, calls a set of subroutines in the proper order, some supplied by the GEANT library and some by the user, which call other subroutines, some supplied by the GEANT library but some supplied by the user. The GEANT manual provides a crude diagram attempting to show these relationships but falls short of adequate.
Other GEANT users have constructed diagrams which are more readable and intuitive (Roetzel and Braithwaite, 1993). A diagram showing subroutine calls made in the program used in this study is presented in Fig. 2. The arrows represent subroutine calls, each with its tail at the calling subroutine and its head at the called subroutine. Execution begins and ends in the main program. Each called subroutine returns control to the calling subroutine when finished. The time flow of the diagram is generally top to bottom. Not all available user subroutines had to be provided in the present program; those not needed are not shown.

![Diagram of subroutine calls](image)

Fig. 2. Subroutine calls in currently used GEANT simulation Program.

In reading the diagram in Fig. 2, one may notice naming conventions for GEANT subroutines. All GEANT library subroutines begin with the letter “G.” User-supplied subroutines begin with “UG” or “GU.” For historical reasons, everything in FORTRAN is in uppercase type, and that convention is seen in the names of subroutines in the diagram and elsewhere in this work. Although most user-supplied subroutines are mandatory, some are optional and have default subroutines in the library which will be used if one is not supplied by the user.

An aspect of Cernlib software that is important to understand is the liberal use of COMMON blocks. The COMMON statement was provided by the designers of FORTRAN to add versatility. COMMON blocks are used by Cernlib to work around limitations in FORTRAN 77, to provide global variable space and dynamic memory allocation.

COMMON blocks are inherently dangerous because there is no protection against the uncoordinated alteration of a block's contents by different parts of a program. This can lead to undetected errors in the results of the program. In a complex programming environment such as GEANT, multiple programmers sometimes use the same COMMON for different purposes, thereby unwittingly damaging each other's data.

In addition to the choice of distribution, the program can take interactions with nuclei into account. The program simulates a particle's trajectory as a series of steps and calculates the probability of an interaction occurring at each step. The choice of step size is a trade-off between accuracy and computing speed. The program calculates a step size, but the user can impose an upper limit.

The various user-selectable parameters available to the programmer in the version of GEANT current at the time this project was begun raised the issue of determining which permutations of these parameters would give realistic results. We proposed to evaluate these choices and validate the applicability of GEANT to the problem of measuring dE/dx of pions on silicon, comparing our results with experimental data which was to become available.

Results and Discussion

The problem of making suitable choices for the GEANT parameters affecting the results of a simulation involving energy-loss fluctuations was evidently a concern to other researchers, as evidenced by the changes that were made to GEANT by the CERN programmers during the time period of our work. In the newer releases of Cernlib and GEANT, the task of choosing a distribution of energy-loss fluctuations has been automated. The current GEANT program also makes automatic selection of other parameters such as step size.

Automatic selections override the user's input parameters, as evidenced by the lack of discernible difference in the resulting histograms from successive runs of our simulation program in which some of these parameters had been changed over their entire range of values. An example of these histograms is presented in Fig. 3.
Fig. 3. A sample histogram of energy loss for one-million 300 MeV/c pions passing through 300 microns of silicon.

Issues addressed by this study have been recognized independently by the CERN programmers, confirming our concerns were valid. The focus of our study now shifts to the issue of whether the results produced with our simulation using these automated selection processes are realistic. As the production of experimental data for comparison has been delayed, this question remains to be answered.

Plans for future work include searching for means to override the automatic features in the newer versions of GEANT, re-running our simulations to prepare dE/dx distributions using the various permutations of variable parameters, awaiting experimental data for comparison with our simulation results, and speeding processing time with a parallel cluster of workstations using PVM.

ACKNOWLEDGMENTS.—This work was supported by grants funded by the Arkansas Science and Technology Authority, the U. S. Department of Energy (EPSCoR), and the Office of High Energy and Nuclear Physics, Division of Nuclear Physics of the U. S. Department of Energy under grant DE-FG05-92ER40753. This work recognizes the help of the STAR Collaboration (1992).

Literature Cited

Beguelin, A., J.J. Dongarra, G.A. Geist, W. Jiang, R.
Manchek, K. Moore and V.S. Sunderam. 1993. The
PVM Project. Available free from
“ftp:netlib2.cs.utk.edu/PVM3/writeup.ps”.
Subatomic Physics, 2nd ed. Prentice-Hall, New Jersey.

Acknowledgments.—This work was supported by grants funded by the Arkansas Science and Technology Authority, the U. S. Department of Energy (EPSCoR), and the Office of High Energy and Nuclear Physics, Division of Nuclear Physics of the U. S. Department of Energy under grant DE-FG05-92ER40753. This work recognizes the help of the STAR Collaboration (1992).

Literature Cited

Beguelin, A., J.J. Dongarra, G.A. Geist, W. Jiang, R.
Manchek, K. Moore and V.S. Sunderam. 1993. The
PVM Project. Available free from
“ftp:netlib2.cs.utk.edu/PVM3/writeup.ps”.
Subatomic Physics, 2nd ed. Prentice-Hall, New Jersey.
An Introduction to Monte Carlo Methods

S.E. McCloskey and W.J. Braithwaite
Department of Physics and Astronomy
University of Arkansas at Little Rock
Little Rock, AR 72204

Abstract

Monte Carlo computer programming is becoming increasingly popular to those who use it, due to the ease with which complex problems may be formulated and solved. However, the growth of MC programming for small projects is inhibited by a frequent misconception of difficulty, inferred from the high level of complexity of problems solved in High Energy and Nuclear Physics using MC methods. In addition, few students of science and engineering are receiving exposure to the basic issues involved in the Monte Carlo process despite the ease with which MC can be used to solve classical physics problems, especially those problems with little symmetry or unusual geometry. Few upper-division or graduate students have begun to exploit this approach, even in research projects. Thus, an introduction to Monte Carlo methods would be valuable, even for the beginning science or engineering student. The present work introduces integration of area and volume, then expands this effort to include surface and volume integrals of scalar and vector functions. Next, integration over unusual geometries introduces programs which convert the geometries defined by CAD (Computer Aided Design) to geometries convenient to the Monte Carlo process. Finally, Gauss's Law uses MC to calculate the size of an asymmetrically positioned charge and a classic example from Sir Isaac Newton uses MC to calculate the effect of a spherically symmetric shell of mass on an exterior field point where the average force components \(F_x, F_y, F_z\) are calculated. These final examples introduce singularities and convergence problems arising in the Monte Carlo averaging process.

Introduction

Monte Carlo programming would be growing faster today if it were not for the frequent misconception of difficulty inferred from exposure to the huge Monte Carlo programs used to solve problems in High Energy and Nuclear Physics. Examples include complex Monte Carlo modeling programs like GEANT (Roetzel and Braithwaite, 1993) or the need for optimizing parallel computing for MC problems (Byrd et al., 1993). This misconception inhibits the growth of MC programming, which can be extremely useful for much smaller projects than those encountered in High Energy and Nuclear Physics.

Despite these inhibition to newcomers, Monte Carlo computer programming is becoming increasingly popular to its frequent users, due to the ease with which fairly complex problems may be formulated and solved for numerical answers. In many instances, calculational demands of MC are so slight that spreadsheet programming is sufficient to formulate a problem. However, few students of science and engineering receive early exposure to the basic issues involved in the Monte Carlo process. Indeed, upper-division and graduate research projects could be enhanced by using MC, making the introduction to Monte Carlo methods in some tangible examples desirable for beginning science and engineering students (Buslenko et al., 1966; Hammersley and Handscomb, 1986).

Monte Carlo integration has been chosen as the process for introducing Monte Carlo methods, as MC algorithms are useful in solving integral equations (Sabelfield, 1991; Mikhailov, 1992). For applications like integration, the Monte Carlo approach is an averaging process using random numbers to sample the space being integrated. Despite its random nature, the MC averaging process must be set up so as to uniformly sample the space (or domain) being integrated. It is worth noting the Monte Carlo averaging process, as it applies to integration, converges asymptotically \(N \to \infty\) to the exact solution.

The simplest example presented is the calculation of the ratio of the area of a circle inscribed in a square to the area of the square. The ratio, \(\text{Area(Circle)} / \text{Area(Square)}\), is \(\pi/4 = 0.7854\). The inscribed circle is shown in Fig 1a with Fig. 1b showing 200 \((x, y)\) points each chosen randomly for sampling the square. The procedure used to integrate the area of the circle in units of the square (in which it is inscribed) is to count the number of points falling within the circle \(N_{\text{hits}}\), then divide by the total number of points sampling the square \(N_{\text{total}}\). The ratio \(N_{\text{hits}}/N_{\text{total}}\) is the same as the ratio of areas, \(\text{Area(Circle)} / \text{Area(Square)}\), provided the coordinate pairs of random numbers uniformly sample the square as \(N \to \infty\).

The \((x, y)\) points chosen to sample the square come

Proceedings Arkansas Academy of Science, Vol. 49, 1995
from random number pairs each chosen between (-1, +1). Despite expectations that these random \((x, y)\) point-pairs uniformly sample the square as \(N \to \infty\), a small sampling group (like the one in Fig. 1b) looks "spotty" to everyone. How large a sample is needed for the Monte Carlo process to converge to useful results? This important question of convergence is answered qualitatively by repeating the random \((x, y)\) point selection process several more times to see if it reduces the apparent spottiness of the sampling process.

![Fig. 1](image1.png)

Fig. 1. (a) A "target" Circle is inscribed within a square. (b-f) Five sets of 200 2-D Monte Carlo samplings of the area of the square.

Figure 1c,d,e,f provides graphs showing four additional distinct groups of 200 random \((x, y)\) points where all five groups of 200 points and the "target" circle inscribed within a square (shown in Fig. 1) may be copied to transparencies (with enlargement) and progressively laid one above the other. This progression shows a reduction of the "spotty" appearance every time the sampling is increased by 200 events. This sampling increase may be accomplished by placing each successive transparency containing 200 events on top of the transparency showing the target circle inscribed in a square.

![Fig. 2](image2.png)

Fig. 2. Monte Carlo "target" area sampling for visualizing the integration of a circle.

The area of the square is chosen as \(2 \times 2 = 4\), where all \((N_{\text{total}})\) of the \((x, y)\) random number pairs fall within the area of the square, randomly and uniformly sampling the area of the square. Two plots of the ratio \(\text{Area(Circle)} / \text{Area(Square)}\) versus the number of 2-D MC samples are shown in Fig. 3. Most \((x, y)\) points sampling the square also fall within the circle where the Pythagorean Theorem is used to test the "hit" or "miss" status of each \((x, y)\) point. The test is whether \(x^2 + y^2 < 1\), if successful, \(N_{\text{hits}}\) is incremented. The ratio of the area of the inscribed circle to the square is given by:

\[
\frac{\text{Area(Circle)}}{\text{Area(Square)}} = \frac{N_{\text{hits}}}{N_{\text{hits}} + N_{\text{misses}}} = \frac{N_{\text{hits}}}{N_{\text{total}}} = \frac{\pi(1)^2}{4} = \frac{\pi}{4} = 0.7854.
\]

Figures 3 addresses convergence graphically by showing two envelopes labeled as \(\pm 1\sigma\). These two envelopes show one standard deviation on each side of the mean (of \(\pi/4 = 0.7854\) with the figure of merit being the event fraction lying within \(\pm 1\sigma\) (.693 as \(N \to \infty\)). The statistical theory of binomial sampling provides formulas for these two \(\pm 1\sigma\) envelopes as a function of 2-D samples \((N)\): \(0.7854(1 \pm \sqrt{(1 - 0.7854)/0.7854})\).

The next example of Monte Carlo integration is the calculation of the volume of a sphere inscribed within a cube. All \((x, y, z)\) points fall within the cube with only
about half of these points falling within the sphere. Analytically, the volume of a sphere is calculated to be \(\frac{\pi}{3} = 1.0472\) times larger than half the volume of the cube.

The drawing in Fig. 4 shows an example of an \((x, y, z)\) point on the target sphere. This target picture of the sphere is useful in visualizing the test for integration of a spherical volume by Monte Carlo averaging. The status of each \((x, y, z)\) point is tested using the 3-D Pythagorean Theorem (developed in Fig. 4). This test asks the question: Is \(r^2 = x^2 + y^2 + z^2 < 1?\) A “yes” is a “hit” within the sphere.

To calculate a volume using Monte Carlo, consider a sampling of \((x, y, z)\) random-triplets, where each is viewed as a coordinate point within the cube. Large numbers of \((x, y, z)\) random triplets are used to uniformly sample the cube; this sampling is used to extract the volume of the sphere inscribed within this cube.

The increasingly uniform sampling of a square with increasing sample size, using \((x, y)\) random pairs, was seen in the 2-D example presented above. Convergence in this earlier 2-D work is reassuring to a new MC user as it relates to the 3-D problem; it corresponds to examining each face of the cube from a position of normal incidence.

\[
\rho^2 = x^2 + y^2 \quad \text{and} \quad r^2 = \rho^2 + z^2, \quad \text{so:} \quad r^2 = x^2 + y^2 + z^2
\]

Figure 5 has two plots of calculated \(\frac{\text{Volume(Sphere)}}{\text{Volume(Cube)}}\) versus the number of 3-D MC events \((N)\). Also, each plot shows two envelopes labeled at \(\pm \sigma\). These two envelopes are one standard deviation on each side of twice the mean of the volume ratios \((\frac{\pi}{3} = 1.0472)\), with each plot giving a figure of merit (event fraction within \(\pm \sigma\)) for \(N = 1600\) (approaching 0.693 as \(N \to \infty\)). These two envelopes may be written as \(1.0472(1 \pm \sqrt{(2-1.0472)/1.0472})\) as a function of 3-D samplings \((N)\). Note the

\[
\frac{\text{Volume(Sphere)}}{\text{Volume(Cube)}} = \frac{N_{\text{hit}}}{N_{\text{total}}} \to \frac{\frac{4}{3} \pi (1)^3}{8} = \frac{1}{2} \frac{\pi}{3} \frac{1}{2}(1.0472...) \approx 50\%.
\]

This second example uses a spreadsheet with graphics to calculate 1600 volume samplings of the cube. Figure 6 displays a matrix of 20 distinct MC calculations of the volume of the sphere versus \(N\) [the number of \((x, y, z)\) triplets of random samples]. Each plot has two envelopes indicating one standard deviation from \(\pi/3\) as a function of \(N\). The number in each calculation is the figure of merit indicating the event fraction lying within this \(\pm 1\) standard deviation for each set of 1600 samples.
Figure 6 shows the large variation in MC predictions for repeated calculations as a function of N. Envelopes of ±1σ generally show the convergent trend as the number N (of 3-D MC events) increases to 1600. Despite this convergent trend, large variations are observed in repeated calculations of volume as the calculation process is repeated over-and-over; each calculation could be available graphically in seconds using modern Workstations.

Results and Discussion

Integration of area may be expanded to include surface integrals of scalar and vector functions. First consider integrating a scalar function \( f(x, y) \) over a circle (inscribed within a square) using MC. Little change in procedure is needed from that used to integrate the area of the circle. For each “hit” (defined above) form a running sum of the evaluated function \( f(x_h, y_h) \), but ignore the sum for a “miss.” If a spreadsheet like EXCEL is used, the logical IF statement is a function subroutine which returns a 1 (true) or a 0 (false) which can be multiplied by the function \( f(x, y) \) for \( R^2 < 1 \) [\( R^2 = x^2 + y^2 \)]. Using a statement like \( S2 = S1 + IF(R^2 < 1, 1, 0)*f(x, y) \), effectively removes it from the sum in the “fill-down” (S1 is 0). In FORTRAN an expression like \( \text{sum} = \text{sum} + f(x_h, y_h) \) is evaluated for a “hit,” but skipped over for a “miss” (with sum initially 0).

In summary:

\[
\int \int f(x, y) \, dx \, dy = \text{average} \left[ f(x_h, y_h) \right] \cdot A(Circle) \rightarrow \frac{\text{sum} \cdot N_{hit}}{N_{total}} \cdot \text{Area(Square)}.
\]

Similarly, integration of volume can be expanded to include surface or volume integrals of scalar and vector functions. First consider integrating the function \( f(x, y, z) \) over the sphere (inscribed within a cube) using MC with little change in procedure from that used to integrate the volume of the sphere. In similar fashion to the integral of the 2-D \( f(x, y) \) outlined above for each 3-D “hit,” form a running sum of the evaluated function \( f(x_h, y_h, z_h) \), but ignore the sum for a “miss.” Spreadsheet and FORTRAN procedures are essentially the same as outlined for the 2-D integral above. In summary:

\[
\iiint f(x, y, z) \, dx \, dy \, dz = \text{average} \left[ f(x_h, y_h, z_h) \right] \cdot \text{Vol(Sphere)} \rightarrow \frac{\text{sum} \cdot N_{hit}}{N_{total}} \cdot \text{Vol(Cube)}.
\]

Integration of a function over an unusual volume, such as a closed “teapot” in a rectangular box, would follow similar procedures once the MC geometry is defined. Programs are available for converting CAD (Computer Aided Design)
geometries to geometries to geometries convenient to Monte Carlo (Cloth and Sterzenbach, 1995). An example of this type of program is OCTAGON (Dragovitsch et al., 1992), a program for converting CAD geometries defined in the drawing of High Energy Physics detector elements to geometries compatible with CERN's Monte Carlo detector modeling (GEANT, 1994).

Gauss' Law may be used with MC where the field point is replaced by another spherical shell which is used to define the surface integral over a sphere. This shell uses three random numbers to form the unit vector: 

\[ \mathbf{r}_{\text{field}} = (x, y, z)/\sqrt{x^2 + y^2 + z^2} \]

where (the scalar) \( r \) is the distance of the source shell from its symmetry center. Spherical symmetry is preserved in the MC 3-D sampling if \( \mathbf{r}_{\text{source}} \) and \( \mathbf{r}_{\text{field}} \) are used. The field point is located outside the shell for \( r < 1 \), and MC sampling of \( 1/\mathbf{r}_{\text{source}} \cdot \mathbf{r}_{\text{field}}^2 \) converges to 1, provided a sufficiently large MC sampling is taken when \( r \) is near one. The vector integral is calculated for the force \( (F_x, F_y, F_z) \).

The graph for any force component may be presented in a different color on a computer display, so changing the unit vector field assignment to another coordinate axis changes the color of the force component averaging to 1, with color of the graph of the original force component now averaging to 0 (along with a third graph). The display will change when any other arbitrary unit vector field point is chosen such as:

\[ (1,1,1)/\sqrt{3}. \]

In this case all 3 components converge (as \( N \) increases) to the same value.

---

**Fig. 7.** (a) MC is used to integrate Gauss' Law by averaging \( E \cdot \mathbf{n} \) over a spherical shell. \( E \) is due to a unit charge located off-center from the spherical shell. (b) MC averaging provides the vector integral of the force \( (F_x, F_y, F_z) \) at the field point \( (0, 1, 0) \) due to a spherically symmetric unit-mass shell at \( r = 0.5 \).

To appreciate the problem of convergence, consider \( r=1 \) where the MC weighting term is singular, as \( \mathbf{r}_{\text{source}} \cdot \mathbf{r}_{\text{field}}^2 \rightarrow 0 \) at closest approach of source to the field point so the MC calculation cannot converge. At \( r = 0.90 \), the closest approach point of the source shell (of mass) is 0.1, and the weighting term in the MC is 100. In contrast, weighting for force contributions from the far side of the source shell \( r = 0.9 \) (or 1.1) a sampling of 1600 MC triplets is insufficient and a
An Introduction to Monte Carlo Methods

much larger value of N must be used. Students are asked to estimate how many MC samplings are needed of \( r = 0.95 \) and for \( r = 0.99 \), etc. This example allows students the opportunity to explore near singularities and their effect on the convergence of the Monte Carlo averaging process. Rough estimates are useful in determining N, the number of MC samplings which will be sufficient to assure reasonable convergence; for \( r = 0.9 \) a safe but unduly large estimate of N is 100*1600.

In summary, the present work shows that the calculational demands of Monte Carlo methods for many simple problems are so slight that spreadsheet programming is often sufficient to provide useful results (e.g., when evaluating surface or volume integrals of scalar or vector functions). An example of a near-singularity in MC was presented where the remedy requires a substantial increase in the number of MC samples. Examples presented above were indicative of the ease with which MC calculations can be used to provide tangible results when solving many science and engineering problems encountered in upper division or graduate coursework. Monte Carlo methods can complement the formal mathematics by providing an easy way to arrive at a numerical answer, especially for those problems with little symmetry or unusual geometry.

Acknowledgments. — This work is supported by the U.S. Department of Energy: Office of High Energy and Nuclear Physics, Division of Nuclear Physics, under grant DE-FG05-92ER40753.

Literature Cited


GEANT. 1994. GEANT Users’ Guide: Detector Description and Simulation Tool, CERN Program Library Internal document, CERN Data Division, Geneva, CH.
Cavity Protection Techniques for Red-cockaded Woodpeckers

Warren G. Montague
Poteau Ranger District - Ouachita National Forest
USDA-Forest Service
P.O. Box 2255
Waldron, AR 72958

Abstract

Population growth of red-cockaded woodpeckers (Picoides borealis) is often limited by the availability of suitable cavities. Structural damage to natural and artificial cavities intended for use by P. borealis is common. Roost and nest cavities of P. borealis often become occupied by other cavity-dependent species. Techniques for preventing damage to artificial cavities and for deterring southern flying squirrel (Glaucomys volans) use of otherwise serviceable cavities are described. Such cavity protection techniques may be necessary to prevent extirpation of small, isolated populations of P. borealis.

Introduction

Since the red-cockaded woodpecker (Picoides borealis) was listed as an endangered species in 1970, establishing viable populations of the species has been a goal of wildlife conservationists. This woodpecker is endemic to pine forests of the southeastern United States and has a limited distribution in Arkansas (James et al., 1981; James and Neal, 1986, 1989; Neal and Montague, 1991). Considerable research effort has been committed to determining the factors which limit species recovery efforts (Ligon et al., 1986). Land management activities geared toward species recovery currently emphasize providing mature pine forest habitat of a sufficient quantity and quality to meet recovery objectives (U.S. Fish Wildl. Serv., 1985). This paper describes techniques for preventing damage to artificial cavities and for deterring southern flying squirrel (Glaucomys volans) use of otherwise serviceable cavities. The study area where these techniques were employed included the Ouachita National Forest (Ouachita NF) in Scott County, Arkansas; the Crossett Experimental Forest, Ashley County, Arkansas; and the Arkansas Natural Heritage Commission's Pine City Natural Area, Monroe County, Arkansas.

Materials and Methods

Protection of Insert Boxes.—In order to supplement numbers of natural roost and nest cavities of P. borealis, 145 artificial cavity insert boxes were installed on the study area from 1991 to 1993 using Allen's (1991) technique. This technique was modified in 1993 by fitting the insert boxes with steel protectors, which functioned to prevent damage to the entrance tunnels of these artificial cavities (Fig. 1). These protectors were made from 2-mm thick exhaust pipe stock having an exterior diameter of 50 mm (2 in) and an interior diameter of 46 mm. Such steel tubes, which can be made at any custom automotive exhaust shop, were pressed to create a 12-mm flange at one end and then cut to an overall length of 50-55 mm. Because insert box entrance tunnels are drilled at an eight-degree angle, the top one-half of the flange was cut off at a similar eight-degree angle. This allowed the tube to be inserted into the entrance tunnel and pounded rearward until the remaining portion of the flange was flush against the front of the insert box. Use of 50-mm exhaust pipe stock required that all insert boxes have entrance tunnels drilled with a 50-mm diameter substituted for the 45-mm dimension described by Allen (1991). Once pounded into the drilled insert box entrance tunnel, no nails or screws were required to hold the tunnel protectors in place.

Prior to insertion of a tunnel protector, a 20 x 20-cm square of 6.4-mm mesh hardware cloth was stapled to the tree and insert box (Fig. 2). This was done by placing the upper edge of the mesh wire square flush with the entrance tunnel floor, and by centering it to allow approximately 5 cm of overlap on either side of, and below, the insert box (Fig. 2). This hardware cloth "insert box face-protector" was eventually covered with a thin layer of wood filler and served as a substitute for the special insert box cavity restrictor described by Allen (1991). It served to protect the insert box face from damage by potential cavity usurpers and sealed the gaps between the insert box walls and tree. Installation of tunnel protectors after attachment of wire face-protectors allowed the flange of the tunnel protector to secure the upper edge of the hardware cloth square (Fig. 2).

A 10 x 10-cm restrictor similar to that described by Carter et al. (1989) was then applied. The restrictor effectively reduced the interior diameter of the slightly oversized tunnel protector. This reduced size prevented avian cavity usurpers larger than P. borealis from entering the
Cavity Protection Techniques for Red-cockaded Woodpeckers

insert box (Raulston, 1992; Neal et al., 1992).

Finally, a thin coat (<1 mm) of wood filler was spread on all metal surfaces and pressed into all gaps around the restrictor and tunnel protector. Paint was applied to enhance the appearance of the final product (Allen, 1991; Taylor and Hooper, 1991).

Tunnel protectors were applied during all insert box installations after April 1993. Insert boxes installed prior to April 1993 were retrofitted with tunnel protectors during routine maintenance work. A portable drill with a 50-mm (2 in) Forstner drill bit was used to enlarge slightly undersized entrance tunnels of insert boxes previously installed without tunnel protectors.

Effectiveness of tunnel protectors and associated face-protectors in preventing damage to insert boxes was determined by visual inspection. Acceptance of treated artificial cavities for nesting or roosting by P. borealis was initially determined by visual inspection of the cavity trees and cavities. If evidence of cavity use was present, use was confirmed by morning and evening roost period observations.

Exclusion of Flying Squirrels.—G. volans frequently uses P. borealis nest and roost cavities and sometimes usurps them (Loeb, 1991; Montague et al., 1995; personal observation). A technique was employed in the Ouachita NF to attempt to deter G. volans from accessing serviceable cavities of P. borealis in 1991 (Montague et al., 1995). This double-strip (or two-strip) squirrel excluder device (SQED) consisted of two bands of aluminum flashing. One band was placed above and one band was placed below the cavity entrance. This SQED was subsequently modified in a variety of ways.

The version of SQEDs adopted in November 1993 utilized a single 0.95 m-wide strip of lightweight aluminum flashing (Fig. 3). The single strip of flashing was off-centered over the cavity entrance; a slightly wider portion of the flashing extended above the cavity entrance than extended below it. The strip was then stapled to the tree. A smooth-edged, triangular-shaped hole with a 10 - 15-cm base was cut around the cavity entrance so that some flashing material remained connected below the cavity entrance. This material was then cut away so that

Fig. 1. A steel entrance tunnel protector used with artificial insert cavity nest and roost boxes for Red-cockaded Woodpeckers (P. borealis).

Fig. 2. A steel tunnel protector installed in the entrance tunnel of an artificial insert cavity nest/roost box for Red-cockaded Woodpeckers (P. borealis). The flange of the tunnel protector secures the upper edge of the hardware cloth insert box face-protector.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
only a 4 - 5-cm sap deflector flap with rounded edges remained below the cavity entrance. The hole in the SQED strip around the cavity entrance needed to be only large enough to expose the entrance tunnel and provide 2.5 - 5-cm of bare wood as a foothold for *P. borealis*. As was the case with the double-strip version, single-strip SQEDs were unpainted. This design also employed sap deflectors with gap flaps similar to those described by Montague et al. (1995).

![Image](image-url)

**Fig. 3.** Single-strip Squirrel Excluder Device (SQED) with sap-deflector on the Ouachita National Forest, Scott County, Arkansas. (Cluster 1257/20 - Tree #13).

After May 1991 it became a routine procedure to periodically inspect all cavities in cavity tree clusters of *P. borealis* for presence of *G. volans*. Those *G. volans* which did not escape from a cavity were removed using the technique described by Montague et al. (1995).

Effectiveness of SQEDs to deter access to treated cavities by *G. volans* was evaluated by periodically examining cavity chambers for evidence of *G. volans* occupation. Such evidence included nuts or nutshell fragments, nest materials, or presence of *G. volans*. Use of treated cavities for roosting by *P. borealis* was initially determined by visual inspection of the cavity trees and cavities. If evidence of cavity use was present, use was confirmed by morning and evening roost period monitoring.

**Results**

**Protection of Insert Boxes.**— Tunnel protectors were accepted by *P. borealis*. As of March 1994 seven insert boxes with this modification had been used or were being used in the Ouachita NF, and nine had been used or were being used in the Crossett Experimental Forest. On 22 September 1993 at the Arkansas Natural Heritage Commission's Pine City Natural Area, the author observed a subadult female *P. borealis* arrive at an insert box cavity fitted with a tunnel protector. The insert box had been installed 3-4 hrs earlier that day. She pecked at the soft wood filler and paint around the entrance of this new insert box for approximately ten minutes and then entered the cavity where she roosted that night.

From October 1992 to April 1993 a modified tunnel protector, which covered only the lower half of the entrance tunnel, was tried unsuccessfully. Structural damage to the exposed wood of the upper half of the entrance tunnel by potential cavity usurpers still occurred.

**Exclusion of Flying Squirrels.**—In 13 cases individual *P. borealis* chose cavities with unpainted double-strip (n = 12) or single-strip (n = 1) SQEDs for roosting. It appeared that as with the unpainted double-strip design described by Montague et al. (1995), the single-strip treated cavities were accepted for roosting by *P. borealis*. None of the five cavities (three natural cavities and two insert boxes) treated with single-strip SQEDs as of March 1994 appeared to have been occupied by *G. volans* at any time since their installation.

On 23 November 1993 single-strip SQEDs were installed on two natural cavities of *P. borealis* on the Poteau Ranger District of the Ouachita NF. These two cavities had evidence of recent *G. volans* use. One of the treated trees was located in a cavity tree cluster occupied by an unpaired, adult female *P. borealis*. The cavity tree cluster was comprised of two clean, suitable natural cavities and three clean and vacant insert box cavities. The natural cavity unoccupied by a *P. borealis* had a single-strip SQED attached to the hole of the tree. On 29 December 1993 the author observed a subadult male *P. borealis* occupy the SQED-treated natural cavity in this cavity tree cluster. The bird originated 2.4 km west of this treated roost cavity as part of an unsuccessful two-bird translocation, which occurred 17 November 1993. He and his apparent mate still occupied these roost cavities on 3 March 1994.
Cavity Protection Techniques for Red-cockaded Woodpeckers

Discussion

General.—Studies which describe possible mechanisms for population growth of *P. borealis* frequently refer to the importance of having adequate numbers of high-quality cavities for nesting and roosting (Copeyton et al., 1991; Walters, 1991). Hooper and Lennartz (1983) observed open and extraterritorial roosting behavior of *P. borealis* when shortages of suitable cavities occurred. Such shortages of cavities may result from interspecific competition for cavities or from enlargement of cavities by other woodpeckers (Jackson, 1978; Neal et al., 1992), which makes them uninhabitable for *P. borealis*.

Protection of Insert Boxes.—Numerous techniques have been developed to provide sufficient numbers of serviceable cavities to stabilize and increase *P. borealis* populations. Artificial cavities are constructed using cavity drilling (Copeyton, 1990; Taylor and Hooper, 1991), or insert box installation (Allen, 1991) techniques. Natural cavities are protected from enlargement or, once enlarged, can be restored to serviceable condition using cavity restrictors (Carter et al., 1989; Raulston, 1992). Cavity restrictors are also used to protect insert box entrances from enlargement.

Following the installation of 145 insert boxes in the study area, damage to insert boxes fitted with cavity restrictors occurred. This damage by potential cavity usurpers was in the form of enlargement of entrance tunnel floors and sidewalls. Continued erosion of the entrance tunnel can allow rainwater or sap to flow into the cavity chamber. This could render such cavities dangerous for *P. borealis* to use or make them uninhabitable. The steel tunnel protector (Fig. 1) was designed and field-tested to prevent this structural damage from occurring.

Exclusion of Flying Squirrels.—The problems of cavity usurpation or damage to natural or artificial cavities intended for use by *P. borealis* can be virtually eliminated by using a variety of techniques including combinations of cavity restrictors and tunnel protectors. However, one species for which these techniques are not effective is *G. volans*. Cavity usurpation or use by *G. volans* has been noted in numerous studies (Dennis, 1971a; Baker, 1983; Harlow and Lennartz, 1983; Table 2 in Neal et al., 1992; Loeb, 1993). Habitat occupancy (Muil, 1968, 1974), den selection (Bendel and Gates, 1987), and population densities (Sawyer and Rose, 1985) of *G. volans* are all dependent upon availability of numerous cavities. This makes cavity tree clusters of *P. borealis* potentially ideal environments for propagating large numbers of *G. volans*.

While some studies have revealed insignificant amounts of animal matter in the diets of *G. volans* (Harlow and Doyle, 1990), other studies have implicated *G. volans* as an occasional predator of birds eggs and nestlings (Stabb et al., 1989). Potential predatory behav-ior of *G. volans*, its possible disruption of *P. borealis* nesting activities (Harlow and Lennartz, 1983; personal observation), and its apparent preference for high quality *P. borealis* cavities with small entrances (Loeb, 1993; personal observation) increases the probability that these squirrels may adversely impact populations of *P. borealis*. Rudolph et al., (1990) dismissed the importance of cavity competition between *G. volans* and *P. borealis* from March to May 1986 in their Texas study. However, they did suggest the possibility of significant cavity competition at other times, especially during the immediate post-fledging period when cavities are in short supply.

During the *P. borealis* breeding season of 1991, attempts began in the Ouachita NF to deter *G. volans* from accessing serviceable cavities of *P. borealis* (Montague et al., 1995). *G. volans* was frequently able to evade the double-strip SQEDs used in that study. Even with sap deflector flaps to prevent formation of sap "bridges", and removal of some offending individual *G. volans*, squirrels still reoccupied some of the treated cavities. Some of this difference in effectiveness between single and double-strip SQEDs may be attributed to the lack of sap deflectors in earlier double-strip SQED designs and to the fact that *G. volans* were not routinely removed from cavity tree clusters until after May 1991.

The ability to circumvent the double-strip SQED design is in keeping with Muil's (1968) description of the ability of *G. volans* to glide to and from isolated trees and use specific, well established travel and escape glide paths. Loeb (1993) determined that around cavity trees, wider tree spacing by clearing midstory was not sufficient to keep flying squirrels from using *P. borealis* cavities. These behavioral characteristics of *G. volans* and the apparent inability of the original double-strip SQED design to deter *G. volans* occupation of cavities prompted development of the single-strip SQED.

The preliminary results of this field test of the single-strip SQED design have management implications which go beyond their potential to exclude *G. volans*. The 0.95-m wide SQED version may provide additional protection from predation by black rat snakes (*Elaphe obsoleta obsoleta*). Single-strip SQEDs are scaled-down versions of devices tested by Neal et al. (1993) and Withgott et al. (1995), which are used to deter climbing of cavity trees by rat snakes.

The SQED technique may also serve to provide some visual stimulation of *P. borealis*. In 13 cases cavities with unpainted double-strip or single-strip SQEDs were selected for roosting when other untreated cavities were also available, suggesting there may be some visual attraction involved. If so, SQEDs could serve a dual purpose by deterring use of cavities by *G. volans* and by assisting dispersing *P. borealis* in locating vacant cavity tree clusters with serviceable cavities. The concept of visual attraction...
relates to the original debate about the functions of cavity tree resin flows and the resulting candlestick appearance of fully developed cavity trees. These ascribed functions included protection from snakes and other animals (Ligon, 1970; Dennis, 1971b). Ligon (1970) and Lay and Russell (1970) suggested that resin flows might provide visual cues to \textit{P. borealis}. This needs to be tested by deploying SQEDs in recruitment stand clusters of artificial cavities.

Conner and Rudolph (1989) suggested that the presence of hardwood midstories in and around \textit{P. borealis} cavity tree clusters might increase competition for cavities with \textit{G. volans}. Habitat managers throughout the range of \textit{P. borealis} are striving to create open forest habitat: a condition with little midstory which favors this endangered woodpecker. However, it will be a slow process to reverse the effects of the decades of fire suppression, which has allowed these dense midstories to develop on extensive acreages of pine forests in the southeastern United States. In the interim period of habitat restoration or renewal, more intensive cavity protection techniques are necessary to prevent extirpation of small, isolated populations of \textit{P. borealis}.

**ACKNOWLEDGMENTS.**—I thank Keith Piles for his assistance in translating the concepts of the techniques described here into on-the-ground realities. Michael Farmer’s attention to detail in preparing the figures is greatly appreciated. I also thank George Bunkenhofer, Joe Neal, Jean Montague, and William Shepherd for their helpful comments about various drafts of the manuscript.

**Literature Cited**


Proceedings Arkansas Academy of Science, Vol. 49, 1995


Using Geant to Model Calorimeter Response for Electromagnetic Cascades from Nucleus-Nucleus Interactions in a Cosmic Ray Detector

Kazuhiro Murai, Carlos A. Sánchez and Donald C. Wold
Department of Physics and Astronomy
University of Arkansas at Little Rock
2801 S. University Avenue
Little Rock, AR 72204

Abstract

A scintillating optical fiber calorimeter (SOFCAL) is being developed by NASA/Space Flight Center for use in balloon-borne experiments to study the spectrum of high-energy cosmic rays and gamma rays. SOFCAL will not saturate for long exposures and the calorimeter will be useful in emulsion chambers to study primary cosmic-ray nuclei with energies from 100 GeV to 1,000 TeV. The event generator FRITIOF was used to model the collision of a cosmic-ray projectile with a target nucleus in an emulsion chamber. The measurements of charged particles from the interaction in the emulsions are related to the energy of the primary cosmic ray nucleus-nucleus interaction, computer simulations of electromagnetic cascades allow computation of the energy $\Sigma E_{\gamma}$ deposited in different regions of the calorimeter. The Monte Carlo program GEANT was used to model SOFCAL response to incident gamma rays and to compute the measure of energy deposition $\Sigma E_{\gamma}$ in different layers of the calorimeter within the emulsion chamber. The partial coefficient of inelasticity $k_{\gamma}$ defined by $\Sigma E_{\gamma} = k_{\gamma} E_0$ was computed for different energies $E_0$ of primary cosmic rays. The $k_{\gamma}$ distributions were computed and compared with existing calorimeter data. Funding was provided by the NASA/University Joint Venture (JOVE) Program.

Introduction

Cosmic rays are now known to span the energy range from $10^9$ to beyond $10^{20}$ eV (Asakimori et al., 1993a; Asakimori et al., 1993b; Swordy, 1994; Teshima, 1994). They are, predominantly, the nuclei of atoms from hydrogen to iron. Above $10^{14}$ eV the particles are so rare that their detection relies mainly on observations of the giant cascades or extensive air showers created in the atmosphere which may be observed with arrays of particle and optical detectors at ground level. The flux of particles decreases inversely as the square of the energy rises, up to $10^{19}$ eV, and continues to decrease above $10^{19}$ eV as only about one particle per km$^2$ per year is collected (Watson, 1994). The origin of these particles is unknown and how they are accelerated to such high energies is a major astrophysical puzzle (Bird et al., 1993).

Even though the flux of the primary cosmic rays is so low that small detectors in spacecraft or balloons can intercept only a small number for study, emulsion chambers are an important tool for the direct measurement of the composition and spectra of primary cosmic rays above $10^{12}$ eV/nucleus (Parnell et al., 1989). The emulsion chamber method (Burnett et al., 1986) is especially useful for ultrahigh energy cosmic ray observations because (1) the efficiency for detecting interactions approaches 100% above about 10 TeV and (2) the energy resolution is approximately constant with energy for a given incident species. Most other energy measuring techniques are impractical for balloon observations of primary cosmic rays at such high energies.

Balloon-borne emulsion chambers employing calorimeters (Fig. 1) have been used for direct measurements of cosmic-ray composition (protons through Fe) between $10^{12}$ and $10^{15}$ eV (Kaplon et al., 1952; Minakawa et al., 1958; Niu et al., 1971; Burnett et al., 1986; Takahashi et al., 1986; Burnett et al., 1987; Parnell et al., 1989; Burnett et al., 1990; Asakimori et al., 1993a; Asakimori et al., 1993b). The typical emulsion chamber (Burnett et al., 1986) is composed of four parts: (1) a charge-determination module, (2) a target module with ~0.2 vertical interaction mean free paths for protons, (3) a spacer module, and (4) an emulsion calorimeter module with about fourteen vertical radiation lengths.

The "target section" includes many layers of nuclear emulsion plates to measure the charge of the incident particle and the emission angles of the produced charged particles with high accuracy (0.01 mrad). The "calorimeter section" includes layers of nuclear emulsion and X-ray film among lead plates to measure the electron distributions from the electromagnetic cascades initiated by gamma rays from $\pi^0$ decay. The calorimeter is used to

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Using Geant to Model Calorimeter Response for Electromagnetic Cascades from Nucleus-Nucleus Interactions in a Cosmic Ray Detector

measure the spectrum of energy deposition $\Sigma E_y$ from which the primary energy $E_0$ spectrum is derived (Burnett et al., 1986). The SOFCAL simulations (Yang et al., 1994) described here are for a scintillation optical fiber counterpart to the calorimeter section in the emulsion chamber.

![Typical Emulsion Chamber](image)

Fig. 1. Block diagram of an emulsion chamber (Parnell et al., 1989).

Methods

That part of the primary energy going into gammarays $\Sigma E_y$ is the parameter most easily related to the primary cosmic ray spectrum in emulsion chamber experiments. The photons originating from a primary interaction will develop individual electromagnetic cascades in the calorimeter. The ability to measure the energies of these electron-photon cascades is one of the most important functions of the calorimeter. In the initial simulations, a calorimeter module with ten vertical radiation lengths of Pb was used. In one geometrical configuration each subsection of the calorimeter consisted of a 4-mm lead block, 100 fibers (0.5-mm thick) in the x-direction and 100 fibers (0.5-mm thick) in the y-direction. This lead and optical fiber combination was repeated fourteen times.

![The Shower Caused by a Photon with E=1 GeV](image)

Fig. 2. The trajectories of a photon event with 1 GeV energy in the calorimeter SOFCAL. The cascade was modeled with GEANT and PAW for the graphic simulation.

![Energy Deposition Transition Curve](image)

Fig. 3. The corresponding energy deposition and transition curve for 1 GeV photons incident on the calorimeter SOFCAL.

The trajectories or cascade of electrons and photons produced by a gamma ray with an incident energy of 1 GeV is illustrated in Fig. 2. For these simulations with
GEANT, the incident gamma ray lies along the z-axis which is normal to the plane of each lead plate and layer of fibers. The corresponding energy deposited in each x-layer of fibers, as a function of distance through the calorimeter, is shown in Fig. 3. GEANT has the advantage that it is relatively easy to modify the geometry of the SOFCAL detector and to observe changes in the location and size of the electromagnetic cascade within the calorimeter.

For modeling primary cosmic ray interactions, calculations must be performed with particle event generators to predict distributions in the electromagnetic component $\Sigma E_\gamma$. The event generator FRITIOF and LUCIAE (Sjöstrand and Begtsson, 1987; Pi, 1992; Sa and Tai, 1994) were used to model nucleus-nucleus interactions in an emulsion chamber and the subsequent emission of particles. The Monte Carlo program GEANT (CERN 1992a) and PAW (CERN 1992b) are used to determine the associated optimum "window" settings for the calorimeter. GEANT computes the energy deposited in each layer of the calorimeter by those gamma rays which enter the calorimeter (Yang et al., 1994). The primary cosmic ray interactions were modeled with FRITIOF and LUCIAE on a DEC 3000 AXP processor. The photon and electron events in the Scintillating Optical Fiber Calorimeter (SOFCAL) were modeled with GEANT version 3.21 on DEC 5000 workstations.

The event generator program included LUCIAE 2.0 for simulating gluelon emission in the FIRECRACKER model and the rescattering of produced particles in the nuclear environment. The program, written in FORTRAN 77, was used with FRITIOF7.02R, JETSET7.3, PYTHIA5.5, and ARIADNE4.02R. The task of PYTHIA is to describe the partonic processes taking place in hadronic collisions. How these partons are transformed into the experimentally measurable particles, i.e., the process of fragmentation, is handled by JETSET. PYTHIA can be combined with any well-defined fragmentation scheme. Although independent fragmentation is included as an option, the fragmentation scheme of JETSET is the Lund string model. ARIADNE is a Monte Carlo program for QCD cascades in the color dipole formulation. Gluon splitting into quark-antiquark pairs and photon emission in the dipole cascade are allowed.

The measured spectrum of $\Sigma E_\gamma$ is a convolution of the primary cosmic ray spectrum with energy response function of the detector. The latter depends on the distribution of partial inelasticity $k_\gamma$. There is a unique relation or simple scale shift between the $\Sigma E_\gamma$ spectrum and the corresponding primary spectrum (Parnell et al., 1989), as long as the spectral index and the characteristics of the interactions do not change substantially over the observed energy range. When the differential primary ($E_0$) spectrum of a cosmic ray species is given by the simple power law relation

$$g(E_0)dE_0 = I_0E_0^{-\beta}dE_0,$$

the differential spectrum ($E_m$) measured by an emulsion chamber is given by

$$G(E_m)dE_m = F(\beta)I_0E_m^{-\beta}dE_m.$$

Therefore, the measured spectrum has the same slope as the primary spectrum but the normalization has changed by the factor (Burnett et al., 1986)

$$F(\beta) = \int_0^1 h^\beta f(k)dk.$$

This result holds for any $f(k)$ as long as that distribution is independent of energy. Furthermore, it can be shown that the conversion factor

$$C_\gamma \gamma = [F(\beta)]^{1/\beta}$$

represents the energy scale shift required to go from the $E_0$ spectrum to the $E_m = \Sigma E_\gamma$ spectrum. Therefore, the primary $E_0$ spectrum can be found by shifting the $E_m$ spectrum up in energy by the factor, $[C_\gamma \gamma]^{1/4}$, the reciprocal of $C_\gamma \gamma$.

Results

Typical emulsion chambers contain plastic (CHO) and emulsion targets (Burnett et al., 1987; Parnell et al., 1989). The composition of CHO was 33% C, 53% H, 14% O. The composition of emulsion was 17.5% C, 40.7% H, 4.0% N, 12.0% O, 0.17% S, 12.7% Br, 12.8% Ag, and 0.07% I. The main absorber material in a typical calorimeter is lead, which is used to improve energy resolution. Therefore, a light target nucleus (C) and a heavier target nucleus (Ag) were used in modeling the interaction of cosmic ray particles within the emulsion chamber. For a proton, nitrogen, and iron nucleus incident on a fixed target carbon nucleus, the distribution of gamma rays produced by an incoming projectile with an incident energy of 1000 GeV/nucleon is shown in Fig. 4. For these primary cosmic rays incident on a fixed target silver nucleus, the distribution of gamma rays produced by an incoming projectile with an incident energy of 1000 GeV/nucleon is shown in Fig. 5. Each distribution was based on 2000 events.

In a calorimeter the maximum electron number in an electromagnetic cascade can be related to the total energy of the electromagnetic component $\Sigma E_\gamma$. This quantity is directly proportional to the energy $E_0$ of the original cosmic ray: $\Sigma E_\gamma = k_\gamma E_0$. The factor $k_\gamma$ is the partial coefficient.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
of inelasticity, which represents that fraction of the energy of the primary cosmic ray used to create the $\gamma$-rays. It is a function of the mass number of both the primary nucleus and the target nucleus (Burnett et al., 1986). Once the target nucleus and the primary cosmic ray have been identified in an emulsion layer of the apparatus, the distribution of $k_\gamma$ becomes a known quantity. This distribution and the energy of the electromagnetic cascade are used to estimate the energy of the primary cosmic ray (Parnell et al., 1989).

![Graph](image)

Fig. 4. The energy distribution of gamma rays due to a proton, nitrogen or iron nucleus incident on a fixed target carbon nucleus. Only gamma rays within a polar angle of 30° from the axis of the incident projectile were counted.

Using 2000 events, representative distributions for $f(k_\gamma)$ are shown in Fig. 6 for a cosmic ray proton, nitrogen, or an iron nucleus colliding with a fixed target lead nucleus ($A = 207$) in an emulsion chamber. Each projectile has an energy of 200 GeV/nucleon. By using FRITIOF and LUCIAE to generate gamma rays from the primary interaction, partial inelasticity distributions were calculated from those gamma rays within a polar angle of 30° from the z-axis. The energy conversion factors $C_k$, for obtaining the primary $E_0$ spectrum from $\Sigma E_\gamma$ were 0.256 and 0.108 for proton and iron, respectively, where $\beta = 1.7$ is the assumed primary particle spectral index. An energy of 200 GeV/nucleon was used for the primary energy of the proton and iron nucleus that interacts with a fixed target lead nucleus. These $C_k$ should be compared with those calculated with the Multi-Chain Model (Asakimori et al., 1993b), where all successive collisions are included. For events that interact within the calorimeter section of the chamber, they found that the energy conversion factors $C_k$ are typically 0.273 and 0.108 for proton and iron, respectively, (Parnell et al., 1989).

![Graph](image)

Fig. 5. The energy distribution of gamma rays due to a proton, nitrogen or iron nucleus incident on a fixed target silver nucleus. Only gamma rays within a polar angle of 30° from the axis of the incident projectile were counted.

**Discussion**

Cosmic rays span a very large energy range from $10^9$ to beyond $10^{20}$ eV. A realistic modeling of particle detectors should include those energies which are likely to be encountered and measured by the cosmic ray or gamma ray detector. The primary cosmic rays were modeled for nucleus-nucleus interactions in an emulsion chamber. These simulations were done with FRITIOF and LUCIAE up to 1000 GeV/nucleon and appear to agree well with existing data. For detailed modeling of electron-photon cascades in the calorimeter, GEANT and PAW were used to determine energy deposition and transition curves for the electromagnetic energy incident on the calorimeter. By using the actual dimensions of the SOFCAL detector, which will be tested in a balloon flight this year, the modeling of SOFCAL will be useful for analyzing cosmic ray

Proceedings Arkansas Academy of Science, Vol. 49, 1995
events. At the same time, modeling the primary cosmic ray interaction in the emulsion chamber should be done at energies higher than 1000 GeV/nucleon with FRITIOF and LUCIAE to determine primary energy and composition of the incident cosmic rays.

Distributions of \( f(k_y) \) versus \( k_y \)

Fig. 6. Some distributions of \( k_y \) for the partial inelasticity into gamma rays \( f(k_y) \). These are for a primary proton, nitrogen, and iron nucleus which interact with a fixed target nucleus of lead. The assumed primary particle spectral index was \( \beta = 1.7 \). The electromagnetic component was calculated with FRITIOF and LUCIAE.

ACKNOWLEDGMENTS.—The authors acknowledge the help of colleagues at the NASA George C. Marshall Space Flight Center, Huntsville, Alabama and the University of Arkansas at Little Rock. Dr. Thomas A. Parnell, Dr. Geoffrey N. Pendleton, and Ms. F. Ellen Roberts generously gave the authors valuable support. Mr. Lon Jones III has served as systems manager for the DEC 3000 AXP and the DEC 5000 workstations. This work was supported in part by NASA and funding for the project was provided by the NASA/University Joint Venture (JOVE) Program.

Literature Cited


Using Geant to Model Calorimeter Response for Electromagnetic Cascades from Nucleus-Nucleus Interactions in a Cosmic Ray Detector

CERN Data Division. CERN Program Library Office, CERN-CN, CH-1211 Geneva 23, Switzerland.

CERN. 1992B. PAW Physics Analysis Workstation. CERN Program Library Long Write-up Q121. CERN Geneva, Switzerland.


Additions to the List of Schizocosa (Family Lycosidae) for Arkansas

Risa Parker and Peggy Rae Dorris
Department of Biology
Henderson State University
Arkadelphia, AR 71999-0001

Abstract

Schizocosa rovneri and Schizocosa stridulans, collected by the pitfall trap method in Drew and Ashley Counties, are reported as new species for the Arkansas state list. Palp variation and leg morphology are the main distinguishing characteristics between these species. Two previously defined species of Schizocosa are also discussed for clarification.

Introduction

Two new species of Schizocosa from Ashley and Drew Counties are reported for Arkansas, Schizocosa stridulans and Schizocosa rovneri. Two previously defined species of Schizocosa, S. crassipes and S. ocreata are also redefined because of new information which has been presented by Dondale and Redner (1978). Previous identification of these four species has been difficult resulting in a state of confusion and dispute for taxonomist until leg morphology and micrographic studies of pedipalps elucidated the morphological differences.

Schizocosa stridulans is identified by dark brown to black pigmentation present on the tibia, patella, and distal 1/3 to 1/2 of femur I (Stratton, 1991). S. rovneri is recognized by the lack of this pigmentation and by the lack of a fine, thick brush of black hairs present on tibia I and the proximal half of metatarsus I which is present on S. crassipes, as shown in Fig. 1. S. ocreata, which is very similar to S. crassipes, is also determined by a fine, thick bristle of black hairs present on tibia I and the proximal half of metatarsus I of the male.

---

Schizocosa crassipes and S. ocreata may be differentiated by the prominence along the retrolateral side of the

---

Fig. 2. Ventral aspect of left palp of Schizocosa species.
(1) S. stridulans
(2) S. rovneri
(3) S. ocreata
(4) S. crassipes

Fig. 1. Leg morphology of Schizocosa Spp.
paleal process of the pedipalps (Dondale and Redner, 1978). The photomicrographs in Fig. 2 (Stratton, 1991) show minute details of palpal processes. Dorris (1985) listed *S. crassipes* and *S. ocreata* as two distinct species in her Arkansas checklist but controversy over *S. crassipes* and *S. ocreata* has existed for many years as "lumpers" have put the two species together and "splitters" have separated them. Kaston (1948, 1978) listed only *S. crassipes* and Comstock (1965) listed only *S. ocreata*. It was not until Dondale and Redner (1978) published their revision of the *Schizocosa* genus that the controversy was ended. *S. ocreata* has a rugose or wrinkled prominence along the retrolateral side of the paleal process of the pedipalp as compared to *S. crassipes* which has a smooth prominence. While leg markings are the identifying characteristic for *S. stridulans* and *S. rovneri*, pedipalps are the key to identification of *S. crassipes* and *S. ocreata*.

Materials and Methods

Pitfall traps with rain covers are constructed in the following way: a 16 oz. plastic drinking cup is placed in a one quart metal oil can opened at both ends and inserted into a hole in the ground. The cup contains 5 fl. oz. of a one to one mixture of antifreeze (ethylene glycol) and water. The cup can be easily removed and its contents placed in baby food jars for transportation to the laboratory. A one ft. square plywood rain lid, held one in. over the cup with rocks or wood blocks, reduces the amount of rain and leaf litter entering the trap. Traps are emptied weekly, sorted by forest treatment, and placed in 80% ethyl alcohol. Weekly collections from all traps within each treatment area are pooled for storage. Specimens are later identified with a stereoscopic microscope, placed in screw cap vials with 70% ethyl alcohol and placed in spider storage cabinets.

Results and Discussion

Spiders of the *Schizocosa* genus can be distinguished from each other by the following criteria: courtship behavior, geographic distribution and habitat, leg morphology and pedipalps. For sympatric species, courtship behavior is an isolating mechanism (Stratton, 1991). The bounce, which is the rapid and forceful slamming of the male's body to the substrate during mating, differs from species to species (Stratton and Miller, 1994). Males of certain species will not court females of a different species, nor will females mate with males of differing species (Stratton, 1991). The courtship behavior can be distinguished from species to species by the manner in which the male moves his legs and body during mating. It is those movements which the female recognizes as compatible with her; thus, this is the way in which courtship behavior serves as a key to identification and as an isolating mechanism between species (Uetz and Denterlein, 1979).

The range of *S. stridulans* overlaps that of *S. rovneri* and *S. ocreata*. The habitat of *S. stridulans* is upland leaf litter in oak or hickory forests (Stratton, 1991). Previous collections of *S. stridulans* have been made from southern Ohio, Illinois, Kentucky, Tennessee, Missouri, Alabama and Mississippi (Stratton, 1991). This paper also verifies its presence and that of *S. rovneri* in Ashley and Drew Counties (Fig. 3).

Schizocosa rovneri is primarily found in floodplains and bottomlands and co-occurred with *S. ocreata*. The spiders are often found in or on flattened mud-packed leaf litter or in and on piles of drift that occur in floodprone ecosystems (Stratton, 1991). However, further studies done by Stratton and Miller (1994) indicate that *S. rovneri* is not the dominant medium-sized wolf spider in the floodplains of the south but is found in moist deciduous woods.

Schizocosa ocreata is often found in moist areas in association with *S. crassipes* and *S. floridans*. *S. ocreata* has been collected in floodplains and wet areas, along drier uplands, and along bottomlands. It appears that it is not selective and that the habitat preference should depend on geographic locality and on the presence or absence of competing species according to Stratton (1991). The distribution and locomotor activity is directly related to

Proceedings Arkansas Academy of Science, Vol. 49, 1995
moisture and the physical features of the habitat (Cady, 1984). Also, S. ocreata is more likely to be found in areas of full leaf litter and high soil moisture. Microhabitat selection appears to be important in courtship activities.

Although Schizocosa crassipes and S. ocreata have been identified as two distinct species, and although they co-exist in Arkansas, S. crassipes has been identified as the more southern species. Studies of behavior have primarily been done in more northern states where S. ocreata is more prevalent; consequently, the relationship between S. crassipes and other spiders of the Schizocosa genus is not as clearly known as the affinities of S. ocreata and requires further research. As a result, most information is put in terms of S. ocreata rather than S. crassipes when the "brush-legged" spider is mentioned.

Leg morphology was the identifying characteristic of Schizocosa stridulans and S. rovneri. Dark brown to black pigmentation on the tibia, patella and distal 1/2 to 1/3 of femur I is the identification pattern of S. stridulans. Pigmentation is lacking on leg I of S. rovneri which also lacks the brush of leg hairs present on S. ocreata and S. crassipes (Stratton, 1991). Figure 1 shows pigmentation and brush differentiation. The main difference between S. crassipes and S. ocreata must be discerned by the pedipalps. The former has a smooth prominence along the retrolateral side of the paleal process, while the latter has a rugose or wrinkled prominence.

Conclusions

Leg morphology and palp variation are the major criteria by which S. rovneri and S. stridulans, two new species for Arkansas, are being identified. The habitats of S. rovneri and S. crassipes are now known to overlap. Stratton and Miller (1994) reported a range extension of S. rovneri to high moisture deciduous forests which overlaps the range of S. stridulans. Although habitat is not a concrete way to identify arachnids, it is an indicator and can be used to form generalizations. This present research has shown that S. stridulans and S. rovneri co-exist in Arkansas and with clarification of pedipalp structure of S. crassipes and S. ocreata, future conclusions about speciation should be more easily made.

Acknowledgments.—Appreciation is expressed to Henderson State University for research funds which made this paper possible and to Holly Hill and Matt Largen for technical and friendly support.

Literature Cited


Proceedings Arkansas Academy of Science, Vol. 49, 1995
Checklist and Distribution of Arkansas Pteridophytes

James H. Peck
Department of Biology
University of Arkansas at Little Rock
Little Rock, AR 72004

W. Carl Taylor
Department of Botany
Milwaukee Public Museum
Milwaukee, WI 53233

Abstract

Over the past 14 years, an effort was made to summarize and improve our knowledge of the Arkansas pteridophyte flora beyond that developed by Taylor and Demaree (1979). They presented a flora of 68 species plus 2 varieties plus 4 hybrids, for a total of 74 taxa vouchered with 1335 county-level occurrence records. Changes in accepted nomenclature, field work, and herbaria searches have added as new to the flora 10 species plus 1 variety plus 7 hybrids, supported with 74 county-level occurrence records. Another 815 county-level occurrence records were added to the known flora. The Arkansas pteridophyte flora now consists of 78 species plus 3 varieties plus 11 hybrids, supported with 2224 county-level occurrence records. A checklist, 92 distribution maps, a history of Arkansas pteridophyte floristics, corrective nomenclatural notes, and a phylogeny based on a recent national treatment on pteridophytes are provided.

Introduction

The ferns and fern allies (also known as vascular cryptogams or pteridophytes) of Arkansas have warrant ed a continuum of study by researchers who investigated the biodiversity and natural heritage of Arkansas (Peck and Peck, 1988a). The first account of the ferns and fern allies in Arkansas was that of Nuttall (1821, 1835) who reported 23 species from the Arkansas Territory. Lesquereux (1860) recorded 35 species as part of a geological survey. Harvey (1881) compiled an annotated list of 40 ferns. Branner and Coville (1891) reported 45 ferns and fern allies. Buchholz (1924) revised previous lists to arrive at 46 species and 3 varieties. Then Palmer (1924, 1932) reported two species new to the state. A summary report by Buchholz and Palmer (1926) listed 51 pteridophytes. Scully (1937, 1939) reported additional taxa as a result of survey in and around Hot Springs National Park. Dwight Moore, whose contributions on Arkansas ferns spanned three decades, added a spikemoss (Moore, 1940b), published a state pteridophyte flora (Moore, 1940a) of 67 ferns and fern allies, and reported (Moore, 1941) on five fern communities that typified the Interior Highlands. Delzie Demaree, whose contributions on Arkansas ferns spanned five decades, reported on ferns that were rare or new to Arkansas (Demaree, 1943a) and published a list (Demaree, 1943b) of 70 pteridophytes as part of a state vascular flora.

Pteridophytes new to the state or quite rare in Arkansas continued to be reported by Chandler (1941), Moore (1947, 1950, 1951, 1957, 1958), Moore and Hartsoe (1955), Clark (1962), Wagner (1962), Bowers and Redfearn (1967), Farrar and Redfearn (1968), and Tucker (1971). As part of Ph.D dissertation research at the University of Southern Illinois and aided by Dr. Dwight Moore and Dr. Delsie Demaree, Taylor (1976) summarized the known fern flora of Arkansas through inspection and annotation of herbarium specimens, field collection to relocate historic or rare populations (Taylor, 1982; Wagner and Taylor, 1976), general collection to document undercollected plants or regions, and special study of variation of quillworts (Taylor et al., 1975) and spleenworts (Taylor et al., 1976). Taylor's dissertation provided a summary for 70 pteridophytes treated in the first modern work on the flora and distribution of the Arkansas vascular flora (Smith, 1978). Prior to its publication of Taylor's results (Taylor and Demaree, 1979), additions were discovered and reported by Buck (1977), Thomas (1978), and Taylor and Johnson (1979). Subsequently, another fern species new to Arkansas was reported by Werth and Taylor (1980). Moore (1982) prepared a manual for her students to aid them in learning the pteridophyte flora of Arkansas. Summarizing this activity, Taylor (1984) published through the Milwaukee Museum a complete manual to 72 Pteridophytes in 31 genera. The manual's line drawings by Paul W. Nelson caught the attention of many plant enthusiasts in Arkansas and focused additional attention on the pteridophyte flora of Arkansas.

The book-length manual by Taylor (1984), Arkansas Ferns and Fern Allies, graphically portrayed the diagnostic characters and extent of county-level distribution data of Arkansas pteridophytes. This manual facilitated efforts by many to contribute to the Arkansas fern flora, including academic botanists and those hired by the Department of Natural Heritage, the Arkansas Nature Conservancy, and the Ouachita National Forest. Two wood ferns and seven clubmosses were added to the state flora (Orzell and Peck, 1985; Peck and Peck, 1988c; Peck et al., 1985a; Peck et al., 1985b; Peck et al., 1987). Revisions in the systemat-
ics of three genera resulted in the addition of species and varieties that are new to Arkansas or provided a new correct name: Cystopteris (Haufler and Windham, 1991; Hauffer et al., 1985; Hauffer et al., 1990), Polypodium (Hauffer and Windham, 1991), and Woodsia (Windham, 1993). Johnson (1986; 1988) reduced into synonymy the two pepperworts reported from Arkansas. Additionally, many reports on the status of rare plants continued to update our knowledge of Arkansas pteridophytes (Bates and Pittman, 1993; Bray and Marsh, 1993; Culwell, 1994; Farrar, 1985, 1990, 1992; Orzell and Bridges, 1987; Peck, 1985a, 1985b, 1986a, 1986b; Peck and Peck, 1987; Peck and Peck, 1988b; Sundell, 1986). Summary documents were developed to collate and compile these changes (Peck and Peck, 1986; Peck et al., 1987a, 1987b). Smith (1988) incorporated these changes to his checklist and dot maps of the state vascular flora and prepared keys (Smith, 1994) to that flora, including pteridophytes. Recently, a quillwort was reported as new to Arkansas (Brown and Thomas, 1992), and whisk fern was discovered in Arkansas (Bray et al., 1994; Peck et al., 1995).

With the publication in 1993 of Volume 2 of the multi-volunteed Flora of North America North of Mexico, much of which treats pteridophytes, a common and modern basis is now available against which to assess the Arkansas pteridophyte flora. Many changes in nomenclature known to pteridologists were placed together for the first time in one place for pteridologists and non-pteridologists. Changes in generic nomenclature significantly affected six genera found in Arkansas: Lycopodium, Athyrium, Lorinseria, Notholeana, Polypodium and Thelypteris. Other changes affected varieties or forms in Asplenium, Marsilea, Thelypteris and Woodsia. The authors of this paper postponed writing a new summary of Arkansas pteridophytes until this work was available. As contributing authors, we felt it was imperative that any future state treatment concur or refer to the nomenclature of this work as it provides a national "monograph". We include these changes and want to facilitate their integration into the floristic literature of Arkansas. The compiled list by Kartesz (1994) was consulted, but found to unevenly reflect pteridological knowledge. Recent symposiums on the implications of DNA sequences on family classifications of pteridophytes suggest that a final classification has yet to be written.

The most recent treatment of Arkansas ferns (Taylor, 1984) is no longer available. An appreciable amount of collecting since then has added many species and augmented the county-level occurrence records that voucher that flora. With the recent publication of a national pteridophyte treatment, it is possible to write a work with a degree of phylogenetic/nomenclatural stability. Until a book-length version can be written and published, an interim flora is needed to summarize what is currently known and to stimulate a final flurry of field work. This report is provided to summarize the literature and to meet those ends.

Materials and Methods

Voucher specimens were searched in 1994-1995 at research and most teaching herbaria within the state and in adjacent states. Herbaria searched by Taylor (1984) were re-examined. Herbaria code (boldface) and location: APCR, Arkansas Tech University, Russelville, AR; E, Field Museum of Natural History, Chicago, IL; HXC, Hendrix College, Conway, AR; HSU, Henderson State University, Arkadelphia, AR; LRU, University of Arkansas at Little Rock, Little Rock, AR; MEM, University of Memphis, Memphis, TN; MIL, Milwaukee Public Museum, Milwaukee, WI; MO, Missouri Botanical Garden, St. Louis, MO; NCU, University of North Carolina, Chapel Hill, NC; NY, New York Botanical Garden, Bronx, NY; PH, Academy of Natural Sciences, Philadelphia, PA; SIU, Southern Illinois University, Carbondale, IL; SMS, Southwest Missouri State University, Springfield, MO; SMU, Southern Methodist University, Dallas, TX; STAR, Arkansas State University, Jonesboro Station, AR; TENN, University of Tennessee, Knoxville, TN; UAM, University of Arkansas at Monticello, Monticello, AR; UARK, University of Arkansas, Fayetteville, AR; UCA, University of Central Arkansas, Conway, AR; and US, Smithsonian Institution, Washington, DC. A summary data-base of at least one voucher was recorded for each county-level occurrence record.

Inspection of specimens and literature on fern floras from neighboring states was used to direct field efforts in peripheral counties. The following states and sources were consulted: Illinois (Mohenbrock, 1986), Kentucky (Cranfill, 1980), Louisiana (Thieret, 1980; Thomas and Allen, 1993), Mississippi (Evans, 1978; Wofford and Evans, 1979), Missouri (Key, 1982), Tennessee (Evans, 1989), Texas (Correll, 1955; 1972; Correll and Johnson, 1970), and a regional treatment (Small, 1964).

Field work was conducted from 1994-1995 to supplement and complete an ongoing field study initiated by the senior authors in 1981. Travel and collection occurred in every county in Arkansas. During 1994-1995, the senior author traveled over 30,000 miles to inspect vouchers in 20 herbaria, to consult with pteridologists, and to visit field sites to make this flora as complete as possible.

A checklist was prepared to provide the correct name and synonymy. A county-level occurrence map to depict distribution was prepared to summarize minimal floristic information for each taxon.
Checklist and Distribution Maps

The Arkansas pteridophyte flora is presented as a checklist (Table 1) of 92 pteridophytes in 4 divisions, 18 families, and 38 genera, with 78 species, 3 varieties, and 11 hybrids. Distributional data are presented for each of the 92 taxa with a county-level distribution map (Maps 1-92), an increase of 18 over the 74 presented by Taylor and Demaree (1979). The 2224 county-level occurrence records presented here represents a 66% increase over the 1335 presented by Taylor and Demaree (1979).

The recent Flora of North America North of Mexico, Vol. 2: Pteridophytes (1993) provides an excellent, national-level treatment, but requires a few corrective comments with specific regard to Arkansas. The national work incorrectly attributes Asplenium ruta-muraria to Arkansas. The following pteridophytes occur in Arkansas but are not listed nor shown on their maps as present in Arkansas: Pilotium nudum, Pseudolycopodiella caroliniana, Osmunda claytoniana, and Asplenium Xebenoides. The relation of Azolla mexicana and Azolla caroliniana remains unclear in the national work. Arkansas has one species that extends its range northward to Minnesota; pteridologists recognize this plant as Azolla mexicana. This species differs in many aspects with plants of the Coastal Plain of the Southeastern United States that have been called Azolla caroliniana. This species does not occur in the Mid-south or upper Midwest. The range of latter species is over-stated in the national treatment.

Table 1. Annotated checklist of Arkansas ferns and fern allies, giving Division, Family, scientific binomial, common name, and synonymy. The phylogenetic sequence follows that of Flora of North America North of Mexico, vol. 2.

Division PSIOPHYTA
Family PSIOPHYTACEAE
Pilopodium nudum (L.) Beauv., Whisk Fern

Division Lycopodiophyta
Family Lycopodiaceae

| Botrychium lunariaeodes (Michx.) Sw., Winter Grapefern |
| Botrychium virginianum (L.) Sw., Rattlesnake Fern |
| Ophioglossum crotalophoroides Walt., Bulbous Adder’s-tongue Fern |
| Ophioglossum engelmanii Prantl, Limestone Adder’s-tongue Fern |
| Ophioglossum nudicaule L. f., Least Adder’s-tongue Fern |
| Ophioglossum petiolatum Hook., Stalked Adder’s-tongue Fern |
| Ophioglossum vulgatum L. var. pycnostichum Fern., Southern Adder’s-tongue Fern, [Ophioglossum pycnostichum (Fern.) Love & Loe] |

Family Osmundaceae
Osmunda cinnamomea L., Cinnamon Fern |
Osmunda claytoniana L., Interrupted Fern |
Osmunda regalis L. var. spectabilis (Willd.) A. Gray, American Royal Fern |

Family Lycodiaceae

| Lygodium japonicum (Thunb. ex Murray) Swartz, Japanese Climbing Fern |

Family Pteridaceae

| Adiantum capillus-veneris L., Southern Maidenhair Fern |
| Adiantum pedatum L., Northern Maidenhair Fern |
| Argyrochosma dealbata (Pursh) Windham, Powdery Cloakfern |
| [Notholea dealbata (Pursh) Kunze] |
| Cheilanthes alabamensis (Buckley) Kunze, Alabama Lipfern |
| Cheilanthes eatonii Baker in Hook. & Baker, Eaton’s Lipfern |
| Cheilanthes feei Moore, Slender Lipfern |
| Cheilanthes lanosa (Michx.) D. C. Eat., Hairy Lipfern |
| Cheilanthes tomentosa Link, Woolly Lipfern |
| Pellaea atropurpurea (L.) Link, Purple-stemmed Cliff Brake |
| Pellaea giabella Mott ex Kuhn subsp. giabella, Smooth Cliff Brake |
| Peris multifida Poir., Spider Brake |

Family Hymenophyllaceae

| Trichomanes boschianum Sturm ex Bosch, Appalachian Filmy Fern |

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Trichomanes petrosii A. Gray, Dwarf Bristle Fern
Family DENNSTAEDETIACEAE
Dennstaedtia punctilobula (Michx.) Moore, Hay-scented Cup Fern
Polypodium scoupinum D. C. Eat. subsp. appalachi anana (T.M.C. Taylor) Windham, Appalachian Mountain Cliff Fern [Polypodium scoupinum D. C. Eat. subsp. appalachi anana (T.M.C. Taylor)]
Family POLYPODIACEAE

Thelypteridaceae
Macrotelepsis torressiana (Gaudichaud-Beaupre) Ching, Mariana
Maiden Fern, [Thelypteris torressiana (Gaud.-Beau.). Alston]
Phlebodium angustum (Michx.) Fee, Southern Beech Fern
Thelepteris kunthii (Desv.) Morton, Southern Shield Fern. [Thelepteris normalis (Christ.) Mosley]
Thelepteris nobilensis (L.) Nieuwl., New York Fern
Thelepteris palustris Schott var. pubescens (Laws.) Fern., Marsh Fern

Family BLECHNACEAE
Woodwardia areolata (L.) Moore, Net-veined Chain Fern, [Lorinsertia aerolata (L.) Presl]
Woodwardia virginica (L.) J.E. Smith, Virginia Chain Fern

Family ASPLENIACEAE
Asplenium adiantum-nigrum L., Alpine Spleenwort
Asplenium bulbiferum (L.) Bernh., Bulbiferous Spleenwort
Asplenium rhizophyllum (L.) Link, Walking Spleenwort, [Campylogopteris rhizophyllum (L.) Link]
Asplenium trichomanes L. subsp. trichomanes, Maidenhair Spleenwort
Asplenium Xeracoides R.R. Scott, Scott's Spleenwort, [A. phyllus X A. phyllus]
Asplenium Xeracoides Maxon, Graves' Spleenwort, [A. adiantum-nigrum X A. phyllus]
Asplenium Xeracoides McCoy, Kentucky Spleenwort, [A. phyllus X A. phyllus]

Family DRYOPTERIDACEAE
Athyrium filix-femina (L.) Mert. var. asplenioides (Michx.) Farw.,
Southern Lady Fern. [Athyrium filix-femina (L.) Mert. subsp. asplenioides (Michx.) Hulten; Athyrium asplenioides (Michx.) Desv.]
Cystopteris bulbifera (L.) Bernh., Bulbiferous Fragile Fern
Cystopteris prostrata (Weatherby) Blasdell, Prostrating Fragile Fern
Cystopteris tennesseeensis Shaver, Shaver's Fragile Fern
Cystopteris tenusisi (Michx.) Desv., Mackay's Fragile Fern
Cystopteris bulbifera X Cystopteris tennesseeensis
Cystopteris prostrata X Cystopteris tennesseeensis
Deparia acrostichoides (Schwartz) M. Kato, Silvery Glade Fern,
[Athyrium thelypteroides (Michx.) Desv.]
Diplazium esculentum (Sprengel) M. Braun, Narrow-leaved Glade Fern,
[Athyrium esculentum (Sprengel) Sprengel]
Dryopteris carthusiana (Villars) H.P. Fuchs, Spinulose Woodfern
Dryopteris celsa (W. Palmer) Knowlton, Palmer & Pollard, Logfern
Dryopteris ludoviciana (Kunze) Small, Louisiana Logfern
Dryopteris marginalis (L.) A. Gray, Marginal Woodfern
Dryopteris Xanthina (Wherry) Small, Southern Logfern, [D. celsa X D. ludoviciana]
Dryopteris Xanthina Wherry, Leeds' Logfern, [D. celsa X marginalis]
Onoclea sensibilis L., Sensitive Fern
Polyocteium acrostichoides (Michx.) Schott, Christmas Fern
Woodia obtusa (Spreng.) Torr. subsp. obtusa, Blunt-lobed Cliff Fern
Woodia obtusa (Spreng.) Torr. subsp. occidentalis Windham, Blunt-lobed Cliff Fern

Polypodium virginianum L., Rock Polypody

Family MARSILEACEAE
Marsilea vestita Hook. & Grev., Prairie Waterclover [M. microsperma A. Br.; M. urceolata A. Braun]

Pileularia americana A. Braun, American Pillwort

Family AZOLLACEAE
Azolla mexicana Schlecht. & Cham. ex Presl. Mosquito Fern

Checklist and Distribution of Arkansas Pteridophytes

ACKNOWLEDGMENTS.—We thank our many colleagues in pteridological systematics for their discussions on the biology and nomenclature of pteridophytes. We thank all curators of the herbaria cited, with special thanks to Don Culwell, Joyce Hardin, George Johnson, Paul Redfearn, Leon Richards, Ed Smith, Eric Sundell, Dale Thomas, Staria Vanderpool, and Wally Weber. We thank staff biologists of Arkansas Department of Natural Heritage, Arkansas Nature Conservancy, Ouachita National Forest, and Hot Springs National Park, especially John Logan, Steve Orzell, Lance Peacock, Burt Pittman, David Saugey, and William Shepherd. Special thanks are offered to our field trip associates: Eric Sundell, James Bray, Dan Marsh, Don Crank, and Carl Amason. The Milwaukee Public Museum is thanked for permission to utilize and expand the pteridophyte flora published by the junior author. The University of Arkansas at Little Rock is thanked for assigning to the senior author an off-campus duty assignment during the 1994-1995 academic year to conduct

Proceedings Arkansas Academy of Science, Vol. 49, 1995
this research. Gary Heidt and Parker Dozhier are thanked for room and board beyond the call of hospitality. We both acknowledge that Dwight Moore and Delzie Demaree led the way in appreciating the rich pteridophyte natural heritage of Arkansas.

**Literature Cited**


Cranfill, R. 1980. Ferns and fern allies of Kentucky.

Kentucky Nature Preserves Commission, Scientific and Technical Series Number 1. Frankfort, KY.


of a Geological Reconnaissance of the Middle and Southern Counties of Arkansas Made During the Years 1859 and 1860. C. Sherman & Son, Printers, Philadelphia, Pennsylvania.


Sundell, E. 1986. Noteworthy vascular plants from


Conformational Studies of Ortho-and Meta- Isomers and Methyl, Dimethyl, and Chloro Ortho-Substituted Analogues of Dantrolene Using Ab Initio SCF-MO Procedures

Lori L. Rayburn, Amber D. Climer and Jerry A. Darsey
Department of Chemistry
University of Arkansas at Little Rock
Little Rock, AR 72204

Ali U. Shaikh, Kevin S. Robertson and E. Kim Fifer
Department of Chemistry UALR
University of Arkansas for Medical Sciences
Little Rock, Ar 72205

Abstract

The conformation of the nitro group of nitroaromatic compounds relative to the aromatic ring system is suggested to affect their metabolic activation and mutagenicity. We have recently showed the nitrophenylurans skeletal muscle relaxant, dantrolene, to be a potent mutagen in Salmonella. Synthesis of ortho-substituted analogues of dantrolene was achieved in an effort to alter the conformation of the nitro group in a manner that will decrease the mutagenicity. Using ab initio techniques we investigated the minimum energy conformation of the nitro group of dantrolene (p-nitro) and its o- and m-nitro isomers as well as the nitro group conformation of dantrolene's ortho- mono- and di substituted analogues. The most stable conformer for each isomer and analogue was found by optimizing the bond lengths and bond angles for each molecule and rotating about bonds of interest using the STO-3G basis set in the Gaussian-92 program at the Hartree-Fock level.

Introduction

The skeletal muscle relaxant Dantrolene belongs to a group of molecules known as nitrophenylurans and has been shown to be hepatotoxic (Utili et al., 1977). Fifer et al. (1995) have synthesized and investigated the mutagenicities of a series of dantrolene analogues in an effort to develop a less mutagenic substitute for the drug. It has been theorized that the mutagenic activation of nitroaromatic compounds via enzymatic nitroreduction can either be enhanced or inhibited by the orientation of the nitro group (parallel or perpendicular) relative to the aromatic ring. Work being done on nitropolycyclic aromatic hydrocarbons points to parallel (or co-planar) orientation of the nitro group relative to the aromatic ring as more responsible for the mutagenic behavior of compounds than the perpendicular (90 degrees offset from co-planar) orientation of the nitro group (Jung et al., 1991).

Our work with dantrolene and its analogues (Fig. 1 and 2) involves calculating the theoretically most stable (lowest energy) conformers of the drug and its derivatives and investigating the lowest energy conformation of the nitro group of each with respect to the aromatic ring. The low-energy conformers determined by our study may give some insight to the active conformation of the drug inside the body and help guide researchers to a less mutagenic substitute. For our conformational profile, we utilized the Gaussian-92 package (Frish et al., 1992), a program that uses self-consistent field molecular orbital (SCF-MO) ab initio methods to generate useful information about the molecules under study, including total energy.

More specifically, we used the STO-3G basis set in the Gaussian-92 program to determine the optimal bond lengths and angles for the molecules. The STO-3G basis set of functions was also used to determine the theoretically most stable, or lowest energy, conformer by altering specific torsion angles within the molecule.

The results of this study in conjunction with the mutagenicities of dantrolene and its derivatives provide more evidence to support the theory relating nitro group orientation in each compound and its subsequent mutagenicity. This research may aid in the development of an effective less toxic alternative for dantrolene.

Methods and Materials

Ab initio calculations on the molecules were performed using the Gaussian-92 program which was run on the IBM supercomputer cluster at Cornell University (Ithaca, NY) and several Silicon Graphics INDY 500 computers at UALR. Optimizations and rotations were first done at the STO-3G level of approximation, due to the size of the molecules under study (33 atoms or more). Larger basis sets of functions, such as 3-21G and 6-31G, which could render somewhat more accurate results will be used in future more rigorous conformational studies.

The Z-matrix (Hehre et al., 1986) was composed for
Lori L. Rayburn, Amber D. Climer, Jerry A. Darsey, Ali U. Shaikh, Kevin S. Robertson and E. Kim Fifer

Fig. 1. Rotational energy profiles for dantrolene, showing energy barriers to rotation about $\phi_1$, $\phi_2$, $\phi_3$ and $\phi_4$.

each molecule of the study, in which the molecular geometry and connectivity for each was established with bond lengths, interatomic angles, and dihedral (or torsional) angles. The constructed Z-matrices were checked for flaws by using ChemDraft II software, which gives a visual image of the molecule defined by the matrix. These bond lengths and angles were then optimized by the program to provide a reliable starting geometry for rotations about bonds of interest.

The segments of dantrolene that were studied for rotational stability are labeled in Fig. 1. After the optimized geometries were found for each molecule, incremental 30 degree rotations about certain bonds were performed by changing pertinent dihedral angles within the molecule's Z-matrix. By monitoring the Roothan-Hartree-Fock energy calculated for each rotation, a lowest-energy conformation for the entire molecule could finally be determined.

The resulting lowest-energy conformer of dantrolene was used as a template for the starting conformation of its isomers and analogues. Some re-optimations were necessary after the inclusion of new atoms and groups in the Z-matrix of the parent molecule in order to create a reliable starting computational matrix for the isomers and analogues to be studied. For each compound, only the nitro group was analyzed for rotational energies. Initial conformations of each of the studied molecules, along with the bonds about which rotational studies were performed, are listed in Figs. 3a - 3e.
Conformational Studies of Ortho- and Meta- Isomers and Methyl, Dimethyl, and Chloro Ortho-Substituted Analogues of Dantrolene Using Ab Initio SCF-MO Procedures

Results and Discussion

For the parent dantrolene molecule, the plots of energy of the conformation vs. the dihedral angle between critical atoms, ϕ, is shown in Fig. 1. The plummeting energy at certain ϕ values indicates conformational stability at that dihedral angle. After analyzing the results of each rotation, a new, more stable conformer for dantrolene was found to be the one picture in Fig. 2. The nitro group orientation in dantrolene was found to be co-planar with the phenyl group, indicating that an entirely flat structure for dantrolene is energetically favored by the STO-3G basis set. A rotational barrier of slightly over 5 kcal/mol insures this conformation. Another interesting facet of the rotational profile of dantrolene is the strong (13.5 kcal/mol) tendency for the imidazolidine-2,4-dione (or hydantoin) ring to be rotated 180 degrees from its initial position. This may be a result of repulsion between the lone pair electrons of nitrogen #15 and oxygen #22 (see Fig. 1).

The calculated lowest-energy nitro group conformation for the 2-nitro and 3-nitro isomers of dantrolene can
be surmised from the energy vs. $\phi$ plots in Figs 3a and 3b, respectively. The 2-nitro (ortho-nitro) isomer of dantrolene was found to be more stable with the nitro group perpendicular to the phenyl ring of the molecule, with a rotational energy barrier of 100 kcal/mol. This effect is probably due to steric crowding between the nitro group and the furan ring, which pushes the nitro group into a perpendicular position with respect to the rest of the molecule. The calculated stable conformation for 3-nitrodantrolene is shown in Fig. 3b.

The 3-nitro (meta-nitro) isomer of dantrolene was found to be most stable with the nitro group oriented parallel (co-planar) to the phenyl ring. Only a 5 kcal/mol energy barrier was found separating the co-planar and perpendicular orientations in 3-nitrodantrolene. Placement of the nitro group one carbon closer to the furan ring of dantrolene does not sterically crowd the structure enough to force a perpendicular conformation for the nitro group.

Interestingly, in the most stable conformations of the dantrolene analogues, 3-methyldantrolene, 3,5-dimethyl-dantrolene, and 3-chlorodantrolene, the nitro group is not as dramatically positioned at either planar or perpendicular positions. Instead, the 3-methyl and 3-chloro analogues are more energetically stable when the nitro group is rotated 30 degrees out of plane with the benzene ring as shown in the energy plots in Figs. 3c and 3e, respectively.

Placing an atom or group such as chlorine or methyl in an ortho-position to the nitro group on the dantrolene parent molecule causes the nitro group to orient itself outside of the plane of the aromatic ring. Again we propose that the nitro group is forced out of the plane due to steric crowding.

The addition of two methyl groups to the molecule in both ortho-positions produces a lowest energy value when the nitro group is oriented 60 degrees relative to the plane of the phenyl ring as shown in the energy plot in Fig 3d.

**Conclusions**

Our study reveals the lowest energy STO-3G confor-
Conformational Studies of Ortho-and Meta- Isomers and Methyl, Dimethyl, and Chloro Ortho-Substituted Analogues of Dantrolene Using Ab Initio SCF-MO Procedures


Fig. 3e. Rotational energy profile and structure for rotation of the nitro group in 3-chlorodantrolene.

Information for dantrolene and its derivatives. The nitro group in dantrolene was determined to be oriented co-planar to the phenyl ring, as was the nitro group in 3-nitrodantrolene. The nitro group in 2-nitrodantrolene was calculated to be perpendicular to the phenyl ring. In 3-methyl-dantrolene and 3-chloro-dantrolene, the nitro group was found to be 30 degrees from co-planar, and in 3,5-dimethyl-dantrolene it was found to be 60 degrees from co-planar (30 degrees from perpendicular).

Literature Cited

ChemDraft II, version 1.2; C Graph Software, Inc: Austin, Texas.


Frish, M.J., Head-Gordon, G.W. Trucks, J.D. Foresman, H.B. Schlegel, K. Raghavachari, M. Robb, J.S.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Molten Salt Electrolytes for Electrodeposition of CdTe Films

Arif Raza, Robert Engelken, Brandon Kemp, Arees Siddiqui and Omer Mustafa
Optoelectronic Materials Research Laboratory
Department of Engineering
Arkansas State University
P.O. Box 1740
State University, AR 72467

Abstract

We report preliminary investigation of several molten salt electrolytes containing CdCl$_2$ and TeCl$_4$ for the electrodeposition of CdTe films at temperatures well above (>250 °C) those used with aqueous and organic electrolytes. These high temperatures have potential to dramatically increase the crystallite size (Poole, Engelken, et al., 1994), as is important for optoelectronic device applications of CdTe, a leading II-VI semiconductor. This paper will survey the results obtained with electrolytes such as $B_2O_3/HBO_3$ (m.p. = 230°C), NaCH$_2$COO (m.p. = 324°C), ZnCl$_2$ (m.p. = 283° C), and LiCl/KCl (m.p. = 350°C), with an emphasis on the latter two. Key material to be presented includes 1) voltammetric data for the solutions, 2) x-ray diffractometry data for deposited films, 3) a discussion of the numerous practical problems associated with high temperature electrochemistry, especially in corrosive, volatile systems, and 4) emphasis of the value of an operationally feasible high temperature plating system to the commercial viability of electrodeposited semiconductor films.

Introduction

Cadmium telluride, a leading II-VI semiconductor, is used in optoelectronic devices such as photovoltaic and photoconductive cells. Its direct bandgap of 1.44 eV makes it a nearly ideal candidate for solar energy conversion. CdTe films have been electrodeposited from aqueous solutions at low temperatures (< 100°C), but such films tend to be amorphous or have poor crystallinity. Electrodeposition of CdTe from a molten solution should dramatically increase crystallite size due to the much greater thermal energy available to activate diffusion and reaction of plated atoms. Such films, deposited at temperatures above 250°C, have shown a remarkable increase in crystallinity, as reported herein.

This work focused on selection of a suitable electrolyte not only stable at the operating temperature, but also supporting cadmium and telluride electrochemistry and growth of CdTe films. This required extensive research wherein ZnCl$_2$, NaCH$_2$COO, $B_2O_3/H_2BO_3$, and LiCl/KCl, each containing dissolved CdCl$_2$ and TeCl$_4$, were analyzed. The results obtained so far with LiCl/KCl solutions have indicated success in achieving the objective of enhanced crystallinity.

Materials and Methods

Significant research has been performed within the last twenty years on the electrodeposition of semiconductor materials (including CdTe) at temperatures below 250°C (Takhashi et al., 1984; Darkowski and Cocivera, 1985; Engelken and Van Doren, 1985; Poole et al., 1994), but little work has been performed on electrodeposition of semiconductors at elevated temperatures (>250°C). LiCl/KCl solutions have been used previously for electrodeposition of CdSe (Minoura et al., 1985) and metals such as Mo (Gabriel et al., 1994). Electrodeposition at high temperatures has also recently been applied to superconductors (Weston et al., 1992).

The apparatus used in the experiments consisted of an EG&G Princeton Applied Research Model 362 scanning potentiostat, a Hewlett Packard 7046-B x-y-t recorder, a Munsey M88 oven, Pyrex/quartz beakers, and a graphite beaker cover with appropriate holes for the insertion of electrodes. Two inch long cylindrical pieces were cut from a ceramic tube and wedged into the holes to insulate the graphite electrodes from the beaker cover. For voltammetric analysis, 6.15 mm (dia.) x 150 mm (before cutting to 100 mm for use) graphite rods were used as anode, cathode, and reference electrodes. The graphite cathode was replaced by 0.0127 cm thick molybdenum foil when films were being deposited. Initially, all experiments were performed without the graphite reference electrode, but subsequently, three electrodes were used for the detailed analysis of LiCl/KCl solutions. Very small electrode areas (≈ 2 cm$^2$) were immersed in the solutions. Steel clamps with steel nuts and bolts were used to hold the electrodes securely above the beaker cover. An Omega thermocouple and temperature controller were used to measure and control the temperature.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Supplies and reagents used included Aldrich H₃BO₃ (which dehydrated to HBO₂ upon heating), B₂O₃, LiCl, and KC1, Fluka NaCH₃COO, and Alfa/Johnson Matthey ZnCl₂, CdCl₂, and TeCl₄. Distilled water was used to rinse the deposited films.

A Rigaku D-MAX x-ray diffractometer was used to obtain a plot of intensity vs. goniometer angle (2θ). This process gives an indication of the relative crystallinity of the film samples.

The molarity of CdCl₂ and TeCl₄ was maintained near 0.01 M and 0.002 M, respectively. The total volume of the solution was kept between 10 ml and 15 ml. The voltammetric sweeps were usually run from 1.0 V to -1.5 V (cathode-anode, and cathode-reference voltages for the two and three electrode configurations, respectively). This range was found to be suitable to exhibit all required cathodic and anodic structures. Films were deposited by setting the initial sweep voltage at the desired deposition value. This voltage was then applied to the solution for the required deposition time.

The beaker containing the electrolyte was placed in the oven and heated until the electrolyte melted. The B₂O₃/HBO₂ mixture (in the ratio 1:5 by weight) had a melting point of approximately 220°C. NaCH₃COO melted near 325°C. ZnCl₂ had a melting point of 283°C. Although both LiCl and KC1 have melting points above 550°C, their mixture (in the ratio 1:1 by mass) melted at 350°C if the temperature was maintained for a prolonged period of time. The mixture melted much more rapidly if the temperature was allowed to rise further. Usually, the operating temperature was maintained 20°C above the melting point. When the electrolyte had melted completely, CdCl₂, TeCl₄, or a mixture of the two was added to the solution. These dissolved readily in all solutions except B₂O₃/HBO₂. The beaker cover, holding the electrodes, was placed over the beaker. Wires with woven ceramic insulation were connected to the graphite electrodes. This entire assembly was clamped securely to provide good electrical connection between the wire and electrode. These wires protruded through an orifice in the oven.

Results and Discussion

Current vs. voltage structures obtained from voltamograms enable one to deduce the regions in which different elements and/or compounds are being deposited. On the forward sweep, cathodic deposition waves or peaks are observed while the reverse sweep shows anodic stripping peaks.

The B₂O₃/HBO₂ mixture never melted to a clear liquid. It had a tendency to become extremely viscous, and then form large bubbles if the temperature was raised further (beyond 230°C). The CdCl₂/TeCl₄ did not dissolve in this mixture but stayed in a powdery form over the surface. Extremely small currents (of the order of a few μA) were observed. No accurate voltammetric data could be collected due to the interference caused by low frequency electrical noise from the heating element relative to such low currents.

NaCH₃COO did not work well as an electrolyte either, probably due to its strong reducing characteristics at the high operating temperature (380°C). The solution turned greenish black after addition of TeCl₄, probably due to formation of elemental Te. A voltammogram obtained for NaCH₃COO is shown in Fig. 1. Two distinct cathodic deposition peaks can be seen, one at -0.5 V, (cathode to anode) (possibly elemental Te) and the other at -1.1 V (cathode to anode) (elemental Cd), but only one anodic stripping peak is seen, corresponding to cadmium. The appearance of only one weak tellurium plating wave/peak and a poorly defined-to-nonexistent tellurium stripping peak is also consistent with the reduction of Te (IV) to Te (0) by the acetate ion and, hence, decrease in Te ion concentration. The currents seen in the voltammogram were of the order of tens of mA, over electrode areas a few tenths of a cm².

ZnCl₂ proved to be a somewhat better electrolyte than B₂O₃/HBO₂ and NaCH₃COO. Currents of the order of a few mA were obtained over comparable areas near 380°C. Figure 2 shows the voltammetric structure for the solution. Three anodic deposition peaks and three cathodic stripping peaks are observed. From left to right, the peaks are those of elemental Te, CdTe, and elemental Cd. These peaks corresponded to 0.6 V, 0.2 V, and -1.1 V (all cathode to anode voltages). Although the results obtained are significantly better than with the two previously mentioned electrolytes, the electrochemical reduction of CdCl₂ and TeCl₄ was still sluggish, as can be seen from the voltammetric peaks which are small in comparison to the background current. Several attempts were made to deposit a CdTe film from the molten ZnCl₂ bath but they all proved unsuccessful.

The results obtained from LiCl/KCl solutions were far more encouraging than the previous results. High currents were observed at the elevated temperatures (350-380°C). Currents were as large as a few tenths of an ampere for cathodic Cd peaks. With the presence of only CdCl₂ in solution, Cd plated out of the solution at -1.2 V vs. a graphite reference electrode. The plating voltage varied slightly with a change in concentration of the plating species and the presence of additional plating species in the solution. Similarly, the deposition voltage for Te was found to be near -0.8 V vs. graphite. When both CdCl₂ and TeCl₄ are present in solution, three cathodic and anodic peaks are observed, as is shown in Fig. 3. The CdTe peak appears between the Te and Cd peaks at a
Voltammetry was conducted while illuminating the LiCl/KCl baths with 1000 W quartz-tungsten halogen white light through the tempered glass door of the oven. In no case did these "photovoltammograms" exhibit any photocurrent, as normally occurs with photovoltammetry of Cd (II)/Te (IV) solutions in aqueous and organic baths at T < 150°C. The reason is, no doubt, that the high temperatures produced a many order of magnitude increase in the background "dark" current.
in the concentrations of electrons and holes in the deposited CdTe films, thus, driving the material nearly "metallic", and hence, making imperceptible any tiny photomodulated increase in current relative to the large "dark current" values.

Fig. 3. Cyclic voltammogram for a graphite cathode in a LiCl/KCl solution of 0.01 M CdCl₂ and 0.002 M TeCl₄ at 365°C. The sweep rate was 10 mV/s and the voltage was swept from 1.0 V to -1.4 V. The deposition and stripping peaks were extremely sharp. Larger currents were observed.

Gray-black CdTe films were deposited onto Mo foil. CdTe was found to deposit between -1.1 V and -1.2 V vs. graphite. When the films were allowed to deposit too long (approximately 30 minutes), they were very thick and flaked off when rinsed in distilled water. If the deposition time was too short, no or little crystalline film would grow but a grey discoloration of the Mo foil could be seen.

X-ray diffractometry (XRD) of the thicker films was very encouraging. Large CdTe peaks match perfectly and reproducibly with standard CdTe powder diffraction file card peaks; best results were obtained when the CdTe film was deposited at -1.125 V. The large peaks indicated a large crystallite size. Figure 4 exhibits XRD plots with standard powder diffraction file data for CdTe films indicated by the vertical lines.

Fig. 4. X-ray diffraction data for a CdTe film electrodeposited onto Mo foil from a LiCl/KCl solution at 380°C. The deposition voltage was maintained at -1.125 V. The large peaks matched the CdTe powder diffraction file peaks. The two peaks at 58° and 74° were Mo substrate peaks.

Certain obstacles were encountered at the high temperatures. Brown fumes were observed on the addition of TeCl₄ to the LiCl/KCl solution. It is possible that HCl gas was evolved as TeCl₄ was hydrolyzed to TeO₂. More likely is the simple evaporation of TeCl₄ (m. p. = 224°C, b. p. = 380°C); a yellow/red coating would slowly accumulate on the beaker and beaker cover over the electrolyte. The fumes emanating from the solution were probably toxic and had to be treated carefully. The graphite anode was also attacked by the solution. Graphite is very unreactive at low temperatures, but it is likely that high temperatures were causing corrosion. The NaCH₃COO solution was unstable at high temperatures. If it was heated beyond the melting point for a prolonged period, it would decompose and form a dark liquid, probably due to the oxidation ("charring") in the air. As mentioned earlier, the B₂O₃/HBO₂ mixture never melted down completely. Thus, the electrodes were never actually immersed in a true liquid, causing low currents that led to uninformative voltammograms.

The major challenge faced while depositing films on Mo foil was the oxidation of Mo to MoOₓ. This was indi-
uated by the presence of a blue-gray color above the film on the Mo foil. This is once again attributed to the high operating temperature. XRD analysis confirmed the presence of trace MoO2 and TeO2 on some films. Figure 5 and Fig. 6 show XRD data for the same film with standard XRD file data for CdTe and MoO2, respectively. The film clearly indicates the presence of both compounds.

![XRD Data](image)

Fig. 5. XRD data as in Fig. 4 but for a film deposited at 330°C. Three large and four small peaks matched perfectly with the CdTe file card. The intensity of the peaks is greater than observed in Fig. 4, primarily due to a significantly longer deposition time and thicker film.

![XRD Data](image)

Fig. 6. XRD data as in Fig. 5 for the same film but the matching peaks belong to MoO2. Note that all the peaks that had not matched up in Fig. 4 belong to MoO2 (except the Mo peaks mentioned in Fig. 4). The presence of both CdTe and MoO2 on the film was clearly indicated by the XRD plots.

CdTe has significant application in optoelectronic devices such as solar cells and light detectors. Hence, it is important that a cost-effective method for electrodeposition of large-grain, device-grade CdTe be developed. The described procedure tentatively meets this criterion, is simple, and is performed in a relatively uncontrolled (ambient) environment. Films with large crystallinity have been deposited without a vacuum or inert atmosphere. This process is relatively inexpensive, and if implemented in large scale production with some minor alterations, could significantly reduce the cost of production of CdTe-related devices.

We have conducted a preliminary investigation of several molten salt electrolyte candidates for the electrodeposition of CdTe from Cd(II) and Te(IV) ions. NaCH3COO, B2O3/H2O2, and ZnCl2 were found not to be efficacious for electroplating CdTe due to instability or sluggish Cd and Te electrochemistry.

LiCl/KCl mixtures at T > 350°C exhibited facile and distinct electrochemical reduction and oxidation structures for Te, Cd, and CdTe solid phases plated from or dissolved into, respectively, Cd(II) and Te(IV) ions. Furthermore, the gray-black CdTe films deposited onto Mo foil from such baths exhibited excellent polycrystallinity, as evidenced by X-ray diffractometry, although they were very prone to crack and flake upon cooling and rinsing.

Future work will involve identification of additional molten salt electrolytes suitable for electroplating compound semiconductors and plating of other photovoltaic materials such as CdS and CuInSe2 from such baths, especially LiCl/KCl. We also plan to form n-Cds/p-CdTe and n-Cds/p-CuInSe2 solar cells completely through such high temperature electrodeposition processes as part of our work in the Arkansas Advanced Photovoltaic Materials Research Cluster under the AR/NASA EPSCoR program.

ACKNOWLEDGMENTS.—We acknowledge the gracious support provided by the work by both the Arkansas/NASA EPSCoR Program through the Arkansas Advanced Photovoltaic Materials Research Cluster (Dr. Hameed Naseem-Director, Dr. Gaylord Northrop-State Coordinator, and Dr. Dennis Flood-NASA Lewis Research Center-NASA Mentor), and the NASA JOVE Program (Dr. Frank Six and Mr. Maury Estes-NASA Marshall Space Flight Center-Program Administrators, and Dr. Frank Szofer-NASA Mentor).

We also thank the Arkansas Science and Technology Authority (Dr. Joe Gentry-Vice President for Research) and the NSF/Arkansas Science Information Liaison Office (SILO) Student Undergraduate Research Fellowship (SURF) Program for their previous grants that supported work leading up to our current understanding of the problem.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
We are also grateful for the ongoing support provided by Arkansas State University.

Literature Cited


Spectroscopic Temperature Measurements for a Direct Current Arcjet Diamond Chemical Vapor Deposition Reactor

Scott W. Reeve and Wayne A. Weimer
Chemistry Division, Research Department
Naval Air Warfare Center
China Lake, CA 93555

Abstract

The diamond thin film commercial market is projected to exceed one billion dollars by the year 2000. Potential applications of diamond thin films range from cutting tools to electronics to medical devices. The explosion of interest in this field results from the extreme properties diamond possesses: it is the hardest material known to man and yet, has a coefficient of friction similar to Teflon; its ability to conduct heat is five times that of copper; and diamond is completely inert. However, despite the tremendous economic incentive, there are still several technological barriers preventing diamond film scale-up to commercial production. Included among these are a fundamental understanding of the gas phase chemistry leading to diamond film formation and the lack of a reliable in situ, on-line Chemical Vapor Deposition (CVD) monitoring capability. Here we describe the use of optical emission spectroscopy (OES) as a possible direct current CVD plasma jet on-line monitor. Specifically, OES spectra from the C₂ radical, an intermediate species in the diamond CVD process, is utilized to obtain plasma gas temperatures in situ. Additionally, the reliability of a plasma gas temperature determined from OES is examined with Laser-Induced-Fluorescence (LIF).

Introduction

The material properties of diamond can be described by superlatives. Diamond is the hardest material known to man and possesses the highest thermal conductivity. It’s coefficient of friction is similar to that of Teflon and, with the exception of a small window from 3-5 μm, diamond is transparent across the entire optical spectrum (Celii and Butler, 1991). Due to these extreme properties diamond is the material of choice for a remarkably diverse range of potential commercial applications. Examples include heat transfer substrates for computer chips as well as coatings for machine parts and cutting tools (Bigelow, 1993, Sussmann, 1993). Conservative projections predict the commercial market for diamond thin films will surpass $1,000,000,000 by the year 2000 (Bigelow, 1993). Currently, the cost of a 2.54 cm x 2.54 cm x 1 mm diamond film is -$10,000. To become economically feasible, this cost will need to be lowered by at least two orders of magnitude (Craig, 1992). Thus, the film growing process will need to be optimized before the full potential of diamond thin films can be realized.

Diamond thin films and coatings have been grown by several different chemical vapor deposition (CVD) techniques including hot filament CVD (Godbole and Narayan, 1992), microwave plasma CVD (Zhu et al., 1990), oxyacetylene torch CVD (Snail and Hanssen, 1991), and direct current (DC) plasma jet CVD (Reeve et al., 1993). In each case, a small amount of methane (or some other hydrocarbon) is injected into a hydrogen flow with the chemical reactions being initiated by the hot filament or the plasma (Butler and Woodin, 1993). Presumably, after a series of hydrogen abstractions the reactive carbon species encounters the growth surface and becomes incorporated into the diamond film although the chemical sequence for the conversion of methane gas into diamond in CVD reactors and the gas phase diamond growth precursors are still subjects of considerable debate.

While each of the methods listed above produces nearly identical polycrystalline films, the rate of film deposition is highly dependent upon the technique used. To date, the highest linear deposition rates have been obtained with the DC plasma jet (Ohtake and Yoshikawa, 1990). Because this represents the greatest potential for production scale-up, we focussed our attention on this CVD reactor. In this report, we present Optical Emission Spectroscopy (OES) and Laser-Induced-Fluorescence (LIF) spectra for the C₂ species observed under typical diamond growth conditions in the DC plasma jet apparatus at China Lake, California. One of the objectives of the OES experiments was to determine if information beyond the obvious plasma parameters, such as emitting species identification and the corresponding excited state population distributions, could be obtained from the spectra. Therefore, a key feature of the OES work is the development of a method to extract plasma gas temperatures from the spatially resolved spectroscopic measurements. A comparison of the gas temperature obtained from the OES spectra with preliminary LIF measurements suggests...
Spectroscopic Temperature Measurements for a Direct Current Arcjet Diamond Chemical Vapor Deposition Reactor

OES may be a useful diamond deposition process temperature monitor. Parenthetically, the quality and deposition rate of diamond thin films are highly dependent upon the temperature of the plasma gas during film growth (Celii and Butler, 1991). Thus, the plasma gas temperature is a critical parameter to monitor. In addition, the plasma gas temperature profile is needed as input for chemical kinetic models such as the CHEMKIN/PREMIX code (Reeve et al., 1995). It was predictions from a CHEMKIN calculation, that led us to an optimization strategy that, simultaneously, doubled the mass deposition rate and increased the quality of the films grown (Reeve and Weiner, 1994).

A diagram of the China Lake DC plasma jet CVD reactor together with a schematic of the OES and LIF apparatus is shown in Fig. 1. Diamond thin films are grown by injecting a mixture of hydrogen and methane gas, downstream of the electrode gap, into a flowing argon plasma operated at ~60 Torr reactor pressure. Note, argon is the only gas to pass through the electrode gap. The reactive high velocity plasma (~6000m/s) then impinges at normal incidence onto a molybdenum substrate. The substrate is mounted on a water cooled copper block so that a temperature of 1000°C can be maintained at the growth surface. Nominal operating conditions are given in Table 1. The China Lake DC plasma jet CVD reactor has previously demonstrated the ability to produce high quality diamond films as evaluated by both Raman spectroscopy and optical microscopy (Reeve et al., 1993).

![Fig. 1. Schematic of the China Lake DC plasma jet diamond CVD reactor along with the Optical Emission Spectroscopy and Laser-Induced-Fluorescence diagnostic capabilities.](image)

| Table 1. Operating Parameters for the China Lake DC Plasma Jet CVD Reactor. |
|-----------------|-----------------|
| DC voltage      | 20V             |
| DC Current      | 140-150A        |
| Reactor Pressure| 55-60 Torr      |
| Substrate Material | Molybdenum (25mm x 38mm) |
| Plasma Gun-Substrate Distance | -2.5 cm (-1 inch) |
| Gas Flow Rates  |                |
| Ar              | 13.7 slm        |
| H₂              | 5.4 slm         |
| CH₄             | 150-700 sccm    |

Results and Discussion

Optical Emission Spectroscopy.—The OES experiment is quite simple and consists of imaging the illuminous plasma, with a 150mm focal length biconvex lens, onto the end of a 1.0 mm fiber optic bundle. The dispersed spectra were recorded with a Spex Model 1702 scanning monochromator (0.5nm bandpass) and a Hamamatsu Model R928 photomultiplier tube. To increase sensitivity, the emission spectra was chopped and the output from the photomultiplier was sent to a PAR Model 5208 lock-in amplifier. The spectral response of the spectrometer was calibrated with an Optronics Laboratories Model 220M tungsten lamp. To obtain spatially resolved OES spectra, the end of the fiber optic was translated within the image of the plasma.

The details of the nonlinear curve fitting procedure, developed to extract the plasma gas temperature from the OES spectra, are described in the April Journal of Vacuum Science and Technology A (Reeve and Weiner, 1995) and will not be reproduced here. A representative OES spectrum for the d³Π₃ → a³Π₃ (Δν=0) Swan band emission of the C₆ radical is shown in Fig. 2 along with the results obtained from this curve fitting procedure. The spectrum in Fig. 2 was taken at an axial position of 2.36 cm above the growth surface. The vibrational and rotational temperatures, at this position, are 4646 K and 3301 K, respectively. While the agreement between the observed data points and the fitted spectrum is quite good, the validity of using an excited state effective rotational temperature to estimate the plasma gas temperature warrants some discussion. For a temperature determined from an emission spectrum to have meaning, the species responsible for the radiation must be thermalized. The quality of the curve fit to the data in Fig. 2 suggests the C₆ rotational and vibrational levels in the d³Π₃ electronic state can be described by a Boltzmann distribution. While a system in thermodynamic equilibrium will have Boltzmann distributions for the gas, electronic,
vibrational, and rotational energies that can be defined by a single temperature, in reacting plasmas, departures from thermodynamic equilibrium are common for excited species (Hertzberg, 1950). Thus, Boltzmann distributions defined by different temperatures can be expected (Reeve and Weimer, 1995). In Fig. 2, the observed temperature difference is believed to be a direct consequence of an electron impact excitation mechanism for the C\textsubscript{2} species in the DC plasma jet.

![Intensity diagram](image)

Fig. 2. C\textsubscript{2} Swan band optical emission spectrum taken 2.36 cm above the substrate during diamond thin film growth.

Optical emission can be produced by three different processes: chemiluminescent reaction, thermal excitation, and electron impact (Raiche and Jefferies, 1993). Each mechanism will produce qualitatively different emission spectra. For example, a thermal excitation mechanism will produce an excited state species with \( T_{\text{gas}} = T_{\text{vibrational}} = T_{\text{rotational}} \). Based on the observed differences in \( T_{\text{vibrational}} \) and \( T_{\text{rotational}} \) this possibility can be excluded. Although we cannot rule out a chemiluminescent reaction as being the dominant excitation process for the C\textsubscript{2} species in our system, there is evidence to suggest the C\textsubscript{2} emission is the result of an electron impact mechanism.

An electron impact excitation mechanism would produce an excited electronic state vibrational distribution that is governed by the Franck-Condon overlap between the upper and lower electronic states (Raiche and Jefferies, 1993). In addition, because the mass of an electron is small relative to the mass of the C\textsubscript{2} molecule, no appreciable change from the lower state rotational energy distribution would be expected for the upper electronic state (Hertzberg, 1950). Given a thermalized temperature for the lower electronic state \( \text{a}^3\Pi\text{u} \) of C\textsubscript{2}, we can impose the Franck-Condon transition probabilities, predict the excited electronic state population distributions, and calculate the resulting vibrational and rotational temperatures in the \( \text{d}^3\Pi\text{g} \) assuming a Boltzmann distribution (Hertzberg, 1950). Thus, and electron colliding with and electronically exciting a C\textsubscript{2} molecule, in the \( \text{a}^3\Pi\text{u} \), electronic state and initially thermalized at \( T_{\text{gas}} = 3301 \) K, would produce a vibrational distribution defined by \( T_{\text{vibrational}} = 4710 \) K and a rotational distribution defined by \( T_{\text{rotational}} = 3301 \) K in the upper \( \text{d}^3\Pi\text{g} \) state. A comparison with the OES temperatures in Fig. 2 is unmistakable and suggests the C\textsubscript{2} emission here is the result of an electron impact excitation mechanism. Moreover, the Franck-Condon analysis indicates the rotational temperature of \( \text{d}^3\Pi\text{g} \) should provide some measure of the plasma gas temperature.

**Laser Induced Fluorescence.**—The LIF experiment utilized a Lumonics Model 860-4 exciter laser to pump a Lumonics Model EPD-330 dye laser capable of producing narrow band (0.003 nm) pulses (~17 ns pulses) tunable radiation with an energy of ~12 mJ/pulse. Due to the reactor geometry, a relatively long focal length lens (300 mm) was used to focus the beam into the plasma jet. The diameter of the beam in this configuration is approximately 80 μm, still small relative to the spatial dimensions of the system. The transient LIF signals were collected at a right angle to the excitation beam and detected with an RCA Model 1P28 photomultiplier tube positioned behind an aperture to block scattered laser light and a wavelength calibrated optical filter stack designed to pass radiation over a limited wavelength range (~20 nm) appropriate for C\textsubscript{2} detection. The photomultiplier signals are processed with a gated Princeton Applied Research Model 162/164 boxcar averager connected to a Hewlett Packard Model 3455A digital voltmeter and a LeCroy Model 9400 digital oscilloscope. The dye laser, boxcar averager, energy meter, and digital oscilloscope are interfaced with a Hewlett Packard 9836A workstaton. For these experiments, the dye laser is free run and the detection electronics are synchronized to each laser pulse. The raw LIF signals are corrected for both the spectral transmission of the optical filter stack and the dye laser pulse energy.

The LIF measurements are also probing the \( \text{d}^3\Pi\text{g} \leftrightarrow \text{a}^3\Pi\text{u} \) Swan band system of the C\textsubscript{2} radical. However, LIF actually samples C\textsubscript{2} species in the lower \( \text{a}^3\Pi\text{u} \) electronic state. This metastable state is located 716 cm\(^{-1}\) above and is thermally populated by the ground electronic state. As a result, the rotational and vibrational distributions in the \( \text{a}^3\Pi\text{u} \) should be thermalized with the plasma gas temperature. The spectral resolution for the LIF measurements are determined by the excitation laser which has a narrow linewidth of 0.003 nm. At this resolution, we are able to excite individual P(\( \Delta \lambda = -1 \), Q(\( \Delta \lambda = 0 \), and R(\( \Delta \lambda = 1 \)) branch transitions from the \( \text{a}^3\Pi\text{u} \) electronic state to
Spectroscopic Temperature Measurements for a Direct Current Arcjet Diamond Chemical Vapor Deposition Reactor

the d^3II_g state. The v' - v'' = 0 Swan bands near 516 nm are the strongest C_2 transitions in the visible and were chosen for the preliminary measurements. While we could have theoretically excited and detected the d^3II_g fluorescence at 516 nm, laser scatter from the reactor walls was a severe problem and facilitated the need to choose a detection wavelength well separated from the excitation wavelength to avoid saturation of the photomultiplier. Therefore, for the measurements reported here, we excite the d^3II_g \rightarrow a^3II_g (0, 0) transitions at 516 nm and collect the total fluorescence signal from the d^3II_g \rightarrow a^3III_g (0, 1) Swan band near 560 nm. With this detection scheme, we are able to observe 21% of the fluorescence.

Another factor which complicates the LIF detection is the plasma emission from the C_2 species. An illustration of this background emission in the observed fluorescence is provided by the time resolved signal in Fig. 3. The top trace was recorded with the plasma on and no CH_4 flow in the reactive gas mixture. Note the laser scatter from the reactor walls in the top trace. The scatter results from the asymptotic band cutoff of the optical filter stack. With a filter stack centered at 520 nm, this laser scatter simply swamps the fluorescence signal. The bottom trace in Fig. 3 was taken with the plasma on and a CH_4 flow typical for diamond growth conditions. The offset in the baseline is from the C_2 d^3II_g \rightarrow a^3III_g Swan band emission at 560 nm. From the time resolved data, a C_2 d^3II_g state fluorescent lifetime can be obtained. The observed fluorescence decay is actually a convolution of the true molecular fluorescence with the response function of the instrument (Felker and Zewail, 1984). In this case, the top trace in Fig. 3 is a real time response to the 17 nanosecond laser pulse. Fitting the scattered intensity to an exponential function of time yields a time constant for the scattered signal decay of \tau_{\text{scatter}}=8.76 \text{ ns}. With this value in hand, the convolution integral to extract the excited state lifetime can be evaluated. The resulting time resolved spectral fit assigns a fluorescent lifetime to the C_2 d state of 36.0 ns. Since this value is significantly shorter than the 120 ns collision free radiative lifetime, the time resolved spectra suggest the d^3II_g excited state is strongly quenched in the plasma jet, presumably through collisions with H_2 (Reeve and Weimer, 1995). Previously, we reported calculated values for the time duration between quenching collisions with hydrogen for the CH A^2\Delta species (Reeve and Weimer, 1995). The measured C_2 d state lifetime is remarkably close to the \tau_{\text{quenching}} value (35 ns) for the CH A state at 3000 K (Reeve and Weimer, 1995).

In addition to the time resolved fluorescence spectrum, we can measure the C_2 fluorescence intensity as a function of excitation wavelength. We do need to first correct the spectral intensity for the dye laser pulse energy and for the effects of the optical filter stack. A plot of the corrected intensity versus dye laser wavelength for the C_2 d-\epsilon(a,0,0) Swan band is given in Fig. 4. Note, the spectra shown in Fig. 4 is qualitatively similar to the C_2 516 nm Swan band absorption spectrum (Bulewicz et al., 1970) and the C_2 516 nm Swan band spectrum obtained by degenerate four wave mixing (Nyholm et al., 1994) which have been reported previously. Both of these spectra were acquired in an oxyacetylene flame. Here, the assignment of the individual P and R branch transitions are facilitated by these previous studies together with computer simulations of the \Delta v=0 Swan band spectra. With the exception of the P branch bandhead region near 516.5 nm, the individual rotational transitions in Fig. 4 appear to be fully resolved. Keep in mind however, the C_2 Swan bands are \Pi-\Pi electronic transitions and will consist of three sub-bands (Hertzberg, 1950). Thus, each rotational transition is actually a triplet whose splitting becomes larger with decreasing rotational quantum number J (Hertzberg, 1950). This splitting is not resolved for the P branch lines in Fig. 4, although the weaker R branch transitions, beginning at and extending to lower wavelengths, are fully resolved in some instances. Modification of the OES curve fitting routine to handle the high resolution LIF spectra is still in progress. Nevertheless, a rotational temperature can be estimated from Fig. 4 (following Bulewicz et al., 1970) by plotting the logarithm of the rotational population for the a^3II \rightarrow \epsilon state, In(N(\epsilon)), versus the rotational energy (Hertzberg, 1950). The integrated signal intensity for each rotational line is converted to a population by dividing by the rotational degeneracy (Raiche and Jeffries, 1998). For a perfect Boltzmann distribution, a straight line graph with slope -1/kT_rotational is expected. Figure 5 is a plot of In(intensity)/(2J + 1) versus the rotational energy taken from the date in Fig. 4. The linearity in Fig. 5 is an indication of the extent to which the C_2 a^3II state population is thermalized with the plasma gas temperature. The rotational temperature determined from the slope of the line in Fig. 5 is 3174 ± 388 K. The corresponding OES rotational temperature at this spatial position is 3301 K.

In summary, while a chemiluminescence excitation cannot be ruled out, the evidence suggests the C_2 emission in the DC plasma jet is the result of an electron impact excitation mechanism. As a result, the rotational temperature, determined from the OES spectra, should provide a non-intrusive monitoring capability for the diamond DC plasma jet CVD process. Gas temperatures and fluorescent lifetimes determined from the preliminary LIF measurements supply additional experimental evidence to support this conclusion. One does need to keep in mind however, several factors can influence the accuracy of the OES temperature determination including plasma instability, line-of-sight temperature variations.
changes in the plasma opacity, as well as drift in the sensitivity of the spectrometer. For the OES measurements reported here, we estimate the uncertainty to be ± 300 K.

![Image of a graph showing the effect of methane flow on fluorescence intensity](image1)

Fig. 3. Time resolved C₂ fluorescence signal recorded with the CH₄ flow on (lower trace) and off (upper trace).

![Image of a graph showing excitation wavelength vs. intensity](image2)

Fig. 4. Measured C₂ Laser-Induced-Fluorescence spectrum near bandhead in the C₂ Swan (0,0) band.

ACKNOWLEDGMENTS.—This work was supported by the Office of Naval Research. The authors wish to thank Drs. D.C. Harris, C.E. Johnson and D.S. Dandy for useful technical discussions. S.W. Reeve acknowledges the American Society for Engineering Education and the Office of Naval Research for a postdoctoral fellowship.

Fig. 5. Logarithmic plot of the rotational population versus the rotational energy for the a³Πu electronic state.

**Literature Cited**


Ohtake, N. and M. Yoshikawa. 1990. Diamond film preparation by arc discharge plasma jet chemical


Characterization of Cadmium Sulfide Films Deposited
By Chemical Bath Method

Quazi Galib Samdami, Hameed A. Naseem and W.D. Brown
Department of Electrical Engineering
University of Arkansas
Fayetteville, AR 72701

Abstract

Thin film cadmium sulfide is a leading candidate in the fabrication of large area solar cells. The chemical bath deposition method is one of the least expensive sources for the fabrication of device quality cadmium sulfide thin films. In the present work, the deposition of CdS films on glass substrate from an aqueous solution containing cadmium acetate, ammonia, ammonium acetate, and thiourea are investigated. The structural properties of CdS films are characterized. Good quality thin films within 0.1 - 0.5 μm thickness were obtained in 30 minute deposition time, and at 70°-90°C. The films show preferential orientations. The optical transmittance of the films are in the range of 40-65% for wavelengths above the band gap absorption, making the films suitable as a window material in hetero-junction solar cells.

Introduction

Cadmium sulfide (CdS) is a promising TCS (transparent conducting semiconductor) material to be used in a hetero-junction solar cell due to its large bandgap (2.42 eV) at room temperature and good photo-conductivity (Chu and Chu, 1993; Sahu and Chandra, 1987). It is commensurate with two of the leading photovoltaic absorber materials CdTe & CuInGaSe₂. The deposition of CdS films on substrates from an aqueous solution is a low cost scalable technique for the manufacture of thin film solar cells. In the solution growth process, a cadmium complex and an organic sulfiding agent provide very low concentration of Cd²⁺ and S²⁻ in solution. When the product of ion concentration exceeds the solubility product of CdS (1.4E-29 at 25°C), a chemical reaction takes place, precipitating CdS (Chu et al., 1992). CdAc₂, CdSO₄, Cd(NO₃)₂, CdCl₂ etc. can be used as cadmium salt in the chemical solution (Kaur, I., D.K. Pandya, and K.L. Chopra). The present paper describes the deposition of CdS on a glass substrate by using aqueous solution of different molar concentration of cadmium acetate (CdAc₂), thiourea [(NH₂)₂CS], ammonium acetate (NH₄Ac) and 30% ammonium hydroxide (NH₄OH). Here NH₃ acts as a completing agent, thiourea furnishes S²⁻, cadmium acetate furnishes Cd²⁺, and NH₄Ac/NH₃ serves as a buffer.

Materials and Methods

Figure 1 shows a simple setup for chemical bath method for the deposition of CdS films. CdS thin films were deposited on chemically cleaned glass substrate using aqueous solution of cadmium acetate (CdAc₂), thiourea [(NH₂)₂CS], ammonium acetate (NH₄Ac) and 30% ammonium hydroxide (NH₄OH). Here NH₃ acts as a completing agent, thiourea furnishes S²⁻, cadmium acetate furnishes Cd²⁺, and NH₄Ac/NH₃ serves as a buffer.

Fig. 1. A relatively simple setup for chemical bath method for the deposition of CdS.

Proceedings Arkansas Academy of Science, Vol. 49, 1995

155
CdS film can deposit heterogeneously on glass substrate, or homogeneously in the solution, producing CdS precipitate. Since we desire a thin film of CdS with a uniform thickness and which should be strongly adherent to glass substrate, the homogeneous process is undesirable. The homogenous process can be suppressed by using a relatively very low molar concentration of cadmium acetate and thiourea with respect to ammonium acetate and ammonia in the chemical solution.

The deposition of CdS films was studied by using different molar concentration of cadmium acetate (0.005M - 0.02M), ammonium acetate (0.1M - 0.4M), thiourea (0.005M - 0.02M) and with 30% ammonium hydroxide of known volume. The deposition conditions were identified by using a certain volume of cadmium acetate/thiourea, ammonium acetate and ammonium hydroxide and monitoring the volumetric addition of cadmium acetate/thiourea of known molar concentration. The chemical solutions were heated and stirred vigorously with the help of a magnetic stirrer, and the glass substrates were kept immersed vertically in the solution during the deposition processes. When the heterogeneous deposition begins on the glass substrate, it is identified by observing a slight yellow tint within the solution. Further deposition then completes within next 30 - 45 minutes depending on the deposition conditions. The pH of the solutions were varied in the range of 8 - 13.5. Best deposition was found at molar concentrations of 0.005 - 0.01 M and 0.008 - 0.015 M for cadmium acetate and thiourea respectively with concentration of ammonium acetate in the range of 0.1 - 0.2 M. The temperature and pH of the solution mainly controls the rate of deposition. Typical deposition rate was found to be 0.01 - 0.015 μm/minute.

Techniques used for the characterization of CdS films. -- The crystallographic properties of the films were studied using Phillips Analytical XPERT X-ray diffractometer at the HIDECS facility of the University of Arkansas. The diffraction spectra were obtained by scanning 2θ in the range of 25-120°.

For thickness measurement of the films, first a uniform step was made by masking one portion of the film and then etching the unmasked portion by immersing and withdrawing the film quickly in 50% HCl acid. Dektak 3000 thickness monitor at the Physics measurement laboratory of the University of Arkansas was used to measure the step height.

Digital Instrument's Nanoscope machine which uses Atomic Force Microscopy (AFM) technique was used to study the surface topography and roughness of the surface. SEM pictures were taken to view the surface morphology of the films.

A diode array visible UV photo-spectrometer was used to obtain the optical transmittance and absorption spectra for a wavelength range of 300 nm to 820 nm.

The dark-current and photo-current responses of the films were measured by using Keithley Source Measurement Unit (SMU) coupled with Oriel AM1.5 Solar Simulator. Two collinear ohmic contacts were made using colloidal silver paint and later on using indium shots. The voltage at these two contacts was swept from 0 to 50 V in a 0.5V steps, and the corresponding changes in current were measured in the dark and under illumination.

Results and Discussion

Figure 2 shows the plot of the deposition rate of CdS with the variation of pH. A decrease in deposition rate was observed with the increase of pH of the solution. At a given temperature, the rate of formation of CdS is determined by the concentration of Cd²⁺ provided by Cd(NH₃)₄²⁺ and the concentration of S²⁻ from the hydrolysis of (NH₂)₂CS. The rate of hydrolysis of (NH₂)₂CS depends on the pH and temperature of the solution. The various reactions involved in the chemical bath are as follows (Chu et al., 1992):

\[
\begin{align*}
\text{NH}_3 + \text{H}_2\text{O} & \rightleftharpoons \text{NH}_4^+ + \text{OH}^- \quad [1] \\
\text{Cd}^{2+} + 2\text{OH}^- & \rightarrow \text{Cd(OH)}_2 \quad [2] \\
\text{Cd}^{2+} + 4\text{NH}_3 & \rightarrow \text{Cd(NH}_3)_4^{2+} \quad [3] \\
(\text{NH}_2)_2\text{CS} + 2\text{OH}^- & \rightarrow \text{S}^2^- + 2\text{H}_2\text{O} + \text{H}_2\text{CN}_2 \quad [4] \\
\text{Cd}^{2+} + \text{S}^2^- & \rightarrow \text{CdS} \quad [5]
\end{align*}
\]

![DEPOSITION RATE OF CBD CdS AS A FUNCTION OF pH OF THE CHEMICAL BATH](image)

Fig. 2. The dependence of growth rate of CdS with pH of the solution in CBD method.
The presence of NH$_4^+$ salt in the solution shifts the equilibrium position of reaction 1, increasing the concentration of Cd(NH$_3$)$_2^{2+}$ and reducing the concentration of Cd$^{2+}$. Thus, the rate of formation of CdS can be controlled by varying the concentration of ammonia and NH$_4^-$ salt in the solution, which leads to a change of pH of the solution. Further, the hydrolysis of (NH$_3$)$_2$CS is greatly enhanced as the temperature is increased, increasing the concentration of S$^{2-}$ in the solution (Chu et al., 1992). Which also leads to the enhancement of the rate of formation of CdS.

The deposited films demonstrate good adherence to the glass substrate. The XRD analysis shows a strong diffraction peak at 2θ = 26.61° for CdS film of the deposited batches. Some minor peaks were obtained at 2θ = 44.105°, 111.125° etc. Polycrystalline hexagonal and cubic CdS of random orientation are known to show many strong X-ray diffraction peaks. Figure 3 shows a diffraction plot for a 2θ scan from 25° to 120° of a typical film superimposed with the standard diffraction peaks of hexagonal CdS of random orientation. The single strong peak at 26.61° indicates a preferred crystallographic orientation associated with the (002) reflection of hexagonal CdS. The preferred orientation of this type is due to the controlled nucleation process associated with the low deposition rate of CdS.

![Graph](image1)

**Fig. 3.** The X-ray diffraction pattern obtained for one sample of the deposited CdS film and the standard diffraction pattern of the hexagonal CdS (vertical lines).

The average film thickness was found to be in the range of 0.1-0.5 μm from the Dektak measurements. Figure 4 shows the AFM plot of a typical CdS film depicting the surface topography. The maximum roughness was found in the range of 80-100 nm in the smoother region on the film surface from the AFM analysis. Since CdS will

![AFM Image](image2)

**Fig. 4.** AFM plot for surface topography and section analysis a. Surface topography; b. Section analysis

be used as window material in the hetero-junction solar cell fabrication, surface roughness of this range is desirable. In this case the surface roughness will help the base absorber semiconductor to absorb more incident light energy due to the scattering of light in the CdS window surface which ultimately leads to an increase in short circuit current density, $I_{sc}$ in the solar cell improving its efficiency. The average grain size is 0.1-0.5 μm, though some large grains of 1 μm dimension visible in the AFM plot. The large grains are undesirable in solar cell fabrication, and should be eliminated by a controlled nucleation process of the CdS films.

Figure 5 shows UV spectrometer plot for percent transmittance vs wavelength. Percent-transmittance is 64.9% above the bandgap energy for this CdS film, and the overall percent-transmittance was found in the range of 40-65%. The actual transmittance of the films is reduced somewhat due to the scattering of light on the rough crystallographic surface of CdS. An integrating sphere spectrometer might help to get the true transmittance of these chemically deposited CdS films.

The optical bandgap energy deduced from absorbance square vs. photon energy plot in the wavelength range of 300-820 nm is about 2.42 eV as shown in Fig. 6, which
Characterization of Cadmium Sulfide Films Deposited By Chemical Bath Method

matches with the bandgap energy of single crystalline CdS which is also 2.42 eV.

Figure 7 shows voltage vs. current and a voltage vs. resistance plot in the dark and under AM 1.5 illumination. An increase of current was observed under illumination. The overall dark resistance observed for films of different thickness is of the order of 10^6-10^9, and decrement of resistance was observed with films of higher thickness. The ratio of dark resistance to photo resistance varies in the range of 300-800. Typical dark resistivity of the films obtained was 2 x 10^4 ohm-em and photo-resistivity was about 4 ohm-cm under AM 1.5 solar radiation. The obser-

Conclusions

The characterization of CdS thin films was done after the deposition by the chemical bath method. Preferred (002) hexagonal crystal orientation was observed from the X-ray diffraction analysis. The AFM plot provides an average grain size of 0.1 - 0.5 μm with a surface roughness analysis of 80-100 nm in a smoother region on the
film. Observed optical transmittance is 40-65% above the bandgap energy. The measured bandgap energy is 2.42 eV, which is ideal for single crystalline CdS. The varying range of current was observed under illumination and in the dark associated with a change in the measured resistance value. Good ohmic contact is also achieved by using silver paint. The above mentioned characterization indicates a suitable use of chemically grown CdS thin films as a TCS (transparent conducting semiconductor) material in the hetero-junction solar cell fabrication.

ACKNOWLEDGMENTS.—Personal thanks goes to Mr. Shahidul Haque, Ph.D. student, Department of Electrical Engineering, University of Arkansas for his cooperation during the ongoing research in this project.

Literature Cited


Using FRITIOF to Model Nucleus-Nucleus Interactions in a Cosmic Ray Detector

Carlos A. Sánchez, Kazuhiro Mura and Donald C. Wold
Department of Physics and Astronomy
University of Arkansas at Little Rock
2801 S. University Avenue
Little Rock, AR 72204

Abstract

A scintillating optical fiber calorimeter (SOFCAL) is being developed by NASA/Marshall Space Flight Center for use in experiments to study the spectrum of high-energy cosmic rays and gamma rays from 100 GeV to 1,000 TeV. SOFCAL will not saturate for long exposures and this calorimeter in these balloon-borne emulsion chambers will be helpful for the study of the composition of primary cosmic-ray nuclei. For primary nuclei with energies much greater than $10^{14}$ eV, nucleus-nucleus interactions are likely to exhibit characteristics of a quark-gluon plasma (QGP). A particle event generator was used to model the collision of a cosmic-ray nucleus with a target nucleus in an emulsion chamber. FRITIOF with LUCIAE was chosen to model collisions of primary cosmic rays in an emulsion chamber with SOFCAL. Pseudo-rapidity distributions were computed for protons on lead at 200 GeV/c and compared with experimental data. Pseudo-rapidity distributions were computed for protons or iron incident on a carbon or silver nucleus. For gamma-rays from nucleus-nucleus interactions, the total energy of the electromagnetic component $\Sigma E_\gamma$ was computed. The partial coefficient of inelasticity $k_\gamma$ defined by $\Sigma E_\gamma = k_\gamma E_\gamma$ was computed from the primary energy $E_0$ of the cosmic rays. The $f(k_\gamma)$-distributions were computed and compared with existing calorimeter data. Funding was provided by the NASA/University Joint Venture (JOVE) Program.

Introduction

Cosmic rays are now known to span the energy range from $10^9$ to beyond $10^{20}$ eV (Asakimori et al., 1993a; Asakimori et al., 1993b; Swordy, 1994; Teshima, 1994). They are predominantly the nuclei of atoms from hydrogen to iron. Above $10^{14}$ eV the particles are so rare that their detection relies mainly on observations of the giant cascades or extensive air showers created in the atmosphere which may be observed with arrays of particle and optical detectors at ground level. The flux of particles decreases inversely as the square of the energy (Fig. 1), up to $10^{19}$ eV, and continues to decrease above $10^{19}$ eV as only about one particle per km$^2$ per year is collected (Watson, 1994). The origin of these particles is unknown and how they are accelerated to such high energies is a major astrophysical puzzle (Bird et al., 1993).

Even though the flux of the primary cosmic rays is so low at these energies that small detectors in spacecraft or balloons can intercept only a small number for study, emulsion chambers are an important tool for the direct measurement of the composition and spectra of cosmic rays above $10^{12}$ eV/nucleon. The emulsion chamber method (Burnett et al., 1986) is especially useful for ultra-high energy cosmic ray observations because (1) the efficiency for detection interactions approaches 100% above about 10 TeV and (2) the energy resolution is approximately constant with energy for a given incident species. Most other energy measuring techniques are impractical for balloon observations of primary cosmic rays at such high energies.

Balloon-borne emulsion chambers, employing calorimeters, have been used for direct measurements of cosmic-ray composition (protons through Fe) between $10^{12}$ and $10^{15}$ eV (Kaplon et al., 1952; Minakawa et al., 1958; Niu et al., 1971; Burnett et al., 1986; Takahashi et al., 1986; Burnett et al., 1987; Farnell et al., 1989; Burnett et al., 1990; Asakimori et al., 1993a; Asakimori et al., 1995b). The typical emulsion chamber (Burnett et al., 1986) is composed of four parts: (1) a charge-determination module, (2) a target module with $-0.2$ vertical interaction mean free paths for protons, (3) a spacer module, and (4) an emulsion calorimeter module with about fourteen vertical radiation lengths.

The "target section" includes many layers of nuclear emulsion plates to measure the charge of the incident particle and the emission angles of the produced charged particles with high accuracy (0.01 mrad). The "calorimeter section" includes layers of nuclear emulsion and X-ray film among lead plates to measure the electron distributions from the electromagnetic cascades initiated by gamma rays from $\pi^0$ decay. The calorimeter is used to measure the spectrum of energy deposition $\Sigma E_\gamma$ from which the primary energy spectrum is derived (Burnett et
The scintillation optical fiber calorimeter (SOFCAL) is a scintillation optical fiber counterpart to the calorimeter section in the emulsion chamber. SOFCAL is under development at NASA/Marshall Space Flight Center for future applications in cosmic ray and gamma ray measurements.

Materials and Methods

For modeling the primary cosmic ray interactions, calculations must be performed with event generators, such as FRITIOF, to predict distributions of the electromagnetic component \( \Sigma E_y \) in the calorimeter. FRITIOF (Bengtsson and Sjöstrand, 1987; Nilsson-Almqvist and Stenlund, 1987; Sjöstrand and Bengtsson, 1987; Fi, 1992; Sa and Tai, 1994) was used to model nucleus-nucleus interactions in an emulsion chamber and the subsequent emission of particles. GEANT (CERN, 1992a) and PAW (CERN, 1992b) are used for associated optimum "window" settings of the calorimeter.

For the initial modeling of SOFCAL (Yang et al., 1994), a calorimeter module with ten vertical radiation lengths of Pb was used. In one geometrical configuration, each subsection of the calorimeter consisted of a 4-mm lead block, 100 fibers (0.5-mm thick) in the x-direction and 100 fibers (0.5-mm thick) in the y-direction. This lead and optical fiber combination was repeated fourteen times. Photon and electron events in SOFCAL were modeled with GEANT on DEC 5000 workstations.

**Event Generator for Modeling Nucleus-Nucleus Collisions.** FRITIOF is a Monte Carlo program that implements the Lund string dynamics for hadron-hadron, hadron-nucleus, and nucleus-nucleus collisions (Bengtsson and Sjöstrand, 1987). At high energies, a collision between nuclei can be regarded as incoherent collisions between their nucleons. Thus, a nucleon from the projectile interacts independently with the encountered target nucleon as it passes through the nucleus. Each of these sub-collisions can be treated the same way as the usual hadron-hadron collision.

In FRITIOF an interacting hadron behaves like a relativistic string with a confined color field. Two hadrons interact with each other as their fields overlap, and momentum transfer takes place. It is assumed that no net color is exchanged between the hadrons despite the momentum transfer. The possibility of one of the momentum transfers corresponding to large transverse momentum scattering is properly treated according to QCD. After the exchange of momenta, the hadrons are assumed to become two excited string states, which further emit gluonic radiation in a color dipole approach to the QCD parton branching. The final hadronization is performed by using the Lund string fragmentation model.

When both baryon density and energy density are high enough in heavy ion collisions, new features appear compared with hadron-hadron collisions, e.g., high \( P_T \) enhancement, strangeness enhancement, anti-baryon production, etc. They reveal that heavy-ion collisions may possess unknown characteristics or collectivity which are not able to be described by superposition of independent hadron-hadron collisions. The formation of a new state of matter (Harris et al., 1994), Quark-Gluon Plasma (QGP), has been suggested to explain those new features.

Usually, there are many "strings" formed through relativistic heavy-ion collisions. Those strings can thus overlap with each other and produce a heavily interacting system in which the behavior of an individual "string" is affected by the presence of other "strings", which can not be treated independently any longer. In the version of FRITIOF used for the nucleus-nucleus interactions, the Fire Cracker Model (FCM) was used to model the emission of gluons from a system containing several strings formed during collision. In the model, gluons can be emitted collectively from the color field of the multi-string system. Because many particles are produced in high energy nucleus-nucleus collisions, they will scatter with each other and spectator nucleons when going through the interaction region. This rescattering effect...
Using FRITIOF to Model Nucleus-Nucleus Interactions in a Cosmic Ray Detector

(RESCATTERING) has been considered important in heavy-ion collisions. FCM and RESCATTERING, implemented in the Monte Carlo program LUCIAE 2.0, are able to describe high $P_T$ enhancements and increase of strangeness.

The event generator program included LUCIAE 2.0 for simulating gluon emission in the FIRECRACKER model and the rescattering of produced particles in the nuclear environment. The program is written in FORTRAN 77 and was used together with FRITIOF7.02R, JETSET7.3, PYTHIA5.5, and ARIADNE4.02R. The task of PYTHIA is to describe the partonic processes taking place in hadronic collisions. How these partons are transformed into the experimentally measurable particles, i.e., the process of fragmentation, is handled by JETSET. PYTHIA can be combined with any well-defined fragmentation scheme. Although independent fragmentation is included as an option, the fragmentation scheme of JETSET is the Lund string model. ARIADNE is a Monte Carlo program for QCD cascades in the color dipole formulation. Gluon splitting into quark-antiquark pairs and photon emission in the dipole cascade are allowed. The primary cosmic ray interactions were modeled with FRITIOF and LUCIAE on a DEC 3000 AXP processor.

**Primary Energy Spectrum Analysis.**—In emulsion chamber experiments, that part of the primary cosmic-ray energy $E_0$ going into gamma-ray energy $E_{m} = \sum E_{\gamma}$ is the parameter most easily related to the primary cosmic ray spectrum. The photons originating from an interaction will develop individual electromagnetic cascades in the calorimeter. The ability to measure energies of electron-photon cascades is one of the most important functions of the calorimeter because the primary energy $E_0$ spectrum can be found from the $E_m$ spectrum.

In a calorimeter the maximum electron number in an electromagnetic cascade can be related to the total energy of the electromagnetic component $\sum E_{\gamma}$. The measured spectrum of $E_{m}$ is a convolution of the primary cosmic ray spectrum with the energy response function of the detector (Burnett et al., 1986). The quantity $E_{m}$ is directly proportional to the primary energy $E_0$ of the original cosmic ray: $\sum E_{\gamma} = k \cdot E_0$. The response function depends on the distribution of partial inelasticity $k_e$. There is a unique relation (Parnell et al., 1989) or simple scale shift between the $\sum E_{\gamma}$ spectrum and the corresponding primary spectrum, as long as the spectral index and the characteristics of the interactions do not change substantially the observed energy range. It can be shown (Burnett et al., 1986) that the energy conversion factor

$$C = \left( \int_0^1 k^\beta f(k)dk \right)^{1/\beta}$$

represents the energy scale shift required to go from the $E_0$ spectrum to the $E_m = \sum E_{\gamma}$ spectrum. Therefore, the primary $E_0$ spectrum can be found by shifting the $E_m$ spectrum up in energy by the factor, $C^{-1}$, the reciprocal of $C$ (Parnell et al., 1989; Asakimori et al., 1995).

**Results**

For these initial calculations of nucleus-nucleus interactions, the event generator program modeled the emission of gluons from a system containing several strings formed during collision and the rescattering effect. As an illustration of the event generator program results, Fig. 2 shows the distribution of all charged particles as a function of pseudo-rapidity distribution for 200 GeV/$c$ protons incident on fixed target lead nucleus. The predicted values are compared with experimental data (Elías et al., 1980). In Fig. 3 the rapidity distributions for production of all $\pi^+$ and $K^+$ are shown for 1000 GeV/nucleon iron nuclei incident on a fixed target silver nucleus. In Fig. 4 the rapidity distributions for production of all protons and antiprotons are shown for 1000 GeV/nucleon iron nuclei incident on a fixed target silver nucleus. The event generator program included FRITIOF and LUCIAE.

![Figure 2](image_url)

**Fig. 2.** The distribution of all charged particles as a function of pseudo-rapidity for a proton incident on fixed target lead nucleus (Elías et al., 1980). The proton energy was 200 GeV and 2000 events were used in the simulation FRITIOF and LUCIAE were used to model the interaction.
Carlos A. Sánchez, Kazuhiko Murai and Donald C. Wold

Fig. 3. Rapidity distributions of $K^+$ and $\pi^+$ mesons produced by an iron nucleus primary (Fe), with an energy of 1000 GeV/nucleon, incident on a silver target nucleus (Ag). FRITIOF and LUCIAE were used to model the interaction.

Fig. 4. Rapidity distributions of protons and anti-protons mesons produced by an iron nucleus primary (Fe), with an energy of 1000 GeV/nucleon, incident on a silver target nucleus (Ag). FRITIOF and LUCIAE were used to model the interaction.

Typical emulsion chambers contain plastic (CHO) and emulsion targets (Burnett et al., 1987; Parnell et al., 1989). The composition of CHO was 33% C, 53% H, 14% O. The composition of emulsion was 17.5% C, 40.7% H, 4.0% N, 12.0% O, 0.17% S, 12.7% Br, 12.8% Ag, and 0.07% I. Therefore, a light target nucleus (C) and a heavier target nucleus (Ag) were used in modeling the interaction of cosmic ray particles with the target section of the emulsion chamber.

The factor $k_y$ is the partial coefficient of inelasticity, representing that fraction of the energy of the primary nucleus used to create $\gamma$ rays. It is a function of the mass number of both the primary nucleus and the target nucleus (Burnett et al., 1986). Once the target nucleus and the primary cosmic ray have been identified in an emulsion layer of the apparatus, the distribution of $k_y$ becomes a known quantity. This distribution and the energy of the electromagnetic cascade are used to estimate the energy of the primary cosmic ray. Integral or cumulative distributions of $k_y$ for a proton incident on a fixed target lead nucleus (Drake et al., 1980) are shown in Fig. 5. The proton energy was 400 GeV and 2000 events were used in the simulation.

Fig. 5. Integral $k_y$ distributions for a proton with an energy of 400 GeV incident on a fixed target lead nucleus (Drake et al., 1980). FRITIOF and LUCIAE were used to model the interaction.

Number of Events = 2000
Energy = 400 GeV/Nucleon
Cosmic-Ray : P
Target : Pb

+ Drake et al. (1980)
— Simulation

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Discussion

Cosmic rays span a very large energy range from $10^9$ to beyond $10^{20}$ eV. A realistic modeling of particle detectors should include those energies which are likely to be encountered and measured by cosmic ray and gamma ray detectors. The primary cosmic rays were modeled for nucleus-nucleus interactions in an emulsion chamber. These simulations were done with FRITIOF and LUCIAE up to 1000 GeV/nucleon and appear to agree well with existing data, but modeling primary cosmic-ray interactions in the emulsion chamber will be more useful at higher energies where we hope to find evidence for the formation of a quark-gluon plasma. The next step is to show that the primary cosmic ray interaction can be modeled at such energies with FRITIOF and LUCIAE to determine primary energy and composition of the incident cosmic rays. The modeling of SOFCAL can be done with GEANT.

Acknowledgments.—The authors acknowledge the help of colleagues at the NASA George C. Marshall Space Flight Center, Huntsville, Alabama and the University of Arkansas at Little Rock. Dr. Thomas A. Parnell, Dr. Geoffrey N. Pendleton, and Ms. F. Ellen Roberts generously gave the authors valuable support. Mr. Lon Jones III has served as systems manager for the DEC 3000 AXP and the DEC 5000 workstations. This work was supported in part by NASA and funding for the project was provided by the NASA/University Joint Venture (JOVE) Program.

Literature Cited


CERN. 1992b. PAW Physics Analysis Workstation. CERN Program Library Long Write-up Q121. CERN Geneva, Switzerland.

Dake, S. 1980. (Kobe University, Kobe, Japan), unpublished.


Hammett Correlations of Carbonyl $^{13}$C Chemical Shifts in a Series of N-(4-Substituted Phenyl)-6-Chloro-5-Fluoronicotinamides

Frank L. Setliff, John W. Hawley and Alan D. Toland
Department of Chemistry
University of Arkansas at Little Rock
Little Rock, AR 72204

Abstract

A series of nine N-(4-substituted phenyl)-6-chloro-5-fluoronicotinamides exhibited excellent correlations of their carbonyl $^{13}$C shifts ($\delta_{\text{CO}}$, ppm as measured in DMSO) with the standard Hammett substituent constants ($\sigma_R$) of the substituent in the 4-position. The linear relationship was defined by the equation $\delta_{\text{CO}} = 1.22 \sigma_R + 161.50$ with a correlation coefficient of 0.98. The transmission of electronic effects exerted by two substituent was shown to be additive.

Introduction

We have reported (Setliff et al., 1992) that the amide proton chemical shift ($\delta_{\text{NH}}$) in several series of N-(4-substituted phenyl)-2,5, 2,6- and 5,6- dihalonicotinamides correlates extremely well with the standard Hammett substituent constants ($\sigma_R$). In more recent work (Persons et al., 1994) the correlation of the half-wave reduction potentials of these same compounds were also shown to correlate with the standard $\sigma_R$ values. In this paper we describe the results of $^{13}$C NMR studies which reveal very good correlation of the carbonyl chemical shift ($\delta_{\text{CO}}$, ppm) with the Hammett $\sigma_R$ values in a series of N-(4-substituted phenyl)-6-chloro-5-fluoronicotinamides. These compounds were also prepared as candidates for screening as potential agricultural agents.

$^{13}$C chemical shifts have been shown previously to correlate with Hammett substituent constants (Ewing, 1978), but the majority of the early reports dealt with correlations of a ring carbon resonance. Subsequently, work on exocyclic $^{13}$C systems indicated that there was no correlation of standard $\sigma_R$ values in benzylic and related systems. Specifically, in a study of ring substituted benzenamides (R-C$_6$H$_4$-CONH$_2$), attempts to correlate $\delta_{\text{CO}}$ with $\sigma_R$ led unexpectedly to a reverse substituent effect (Bromilow et al., 1981). This reverse effect was explained in terms of pi polarization utilizing a concept coined "molecular lines of force", and was defended by a correlation involving refined Hammett $\sigma_R$ values in a dual substituent parameter equation (Craik et al., 1982). In view of the fact that such complicated substituent effects on the carbonyl electron density occur on the acid side of the amide linkage, we were interested in investigating the effects of aryl substituent groups when present on the nitrogen side of the amide function.

Materials and Methods

The nine N-(substituted phenyl)-6-chloro-5-fluoronicotinamides 1a-11 (Table 1) were prepared from 6-chloro-5-fluoronicotinic acid (Setliff and Rankin, 1972) by the general procedure described previously for the synthesis of analogous dihalonicotinamides (Setliff and Caldwell, 1991). All amides were recrystallized from aqueous ethanol, and melting points were taken on a Mel-Temp II apparatus. Infrared spectra were obtained in KBr disks using a Perkin Elmer 1450 instrument equipped with a Model 7300 data station. Elemental analyses were performed by Desert Analytics Inc., Tuscon, AZ. $^{13}$C NMR spectra were acquired on a Bruker AC-F 200MHz superconducting FT spectrometer with DMSO-d$_6$ as solvent and tetramethylsilane as the internal standard. Sample concentrations were 20 mg/ml. The Hammett plot was produced by an Axum program available from Trimatrix, Inc., Seattle, WA.

Results and Discussion

Sharply melting samples of the nine amides 1a through 11 were obtained in adequate yields (Table 1). All compounds exhibited the expected infrared absorption bands for the secondary amide function. The NH stretch was of moderate intensity in the range 3230-3500 cm$^{-1}$, and the strong CO stretch was found in the range 1640-1680 cm$^{-1}$. Elemental analyses (C,H,N) were all within 0.4% of the theoretical values. The proton NMR spectra (DMSO-d$_6$) also supported the structures. The amide proton resonance, as in all analogous compounds studied, was the signal farthest downfield and occurred as a sharp singlet in the range 11.04-10.42 ppm. The H$_2$ proton (see structure in Table 1) in all cases appeared as a doublet ($J = 2$Hz) in the general range 8.86-8.82 ppm, while the H$_4$
Frank L. Setliff, John W. Hawley and Alan D. Toland

proton, being coupled to fluorine as well as H₂, appeared as a doublet of doublets \( J = 8Hz(2Hz) \) centered in the range of 8.41-8.46 ppm. The H₄ and H₅ protons on the benzene ring appeared as the characteristic AB doublets \( J = 8Hz \) except in compounds 1c and 1d. In the former, with a hydrogen in the 4-position, and in the latter, with a fluorine in the 4-position, H₆ was exhibited as an ill-defined multiplet and H₇ as a triplet \( J = 8Hz \). The methyl protons in 1a, 1b and if appeared as singlets with the respective chemical shifts of \( \delta = 3.75 \), 2.29, and 2.57 ppm. The \( ^{13}C \) spectra were also indicative of the respective structures of the amides, with the carbonyl carbon signal (\( \delta_{CO} \)) being the farthest downfield. These chemical shifts are presented in Table 1. All other carbon signals were assigned, but for the sake of brevity will not be reported herein.

Table 1. Data for the N-(4-substituted)-nicotinamides

<table>
<thead>
<tr>
<th>Cpd.</th>
<th>R</th>
<th>M.p.(°C)</th>
<th>Yld. (%)</th>
<th>( \sigma_R )</th>
<th>( \delta_{CO}(ppm) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>OCH₃</td>
<td>198</td>
<td>67</td>
<td>-0.28</td>
<td>161.11</td>
</tr>
<tr>
<td>b</td>
<td>CH₃</td>
<td>203</td>
<td>80</td>
<td>-0.14</td>
<td>161.35</td>
</tr>
<tr>
<td>c</td>
<td>H</td>
<td>189</td>
<td>91</td>
<td>0.00</td>
<td>161.60</td>
</tr>
<tr>
<td>d</td>
<td>F</td>
<td>175</td>
<td>72</td>
<td>0.06</td>
<td>161.52</td>
</tr>
<tr>
<td>e</td>
<td>Br</td>
<td>197</td>
<td>48</td>
<td>0.22</td>
<td>161.72</td>
</tr>
<tr>
<td>f</td>
<td>COCH₃</td>
<td>260</td>
<td>67</td>
<td>0.47</td>
<td>162.09</td>
</tr>
<tr>
<td>g</td>
<td>CF₃</td>
<td>214</td>
<td>79</td>
<td>0.53</td>
<td>162.19</td>
</tr>
<tr>
<td>h</td>
<td>NO₂</td>
<td>207</td>
<td>85</td>
<td>0.81</td>
<td>162.45</td>
</tr>
<tr>
<td>i</td>
<td>4-Br,3-Me</td>
<td>215</td>
<td>98</td>
<td>0.22+(0.06)</td>
<td>161.62</td>
</tr>
</tbody>
</table>

A plot of the carbonyl carbon shift (\( \delta_{CO} \)) for compounds 1a through 1h vs. the standard \( \sigma_R \) value (Exner, 1988) of the substituent in the 4-position is shown in Fig. 1. The linear relationship is described by the equation:

\[
\delta_{CO} = 1.22 \sigma_R + 161.50
\]

A correlation coefficient of \( r^2 = 0.98 \) indicates a good data fit. The positive slope of the correlation line demonstrates the sensitivity of the system to the removal of electron density from the carbonyl carbon. The downfield shifts observed in those compounds substituted with the electron withdrawing groups (more positive \( \sigma_R \) values) is a reflection of poor nitrogen lone pair resonance with carbonyl carbon. Therefore the resonance contributor \(-)C=\overline{N}=\overline{C}=\overline{H} \) is weak, resulting in a more electron deficient (and thus deshielded) carbon. In those instances where R is electron donating (negative \( \sigma_R \)) there is increased contribution by the resonance structure above, manifesting an upfield shift.

In order to test for the additivity of two substituents, we prepared N-(4-bromo-3-methylphenyl)-6-chloro-5-fluoronicotinamide (1i) and examined its spectrum. If the substituent effects are in fact additive, the algebraic sum of \( \sigma_{Br} \) and \( \sigma_{Me} \) when substituted into the correlation equation should generate a \( \delta_{CO} \) which approximates the experimental chemical shift. The variance of this calculated chemical shift (161.69) from the experimental value (161.62) is only 0.04%. We therefore conclude that the transmission of electronic effects by two substituent on the aryl nitrogen side of the amide is additive. Interestingly, this was shown not to be the case on the aryl carbon side of the amide function (Bromilow et al., 1981).

Fig. 1. Hammett Plot of Carbonyl Carbon Chemical Shifts \( \delta_{CO} \) vs Standard Hammett Substituent Constants \( \sigma_R \).

A plot of the carbonyl carbon shift (\( \delta_{CO} \)) for compounds 1a through 1h vs. the standard \( \sigma_R \) value (Exner, 1988) of the substituent in the 4-position is shown in Fig. 1. The linear relationship is described by the equation:

\[
\delta_{CO} = 1.22 \sigma_R + 161.50
\]

A correlation coefficient of \( r^2 = 0.98 \) indicates a good data fit. The positive slope of the correlation line demonstrates the sensitivity of the system to the removal of electron density from the carbonyl carbon. The downfield shifts observed in those compounds substituted with the electron withdrawing groups (more positive \( \sigma_R \) values) is a reflection of poor nitrogen lone pair resonance with carbonyl carbon. Therefore the resonance contributor \(-)C=\overline{N}=\overline{C}=\overline{H} \) is weak, resulting in a more electron deficient (and thus deshielded) carbon. In those instances where R is electron donating (negative \( \sigma_R \)) there is increased contribution by the resonance structure above, manifesting an upfield shift.

In order to test for the additivity of two substituents, we prepared N-(4-bromo-3-methylphenyl)-6-chloro-5-fluoronicotinamide (1i) and examined its spectrum. If the substituent effects are in fact additive, the algebraic sum of \( \sigma_{Br} \) and \( \sigma_{Me} \) when substituted into the correlation equation should generate a \( \delta_{CO} \) which approximates the experimental chemical shift. The variance of this calculated chemical shift (161.69) from the experimental value (161.62) is only 0.04%. We therefore conclude that the transmission of electronic effects by two substituent on the aryl nitrogen side of the amide is additive. Interestingly, this was shown not to be the case on the aryl carbon side of the amide function (Bromilow et al., 1981).

Based on our previous work involving \( \delta_{NH} \) correlations which indicates that good Hammett relationships exist on the nitrogen side of the amide group regardless of the nature of the acid side of the amide linkage (Setliff et al., 1993), we assume the same to be the case of the \( \delta_{CO} \) correlations. Future work in the \( ^{13}C \) area will include inductive effect sensitivity studies with N-(4-substituted phenyl)-2-halonicotinamides.

ACKNOWLEDGMENTS.—The authors wish to thank the Agricultural Research Division of Rhone Poulenc, Inc. for partial support of this work and a National Science Foundation I.L.I grant for the purchase of the NMR spectrometer.

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Literature Cited


5'-Nucleotidase and Thrombin-Like Activities of Selected Crotalid Venoms

Ali M.S. Shams, Dewey H. Sifford and Bob D. Johnson
Department of Biological Sciences and
Department of Chemistry, Biochemistry and Physics
Arkansas State University
State University, AR 72467

Abstract

Thrombin-like activities were not observed in Crotalus basiliscus, C. molossus and C. scutulatus scutulatus crude venoms. 5'-Nucleotidase specific activities of 0.863, 0.273 and 5.520 units/mg of crude venom protein were observed in C. basiliscus, C. molossus and C. s. scutulatus venoms, respectively. Concanavalin A Sepharose 4 B (Con A) affinity chromatography yielded two fractions from each of the crude venoms. In each instance, both fractions exhibited 5'-nucleotidase activities and the Con A-binding proteins had higher activities than the Con A-nonbinding proteins. 5'-Nucleotidase activities in the DEAE Sephadex A-50 chromatographic fractions were localized in the first elution fraction and the last fraction(s) to elute. EDTA had no effect on the 5'-nucleotidase activities of the crude venoms.

Introduction

Crotalus basiliscus (Cope), the Mexican west-coast rattlesnake is one of the world's largest rattlesnakes. Specimens exceeding 150 cm are common, and the maximum size reported is a little over 200 cm. The range of this species extends from the Rio del Fuerte drainage in extreme southern Sonora, southward along the plains, foothills, and valleys of Sinalo, Nayarit, Jalisco, Colima, and northwestern Michoacan, including the middle Rio Tapalcatpec Valley. The ranges of C. basiliscus and C. molossus overlap and they freely hybridize where they come in contact (Campbell and Lamar, 1989).

C. molossus, the blacktail rattlesnake, is one of the most beautiful rattlesnakes. Its maximum body length is 126 cm. The darkest individuals are usually from habitats featuring dark substrates. C. molossus is found from central and west-central Texas northwest through the southern half of New Mexico to northern and extreme western Arizona southward to the southern edge of Mexican Plateau and Mesa del sur, Oaca. It also occurs on the Tiburon and San Esteban islands in The Gulf of California (Ernst, 1992).

C. scutulatus, the Mojave rattlesnake, has a maximum length of 129 cm (Ernst, 1992). This crotalid species is probably the most dangerous rattlesnake, as its venom is neurotoxic (Minton, 1956; Johnson et al., 1966). C. scutulatus is found from southwestern Washington county, Utah, Lincoln and Clark counties, Nevada, and Kern, Los Angeles, and San Bernardino counties in California, southeast through Arizona and southward from Transpeces, Texas, and southwestern Hildalgo and Otero counties in New Mexico, to the southern edge of the Mexican Plateau in Puebla and adjacent Vera Cruz (Campbell and Lamar, 1989).

Crotalid venoms are very complex with the majority of the venom consisting of numerous protein components having enzymatic activities. The concentrations of proteins, and presumably of different toxins, vary between individual snakes (Johnson et al., 1968). At least 18 different enzymatic activities have been identified in crotalid venoms (Iwanaga and Suzuki, 1979). Among these, there are at least four enzymes involved in the hydrolysis of phosphate bonds. These include endonuclease, alkaline nonspecific phosphatase, 5'-nucleotidase, and phosphodiesterase (Tu, 1977). A specific phosphomonoesterase, 5'-nucleotidase, specifically hydrolyzes phosphate monoester which links at the 5'position of DNA and RNA. Upon dialysis, crude venom 5'-nucleotidase activities increased two or three times that of the nondialyzed samples, suggesting that some substance, probably zinc ions which are abundant in crude venoms, inhibits the activity (Suzuki and Iwanaga, 1958).

Many venoms exert profound effects on the blood coagulation system. Some accelerate the coagulation process and others retard it. Thus snake venoms are often divided into two types, coagulant and anticoagulant. Some venoms contain both coagulant and anticoagulant factors simultaneously, and sometimes a venom becomes coagulant or anticoagulant depending on the concentration used (Tu, 1977). Also, various mechanisms can induce procoagulation or anticoagulation. A venom may act as a coagulant for the following reasons: it has thromboplastin-like activity, it contains a factor X activator, it activates factor V, it activates prothrombin, or it has a thrombin-like activity. A venom may also act as an antico-
Materials and Methods

Lyophilized *C. molossus* and *C. basiliscus* venoms were provided by Dr. H.L. Stahnke of Arizona State University. *C. s. scutulatus* venoms, adenosine 5'-monophosphate, fibrinogen, and thrombin were purchased from Sigma Chemical Company. Ammonium molybdate, hydroquinone, and sodium sulfate were purchased from Fisher Scientific Company. Magnesium sulfate, sulfuric acid, and tris (hydroxymethyl) aminomethane (TRIS) were purchased from Mallinckrodt Chemical Works. Glycine was purchased from Matheson, Coleman and Bell. Sodium sulfate was purchased from J.T. Baker Chemical Company. Sephadex G-25, Concanavalin A-Sepharose 4B (Con A), DEAE Sephadex A-50, and columns were purchased from Pharmacia, Uppsala, Sweden.

Fractionations using Con A gel were performed using 425 mg samples of whole venom on columns which had been equilibrated with 0.05 M ammonium acetate buffer (pH 7.0) (Iscove et al., 1974; Aspberg and Porath, 1970; Hinson et al., 1985-5). The Con A-nonbinding proteins (FI) were eluted at 4 °C with 500 mL of 0.05 M ammonium acetate (pH 7.0) containing 0.5 M NaCl. The Con A-binding proteins (FII) were eluted at 4 °C with 500 mL of 0.05 M ammonium acetate buffer containing 0.5 M NaCl and 0.25 M a-methyl-D-mannoside. Eluates of 110 drops (-4 mL) per tube were collected and stored at -12 °C within 2 hrs after collection (Beasley et al., 1993 and Stegall et al., 1994).

DEAE Sephadex A-50 ion exchange chromatography was performed on 400 mg samples of whole venom dissolved in 0.05 M ammonium acetate buffer (pH 8.0) (Cheng and Ouyang, 1967; Ouyang et al., 1971; Sifford and Johnson, 1978; Hinson et al., 1985). Two stage gradient elutions were performed on each venom using ammonium acetate buffers. The first stage gradient elution was performed with 250 mL of 0.05 M ammonium acetate (pH 8.0) in the mixing vessel and 310 mL of 0.9 M ammonium acetate (pH 6.0) in the reservoir. The second stage gradient elution was performed with 240 mL of 0.3 M ammonium acetate (pH 6.0) in the mixing vessel and 310 mL of 0.9 M ammonium acetate (pH 5.4) in the reservoir. The column (2.5 cm X 56 cm) was maintained at 4 °C and eluates were collected in 5 mL fractions. All fractions were stored at -12 °C within 2 hrs of collection (Beasley et al., 1993).

For protein concentration estimations and 5'-nucleotidase assays, a Beckman DB spectrophotometer and a Spectronic 1201 were used. Protein concentrations of the fractions were estimated from their absorbances at 280 nm. An absorbance at 280 nm of 1.0 for 1.0 mg of venom per mL was used (Sifford and Johnson, 1978).

5'-Nucleotidase activities were determined by the method of Ging (1956), Lo et al. (1966), Sifford and Johnson (1978) and Hinson et al. (1985). The factor (0.250) used by Ging (1956) and Lo et al. (1966) for converting 5'-nucleotidase activities which were measured at 37 °C to values at 25 °C was used. Thrombin-like activities were determined by the method of Sato et al. (1965) with the minor modification used in the works by Sifford and Johnson (1978) and Hinson et al. (1985).

Metal requirements for each enzyme were investigated by incubating 0.5 mL of venom or venom fraction with an equal volume of ethylenediaminetetraacetic acid (EDTA) solution for 10 minutes at 37 °C (Friederich and Tu, 1971; Goucher and Flowers, 1964; Stegall et al., 1994). This mixture was diluted with water to yield a final concentration of 0.6 m EDTA in a total volume of 1.0 mL. Aliquots of this mixture were assayed for 5'-nucleotidase with control samples having water in place of EDTA.

Results and Discussion

Thrombin-like activities were not observed in *C. basiliscus*, *C. molossus*, and *C. s. scutulatus* crude venoms. Thus, subsequent assays for thrombin-like activities were not performed on the venom fractions obtained by affinity and ion exchange chromatography. Thrombin-like activities have been reported in other crotalid venoms, e.g., *Agkistrodon acutus*, *Trimeresurus gramineus*, *T. okinavensis*, *T. flaviridis*, *C. horridus horridus*, and *C. adamanteus* (Tu, 1977). Markland and Dumas (1971) have extensively studied the chemical properties of purified *C. adamanteus* venom thrombin-like enzyme.

Con A fractionation yielded two fractions for each of the whole venoms: Fraction I (FI) was composed of Con A-nonbinding proteins and Fraction II (FII) was composed of Con A-binding proteins. In each instance, the crude venom 5'-nucleotidase activities were higher than the activities in the corresponding FI and FII proteins.

"5'-Nucleotidase and Thrombin-Like Activities of Selected Crotalid Venoms"

Proceedings Arkansas Academy of Science, Vol. 49, 1995
Table 1. 5'-Nucleotidase specific activities of selected crotalid venoms.

<table>
<thead>
<tr>
<th>Venom</th>
<th>Activity*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crotalus basiliscus:</strong></td>
<td></td>
</tr>
<tr>
<td>Crude Venom</td>
<td>0.863</td>
</tr>
<tr>
<td>Concanavalin A-nonbinding proteins (Fl)</td>
<td>0.265</td>
</tr>
<tr>
<td>Concanavalin A-binding proteins (Fl1)</td>
<td>0.740</td>
</tr>
<tr>
<td><strong>Crotalus molossus</strong></td>
<td></td>
</tr>
<tr>
<td>Crude venom</td>
<td>0.273</td>
</tr>
<tr>
<td>Concanavalin A-nonbinding proteins (Fl)</td>
<td>0.024</td>
</tr>
<tr>
<td>Concanavalin A-binding proteins (Fl1)</td>
<td>0.036</td>
</tr>
<tr>
<td><strong>Crotalus scutulatus scutulatus</strong></td>
<td></td>
</tr>
<tr>
<td>Crude venom</td>
<td>5.520</td>
</tr>
<tr>
<td>Concanavalin A-nonbinding proteins (Fl)</td>
<td>0.131</td>
</tr>
<tr>
<td>Concanavalin A-binding proteins (Fl1)</td>
<td>1.010</td>
</tr>
</tbody>
</table>

*5'-Nucleotidase activities are reported as mean μmoles substrate hydrolyzed/min/mg venom

DEAE Sephadex A-50 chromatography of *C. basiliscus*, *C. molossus*, and *C. s. scutulatus* venoms yielded several fractions from each of the whole venoms. 5'-Nucleotidase activities were localized, for the most part, in the first fraction obtained during the first stage elution and in the last few fractions obtained during the second stage elution. The highest specific activities occurred in the first fraction (around tube 20) to elute (Figs. 1-3). These results were comparable to distributions of phosphodiesterase and 5'-nucleotidase activities in the DEAE Sephadex A-50 fractions of *A. bilineatus* venom in which these enzymes eluted in the first fraction (Sifford and Johnson, 1978). *C. basiliscus* and *C. s. scutulatus* venoms yielded only two peaks of activity for 5'-nucleotidase. *C. molossus* venom's 5'-nucleotidase activity was much lower than the activities observed in *C. basiliscus* and *C. s. scutulatus* venoms.

The peak activities for 5'-nucleotidase observed in the DEAE Sephadex A-50 fractions were less than the activities in the crude venoms, suggesting that this enzyme is heat labile or that a necessary activator might have been removed. The mean 5'-nucleotidase activity for *C. s. scutulatus* crude venom in this work was somewhat higher than the activities reported by Hinson et al. (1985) and Childs et al. (1986). The 5'-nucleotidase activities in our Con A fractions, however, were lower than those reported by either Hinson et al. (1985) or Childs et al. (1986).

EDTA had no effect on the 5'-nucleotidase activities of the crude venoms. Thus, no EDTA assays were performed on the venom fractions.
enzyme or several. This question was also raised by Stegall et al. (1994) in their work with proteinases and esterases in C. basiliscus, C. molossus, and C. s. scutulatus venoms.

**Literature Cited**


Polishing of CVD-Diamond Substrates Using Reactive Ion Etching

Gopi M.R. Sirineni, H.A. Naseem, W.D. Brown and A.P. Malshe
High Density Electronic Center (HiDEC)
Department of Electrical Engineering
University of Arkansas
Fayetteville, AR 72701

Abstract

Multichip modules (MCM) have proved to be a viable packaging technology for achieving small size and high performance. By their nature, MCMs typically integrate multiple bare die into a module that can be the plastic or ceramic package. As a result, the MCM requires an efficient mechanism for removing excess heat. Diamond with its excellent thermal conductivity, is the ideal choice as a substrate material for these applications. Chemical vapor deposited (CVD) diamond substrates makes possible the practical realization of a novel diamond based 3-D MCM. However, the diamond films grown by CVD technique are polycrystalline and have non-uniform film roughness and randomly faceted crystals. These non-planar surfaces reduce the diamond's thermal management efficiency. Therefore, it becomes imperative that the as-deposited diamond films be polished for use in MCMs. Chemical assisted mechanical polishing (CAMP) technique has been developed at HiDEC, University of Arkansas. In this technique diamond is lapped against an alumina plate under a load in the presence of certain chemicals. Although CAMP technique reduces the lapping time considerably, still newer techniques must be developed to reduce polishing cost further. We are currently using reactive ion etching (RIE) to substantially reduce the polishing time. Preliminary studies using reactive ion etching showed etch rates of 500 - 1000Å/min at low pressures. These etched films showed a considerably higher polishing rate (using CAMP technique) than the non-etched films. Changes in the morphology and structure of the diamond films due to etching and polishing were characterized by scanning electron microscopy (SEM), Dektak profilometer and Raman spectroscopy. This paper presents a systematic study of RIE and CAMP of CVD-diamond substrates.

Introduction

The need to miniaturize electronic systems and to increase the speed of signal propagation for faster data processing is increasing day by day. The emerging multichip module (MCM) packaging technology offers great improvements in signal speed and performance while reducing the size of the electronic systems. Silicon, metals and ceramics are commonly used substrates for MCM fabrication. But the increase in the current densities and power levels of integrated circuits are causing heat transfer to be a major issue in designing MCMs. Attention is now being directed to thermal management in the MCM packaging. Diamond is one of the most technologically important materials because of its very attractive properties such as high thermal conductivity, high electrical resistivity, low coefficient of thermal expansion and extremely high hardness. These properties of diamond surpasses those of all established substrate materials, and make it an ideal choice for 3-D MCMs. Chemical vapor deposition of diamond substrates makes possible the practical realization of a novel diamond based 3-D MCM. The fundamental process of chemical vapor deposition involved in the growth of polycrystalline diamond film surfaces leads to a high degree of surface roughness. Unfortunately, the higher the quality and growth rate of the diamond films, the rougher the surface tends to be. As a result, contact area of as-deposited diamond with the chips will be less, resulting in poor thermal management efficiency. Techniques for limiting such roughness in the deposition process are being explored, but it is reasonable to assume that some degree of post-deposition surface finishing will be required for most of applications.

During the last few years most of the research work reported in the area of dry etching and plasma polishing at high temperatures. Yang et al., and Yoshikawa reported mechanical polishing with hot metal (Yang et al., Sci. and Tech. of New Diamond, pp. 135-138, 1990; Yoshikawa, SPIE, pp. 1325, 1990). Different plasma polishing techniques like ECR plasma, ion beam, laser beam, and sputtering have been reported for the polishing of diamond films (Beetz et al., MRS Int. Conference Proc., 1991; Tankala et al., New Diamond Sci. Tech., pp. 827, 1991).

Simple room temperature polishing procedures are very difficult and time consuming. Since room temperature polishing increases the polishing cost and more importantly, it has been reported to deteriorate diamond properties. Standard room temperature abrasive polish-
Polishing of CVD-Diamond Substrates Using Reactive Ion Etching

ing has been adopted by many. However, due to the diamond extreme hardness, such techniques have not proven to be economical. At the University of Arkansas, Fayetteville, we have developed a chemical assisted mechanical polishing (CAMP) technique that reduces the polishing time considerably without deteriorating its useful properties. In this study, reactive ion etching (RIE) has been investigated as a potential technique to prepare the diamond surface for final polishing by the CAMP technique at even faster rates.

Materials and Methods

Diamond samples used for this work were supplied by Norton Diamond Films, Northboro, MA. These were 1 cm X 1 cm free standing substrates of thickness 800 μm and surface roughness of 10 - 15 μm. These were grown by magnetically stirred DC Arcjet technique. A Plasma-Therm model SLR reactive ion etching system was used in our experiments to etch the diamond samples. Most of the etching was performed at a RF power of 350 W and in the pressure range of 50 to 250 mTorr. Oxygen was used as reacting gas with flow rates of 20-40 sccm. All etching experiments were done at room temperature. The rate of etching of diamond films was determined from the weight changes measured using an electronic micro-balance.

Two samples, one with RIE etching and the other without, were CAMP-polished under similar conditions for the same amount of time. The results are described below.

Results and Discussion

A scanning electron micrograph (SEM) of a typical as-deposited highly faceted polycrystalline diamond substrate is shown in Fig. 1. It can be inferred from this figure that these films have a large grain size (of around 100 μm), and the grain boundaries are not easily describable. Figure 2 shows a SEM of a polycrystalline diamond substrate after reactive ion etching. It clearly shows a different morphology when it is compared with Fig. 1; holes are seen on several crystals and the grain boundaries have become well defined. Figure 3 shows a SEM of a diamond substrate etched at a pressure of 150 mTorr in the chamber. It shows preferential etching along the grain boundaries. At high pressures (250 mTorr), however, the etching was found to take place preferentially on the top of the crystals (see, for example, Fig. 2). Some wormholes were also observed on top of individual crystals as shown in Fig. 4. Figure 4a shows these wormholes at lower magnification and Fig. 4b shows them at higher magnification. Similar results were also observed by Ramesham with air-microwave plasma etching (Ramesham et al., J. of Electrochem Soc., Vol. 139, No. 7, 1992). Different micro-crystals have been etched selectively in different directions, but there was no particular direction of etching that could be clearly identified.

Fig. 1. Scanning electron micrograph (SEM) of a typical as-deposited polycrystalline diamond substrate.

Fig. 2. Scanning electron micrograph of a polycrystalline diamond after reactive ion etching.

Etch rate of diamond was found to increase with increase in chamber pressure. Figure 5 shows a graph of etch rate vs chamber pressure. It was observed that there was no etching below 50 mTorr pressure. At 150 mTorr pressure the diamond started to etch, but mostly along grain boundaries (as in Fig. 3), initially with an etch rate
of about 500 Å/min. At high pressures (200-250 mTorr) however, etching was mostly on crystal tops as previously shown in Fig. 2 with etch rates of 700-900Å/min. It was also found that etch rate was increased to 1000Å/min with a decrease in the flow rate of the reacting gas.

After etching, diamond samples appeared dark and lost their transparency. Figure 6 shows the Raman spectra of diamond films (a) before and (b) after etching. It can be observed from the figure that there is no increase in graphitic component after etching. Therefore, it can be inferred that the darkening is primarily an optical effect and can be attributed to scattering of light due to the formation of micro channels. Tankala and Debroy also observed similar darkening when they etched diamond films with argon plasma (Tankala K. and Debroy T., New Diamond Sci. and Tech., MRS Int. Conference, pp. 827, 1991).

Figure 7 (a) and (b) show the scanning electron micrograph (SEM) of CAMP-polished diamond samples subsequent to RIE etching and without RIE, respectively. It was observed that the reactive ion etched sample removal rate was high when compared with that of an un-etched sample. Figure 7 (a) shows well polished crystals, whereas Fig. 7 (b) reveals no such polished crystals on the un-etched sample.

Surface roughness was measured at every stage of the process by a Dektak surface profilometer. Decrease in the surface roughness after the RIE was observed in the range of 500-1000 Å.

**Summary and Conclusions**

Etch rates were observed to increase with the increase in the chamber pressure. Under certain conditions diamond was being preferentially etched along grain boundaries. At high chamber pressures micro-channels were etched on top of the facets, but no preferential etch direction could be identified. The etch rates were found to be between 500-1000 Å/min. A decrease in reacting gas flow rate increased the etch rate. Reactive ion etching of diamond before chemical assisted mechanical polishing helps to substantially (may be to the half)
reduce the CAMP polishing time by increasing the diamond removal rate.

ACKNOWLEDGMENTS.—The authors would like to acknowledge the financial support of Norton Diamond Film, Northboro, MA and the U.S. Department of Defense for this research. The assistance provided by Mr. Shi and Mrs. Denise A. Iribarren is also greatly appreciated.

Literature Cited


Fig. 6. Raman spectra of a diamond substrate (a) before etching and (b) after etching

Fig. 7. (a). Scanning electron micrograph of a CAMP-polished diamond substrate with reactive ion etching.

Fig. 7. (b) Scanning electron micrograph of a CAMP-polished diamond substrate without reactive ion etching

Yoshikawa M. 1990. SPIE 1325, Diamond Optics III.
Retrieval of Atmospheric Turbidity Coefficient and Water Column Density from Solar Irradiance Data

Felix Tendeku  
Department of Industrial Technology  
University of Arkansas at Pine Bluff  
Pine Bluff, AR 71601

Abstract

Ground-based measurement of solar irradiance has been made using a spectroradiometer at wavelengths in water absorption band. An algorithm is formulated to retrieve simultaneously the atmospheric water column density and Ångström’s turbidity coefficient. The transmission models used to account for the contribution from diverse atmospheric absorbing and scattering elements are presented.

Introduction

In optical modeling for the development of solar energy devices, the knowledge of the spectral distribution of solar radiation reaching the earth’s surface is essential. When passing through the atmosphere, solar radiation is attenuated due to scattering by aerosols and absorption by various atmospheric components, mainly water vapor and gases such as ozone, carbon dioxide and oxygen. Some of these attenuator are permanent while others vary as a function of time and geographical location. To characterize the atmosphere the minimum parameters required are the turbidity and the amount of water vapor.

Solar radiation is affected by atmospheric water vapor due to absorption bands in the solar spectrum. Also, with increasing humidity water vapor condenses onto aerosols, changing their size and refractive index and consequently their radiation scattering ability. The experimental determination of atmospheric water column density may be made by measurement of the direct normal irradiance in a water vapor absorption band in the solar spectrum, typically at 942 nm.

Atmospheric turbidity is a measure of the attenuation of the direct beam solar radiation by atmospheric aerosols. It is affected by the amount, kind and size distribution of aerosols as well as the amount and distribution of atmospheric water vapor. It is commonly represented as an index. The three indices in use are Linke’s turbidity factor, Tg, Ångström’s turbidity coefficient, \( \alpha \), and Schüepp’s turbidity coefficient, B.

Linke’s turbidity factor (Linke, 1922) is a measure of the number of clean dry atmospheres that would be necessary to produce the attenuation of extraterrestrial radiation equivalent to that produced by the real atmosphere. \( T_g \) is the attenuation due to the presence of aerosols and gaseous water vapor spectrally integrated over the solar spectrum. Although a useful parameter, its drawback is its dependence on air mass. Attempts have been made to relate it to Ångström’s turbidity coefficient (Grenier et al., 1994).

Ångström’s turbidity coefficient is a dimensionless index that represents the amount of aerosols in the vertical column. It appears in Ångström’s formula (Ångström, 1961; and Ångström, 1964), namely,

\[
\tau_\alpha = \beta \lambda^{-\alpha}
\]

where \( \beta \), the turbidity coefficient, is a constant parameter defining the amount of aerosol in the air; \( \tau_\alpha \) is the optical thickness due to aerosol scattering; \( \lambda \) is the wavelength in micrometers; and \( \alpha \) is the wavelength exponent which is representative of the average aerosol size distribution. A number of techniques are currently employed for measuring \( \beta \). In one method, \( \beta \) is obtained by measuring the optical depth at two wavelengths where molecular absorption is negligible. This method yields simultaneously values for both \( \alpha \) and \( \beta \). In another method, \( \beta \) may be measured with a single wavelength instrument at \( \lambda = 1 \mu m \). Under this condition the wavelength effect of \( \alpha \) disappears as can be seen from equation (1). The representation of atmospheric turbidity by Ångström’s turbidity coefficient is very common. Its determination has been the subject of a number of projects, such as Katz et al., (1982); Prodi et al., (1984); Ideriah, (1985); and Louche et al., (1987). It can vary from 0.0 for absolutely clean atmosphere to about 0.40 for very high aerosol amounts.

The third index, Schüepp’s turbidity index (Schüepp, 1949) is obtained by the measurement of the direct spectral irradiance at 500 nm. It is related to Ångström’s turbidity coefficient by

\[
B = \beta^2 \log e
\]

Many atmospheric aerosols are hygroscopic and
change their size according to the humidity. Inspite of this fact, water vapor amount and turbidity are often measured separately. In this paper a method is described to determine the two parameters simultaneously from solar irradiance data measured at wavelengths in opt-water vapor absorption band extending approximately from 890 to 990 nm. Turbidity will be specified by Ångström’s turbidity coefficient.

Methods

The direct solar irradiance on a surface element normal to the sun’s rays at the ground may be written as

\[ I(\lambda) = I_0(\lambda) T_R(\lambda) T_{\text{a}}(\lambda) T_g(\lambda) T_W(\lambda) T_a(\lambda) \]  

(3)

where \( I_0 \) is the extraterrestrial spectral irradiance at mean solar distance; \( T_R, T_{\text{a}}, T_g, T_W \) and \( T_a \) are respectively the spectral transmittance functions of Raleigh (molecular) scattering, ozone absorption, absorption by uniformly mixed gases (CO\(_2\), O\(_2\), CH\(_4\), NO\(_2\), etc.), water vapor absorption and aerosol attenuation.

An expression for molecular scattering transmittance based on Penndorf’s data (Penndorf, 1957) and used in LOWTRAN 5 (Kneizys et al., 1980), is

\[ T_R = \exp \left\{ -m / \left[ \lambda^4 \right] \left\{ 115.6406 - 1.355 / \lambda^2 \right\} \right\} \]  

(4)

where \( \lambda \) is the wavelength in \( \mu \)m, \( m \) is the pressure-corrected air mass, \( m = m_rP/(P_0) \), \( P_0 = 1013 \text{ mb} \), \( P \) is the surface pressure, and \( m_r \) is the relative air mass which may be computed as (Kasten, 1966):

\[ m_r = \left\{ \cos (Z) + 0.15 \left( 93.885 - Z \right)^{-1.253} \right\} \]  

(5)

where \( Z \) is the solar zenith angle.

The transmittance through ozone may be expressed as

\[ T_{\text{OZ}}(\lambda) = \exp \left\{ -k(\lambda) \cdot m_{\text{OZ}} \right\} \]  

(6)

where \( k(\lambda) \) are ozone absorption coefficients (Vigroux, 1953), \( t \) is the integrated ozone amount in the vertical column reduced to standard temperature and pressure, and \( m_{\text{OZ}} \) is the air mass expression for ozone given by Paltridge and Platt (1976):

\[ m_{\text{OZ}} = 35.0 / \left( 1224.0 \cos^2(Z) + 1 \right)^{0.5} \]  

(7)

The transmittance function for a path at air mass \( m \) through uniformly mixed gases is given by (Leckner, 1978):

\[ T_g = \exp \left\{ - \frac{1.41 k_g m}{(1 + 118.3 k_g m)^{0.45}} \right\} \]  

(8)

where \( k_g \) are the effective absorption coefficients for uniformly mixed gases.

Aerosol attenuation is adequately represented by Ångström’s power law; thus the transmittance may be expressed as

\[ T_a(\lambda) = \exp \left\{ - \beta \lambda^{-\alpha m} \right\} \]  

(9)

where \( \alpha \) and \( \beta \) have been defined earlier.

In the treatment of water vapor absorption transmittance, several functional expressions are found in the literature, for example, Moskealenko (1969), Koepeke and Quenzel (1978), Leckner (1978), Bird (1984) and Pierluissi et al., (1989). The spectral transmittance model of water vapor may be expressed as (Leckner, 1978):

\[ T_w = \exp \left\{ - \frac{0.2385 k_w \cdot \lambda}{(1 + 20.07 k_w \cdot \lambda)^{0.45}} \right\} \]  

(10)

where \( k_w \) is the effective absorption coefficient of water vapor for a given wavelength interval \( i \), and \( w \), the column density (gm/cm\(^2\)), is the integrated amount of water in a vertical column defined as:

\[ w = \int_0^Z \rho_w(W) \, dz \]  

(11)

where \( \rho_w \) is the water vapor density (gm/cm\(^2\)), \( z \) is the altitude (cm) and \( Z \) is the elevation above ground at which \( \rho_w \) may be considered to reach zero.

In opt-water absorption region absorption by ozone and uniformly mixed gases is known to be negligible, thus equation (3) may be written as

\[ I(\lambda) = I_0(\lambda) \exp \left\{ -m \tau_i \right\} \]  

(12)

where \( \tau_i = \tau_R + \tau_W + \tau_a \) is the total optical depth; \( \tau_R, \tau_W, \) and \( \tau_a \) are the optical depths due to molecular scattering, water vapor and aerosols respectively.

In the following, a method is described that utilizes the total optical depth, \( \tau_i \), determined from radiometric measurements to obtain both atmospheric water column density, \( w \), and Ångström’s turbidity coefficient, \( \beta \). Water column density, \( w \), is set up as the main variable while aerosol optical depth is calculated, for \( m = 1 \), using

\[ \tau_a = \tau_i - \tau_R - \tau_W \]  

(13)

where, from equation (4)


\[ \tau_R = \frac{1}{\lambda^4 \left( 115.6406 - 11.335 / \lambda^2 \right) } \]  

(14)

and from equation (10)

\[ \tau_w = 0.2385k_i w / \left( 1 + 20.07 k_i w \right)^{0.43} \]  

(15)

For values of \( w \) varying from zero to a maximum, \( \tau_w \) calculated from (13)-(15) are least-squares fitted to (1). The value of \( \alpha \), the wavelength exponent, depends on the location of the experiment. It is found to be in the range 1.3 \pm 0.5 for real atmospheres whereas \( \alpha = 1.30 \) is representative of a standard aerosol size distribution.

The following are calculated at the convergence of the fit:

\[ \chi^2 (w) = \sum_{i=1}^{i=1} \left( \tau_i - \beta_i \lambda_i w \right)^2 \]  

(16)

and

\[ \frac{\partial \chi^2 (w)}{\partial w} = -2 \sum_{i=1}^{i=1} \left( \tau_i - \beta_i \lambda_i w \right) \frac{\partial \tau_i}{\partial w} \]  

(17)

where the summation is made over the wavelengths of measurement. When \( \chi^2 (w) \) attains a minimum and \( \frac{\partial \chi^2 (w)}{\partial w} \), its partial derivative with respect to \( w \) is zero, the corresponding values of \( w \) and \( \beta \) represent water column density and turbidity coefficient. The above minimization technique has been demonstrated in Tendeku (1994).

**Results and Discussion**

Measurements of the direct solar irradiance were made using a spectroradiometer (Tendeku, 1994) with five interference filters centered at 903, 941, 951, 974 and 1000 nm, respectively. The bandwidths of the filters are 10.5, 8.0, 8.2, 11.5 and 8.8 nm, respectively. Four of the filters are in the \( \lambda \)-\( \)water absorption band. Figure 1 shows a typical variation of atmospheric transmission in the \( \lambda \)-\( \)water absorption band.

The filter centered at 1000 nm plays two roles. First, it is used with the other filters to determine the total optical depth; second, it simulates a single wavelength measurement of the turbidity coefficient. From equation (1), at \( \lambda = 1 \mu m \), \( \tau_a = \beta \). The measured total optical depth, \( \tau_o \), is the sum of the molecular scattering optical depth, \( \tau_m \), and the aerosol optical depth, \( \tau_a \), since the absorption by other elements is negligible. Thus, \( \beta = \tau_o - \tau_m \).

Figure 2 shows a typical variation of the direct solar irradiance with solar zenith angle. The irradiance increases from sunrise to a maximum at the sun's highest elevation. A plot of the natural logarithm of irradiance readings versus air mass is made for each of the five filters.

On a sunny day when the atmosphere is homogeneous, the plot produces straight lines whose slopes give the total optical depth of the atmosphere for each wavelength. These values form the input to the minimization algorithm described above. The absorption coefficients, \( k_i \), used in equation (15) are taken from Leckner's table (Leckner, 1978).

Table 1 shows results for days in the first trimester of 1995 when the atmosphere was found to be fairly stable. The mean turbidity coefficient, \( \beta \), for the period is 0.14.
The value is lower for a comparatively drier atmosphere and higher for increasing water vapor amounts. In 1961-66 a network program was established to make routine measurements of turbidity over the United States. Results from this program published by Flowers et al., (1969) show mean turbidities for the eastern parts in the range of 0.10 - 0.20. These results show seasonal variations with low values in winter and high values in summer. Results obtained in this work, shown in Table 1, are considerably higher than those obtained some three decades ago. Increased pollution due to industrial and agricultural activities may be the cause. Results also show a positive correlation between turbidity and atmospheric water vapor content.

<table>
<thead>
<tr>
<th>Date</th>
<th>w (gm/cm²)</th>
<th>β</th>
<th>β¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/20/95</td>
<td>0.3</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>2/18/95</td>
<td>1.2</td>
<td>0.14</td>
<td>0.15</td>
</tr>
<tr>
<td>2/24/95</td>
<td>1.1</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>3/28/95</td>
<td>1.6</td>
<td>0.16</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Table 1. Results of experimental measurement of atmospheric water vapor and Ångström’s turbidity coefficient. β¹ is single wavelength measurement. Location is Pine Bluff (34.13°N, 92.0°W).

**Literature Cited**


A Drift Chamber Utilizing Microstrip Readout for Testing a New Micro TPC Concept

H. Wieman, W.G. Gong and S. Margetis
Nuclear Science Division
Lawrence Berkeley Laboratory
Berkeley, CA 94720

M.T. Burks, W.J. Braithwaite and A.A. Rollefson
Physics and Astronomy
Univ. of Arkansas at Little Rock
Little Rock, AR 72204

Abstract

A drift chamber type radiation detector is being used to examine design criteria for a new type of detector called a micro Time Projection Chamber (micro TPC) which is being proposed for use in high energy nuclear physics experiments. The main advantage of the micro TPC detector is its very low radiation thickness compared to its silicon counterpart. The micro TPC is a charged-particle detector which will be optimized for good two track resolution which is needed in a high track density environment. Such performance requires low electron diffusion and high resolution readout. The diffusion will be reduced by limiting the drift distance to 15 cm and by using a low diffusion gas such as dimethyl ether. High resolution will be obtained by using a new readout technology called microstrips. Microstrips are a recent development using photolithography techniques that allow the creation of anodes a few microns in width with submicron precision. The main purpose of this test chamber is to demonstrate the feasibility of a micro TPC design using a low diffusion gas and to insure the sufficient signal remains after electron attenuation. The drift chamber design and the proposed testing procedures are described.

Introduction

In high energy nuclear physics experiments, such as those proposed for the Relativistic Heavy Ion Collider (RHIC), high particle density puts an extra demand on a detector's ability to distinguish between close pairs of tracks. A new type of detector has been proposed (Wieman, 1994) which will be optimized for low mass and good two-track resolution. This detector, known as a micro Time Projection Chamber (micro TPC), will utilize microstrip anodes for readout.

A time projection chamber works on the principle that radiation passing through a gas ionizes molecules in its path and leaves a trail of electrons along the way. The electrons are forced by means of an electric field to drift towards anode wires at one end of the chamber. As the electrons approach a distance of a few times the wire radius, the electric field felt by the electrons increases as 1/r. In this high potential region electrons accelerate enough to ionize molecules with the new electrons in turn accelerating and ionizing more molecules until an avalanche forms. This avalanche is known as the amplification or the gas gain and insures that a sufficient number of electrons are produced to obtain a detectable signal.

Traditionally, the anodes were thin wires capacitively coupled to readout pads. Recently, however, a new technology known as the microstrip detector (Oed, 1988; Angelini et al., 1991, 1992) has been developed which can be used in a micro TPC as an alternative readout technique. These microstrip detectors use thin metal electrodes on an insulating substrate which, by using precise photolithography techniques, can be spaced accurately on the order of a few microns. This distance is significantly smaller than what one is able to accomplish with conventional readouts and the position and two-track resolution are correspondingly improved. For this project, microstrip detectors have been fabricated at the Berkeley Micro-Fabrication Laboratory (Gong et al., 1994).

Dimethyl ether (DME) has been chosen as a promising candidate for the drift gas of the chamber. The limits of position resolution and two-track resolution in the micro TPC design are set by the diffusion of the drift gas and DME has been shown to have a very low diffusion constant (Villa, 1983). In addition, limiting the drift length of the chamber to 15 cm will help keep the diffusion low.

One of the main concerns of using DME in the micro TPC design is the electron attenuation due to electron attachment coupled to the relatively slow drift velocity, resulting in a loss of part of the signal. The number of electrons lost increases exponentially with the drift length and the concentration of electron-negative epollutants (Sauli, 1977). Since the proposed drift length is relatively long, the purity must remain exceptionally high for proper functioning of the detector. Thus, the primary purpose of this test chamber is to measure the electron attenuation to insure that a sufficient number of electrons reach the microstrip anodes. Also, if necessary, purification methods will be studied to determine how to best minimize pollutants that cause electron attenuation.
Materials and Methods

**Chamber construction.**—The test chamber consists of an aluminum cylinder 18 cm in height and 21 cm in diameter (see Fig. 1). It has quartz windows on one side for the purpose of shining a laser into the gas chamber. The laser will act as an electron point source by ionizing gas molecules. The quartz windows are attached with high vacuum quality flanges. The other side has two thin aluminum windows to allow the passage of X-rays from an $^{55}\text{Fe}$ source. Also, the top of the chamber has a quartz window to allow a laser to shine in from the top. The position of this laser will be varied with a translation stage for the purpose of measuring the diffusion width of the electron cluster.

![DME drift chamber diagram](image)

Fig. 1. A schematic of the 18 cm chamber used to test dimethyl ether as the drift gas for use with micro strip detectors. (This Fig. is provided as a courtesy by Mr. Russ Wells of Lawrence Berkeley Laboratory.)

Inside the chamber is a field cage structure consisting of a stack of 15 annular disks spaced 1 cm apart. This field cage creates an electric field region for the drifting electrons. A resistor chain connecting the plates maintains a uniform potential gradient down the stack.

As mentioned, microstrip detectors have been fabricated and successfully tested in the lab. The microstrip detector currently being used consists of 100 pairs of alternating anode and cathode strips laid out on a glass substrate. The anodes are 10 microns wide, the cathodes are 90 microns wide and there is a 50 micron spacing between each anode and cathode. 16 channels (anodes) of the detector will be bonded to a preamplifier/shaper chip. The detector and preamplifier chip will be attached to a ceramic board which will sit at the bottom of the chamber and define the end of the drift region. It is necessary to make the PC board of ceramic material to help preserve the purity of DME.

The DME gas flows through the chamber at a rate of 0.05 liters/minute. A NanoChem filter is used in line to take out the majority of elector-negative impurities. Also, a hygrometer and oxygen analyzer will be used in line to monitor the has. DME is an excellent solvent of many common construction materials, including several that are often used as o-rings in gas valves (Sauli et al., 1989). Therefore, wherever possible, all metal seals were used in components such as valves and regulators.

**Testing Procedures.**—Two different methods are employed to test DME using this chamber. The first method uses the 5.9 keV X-rays emitted from $^{55}\text{Fe}$. These X-rays pass into the chamber through thin aluminum windows set in the side of the chamber at different heights. The second method utilizes an ultra-violet laser to directly ionize the gas molecules. This laser shines ultra-violet light into the chamber via quartz windows set in the sides and top of the chamber.

The position resolution measured using this chamber is strongly dependent on the diffusion of the drift gas (Basile et al., 1985). As mentioned, DME was chosen because it is a low diffusion gas. The diffusion is measured by reading the signal height on several adjacent anodes. The resulting shape is an approximate gaussian distribution. The width of the gaussian is a measure of the diffusion.

Various properties of DME have previously been measured for small drift distances, but only up to 3 cm (Basile et al., 1985). It is fully expected that the drift velocity and diffusion will scale in a predictable manner for the 15 cm drift distance. Electron attenuation, however, is not expected to behave in a simple manner for the 15 cm distance. The attenuation is highly dependent on electron-negative impurities and will thus depend on the chamber being “clean.” Attenuation in the ionization-electron signal is measured using the UV laser to produce ionization electrons at various heights within the chamber. Depending on their different drift distances, more or less of the electrons reach the anodes to be collected. Since the UV laser produces the same number of ionization electrons, within a statistical variation of roughly 10%, the difference in collected signal directly measures electron attenuation versus drift distance.

The length of the anodes to be used is relatively short. Short anode length is a requirement for adequate two-track resolution. The trade off is between electron signal attenuation and anode length. Electron attenuation is more of a problem with short anodes because fewer electrons reach each anode. Only about 180 electrons/cm will be ionized by X-rays coming from $^{55}\text{Fe}$. Therefore, for
a 3 mm anode length, only about 60 electrons would reach the anode. In addition, electron attenuation will decrease this number even further. The number of electrons will then be boosted by the gas gain; however, one of the goals for this detector is to operate at as low a gain as possible since low gain operation is more stable and has smaller space charge effects (Gong et al., 1994). Thus, once the extent of attenuation is known, an optimization of the anode length can be made to maximize two-track resolution while maintaining a sufficient signal.

Results and Discussion

In summary, a new type of detector, called a micro TPC, has been proposed. This detector would help meet the needs of high energy nuclear physics experiments to track charged particles in high track density environments. The performance of the micro TPC will require a low diffusion drift gas combined with high resolution readout. DME has been chosen initially for the drift gas. The test chamber described above is needed to demonstrate the feasibility of a micro TPC design and to test the performance of DME as a drift gas.

A simulation has been done showing the dependence of the performance of the micro TPC on various parameters such as geometry, multiplicity of particles and the measured value of the DME diffusion constant (Wieman et al., 1995). Unlike other properties of DME, however, the value of electron attenuation at a drift length of 15 cm is very uncertain and must be measured. In addition, measurements of the other properties of DME are being made to confirm earlier reported measurements of its properties. This chamber will allow the testing of different cleaning strategies for DME in order to minimize the attenuation of ionization-electrons within the DME. Also, once the extent of this minimized attenuation has been established as a function of drift length, this data will be used in a simulation for optimizing of the exact length of anode in order to maximize two-track resolution while maintaining a sufficient signal.

Acknowledgments.—This work is supported in part by the Office of High Energy and Nuclear Physics, Division of Nuclear Physics, U.S. Department of Energy under grant DE-FG05-92ER40758 and by the Director of the Office of Energy Research, under contracts DE-AC03-76SF00098 and DE-FG02-89ER40531. This work acknowledges the support of the STAR Collaboration. In addition to support from the above grant and contracts, one of the authors (MTB) is supported in part by a Department of Energy EPSCoR grant with the matching funds supplied by the Arkansas Science and Technology Authority. The present research is conducted as part of an M.S. thesis project (MTB) at University of Arkansas at Little Rock, and it has been approved by the committee for continuation as a Ph.D. dissertation project.

Literature Cited


Wieman, H. 1994. Talk in the SVT group the STAR Collaboration meeting, BNL, Aug. 1994. Much of the information in this talk is available in the following reference as STAR Note #0198.

Wieman, Howard, Spiros Margetis, Wen Gong and Morgan Burks. 1995. A model for evaluating the hit resolving abilities of a VTX style micro TPC in high track density environment. (This STAR Note #0198 is available free from "ftp:rsrgi01.rhic.bnl.gov/star/star lib/doc/www/sno/sn0198.html").
GENERAL NOTES

Vertebrate Fauna of Abandoned Mines at Gold Mine Springs, Independence County, Arkansas

Chris T. McAllister
Department of Biology
Texas Wesleyan University
1201 Wesleyan
Fort Worth, TX 76105-1536

Stanley E. Trauth
Department of Biological Sciences
Arkansas State University
State University, AR 72467

Linda D. Gage
College of Nursing
Texas Woman's University
Dallas, TX 75235

In their second in a series of papers on cave fauna of Arkansas, McDaniel and Gardner (1977) provided records of mammalian fauna (primarily bats) that utilize mines in the Ouachita and Ozark Mountains. Saugé et al. (1985) reported on the use of abandoned mines by the Caddo Mountain salamander, Plethodon caddoensis in the Ouachitas. In a more exhaustive study of vertebrates in abandoned mines of the Ouachitas by Heath et al. (1986), a great deal of information was added to the growing knowledge of mine use by vertebrate fauna. Herein, we report ecological data on vertebrate fauna in a series of mines in the eastern Ozarks.

Between December 1991 and March 1995, we made eight visits to a series of three abandoned mines (designated numbers 1, 2, and 3) located 12.1 km NW of Possum Grape at Gold Mine Springs, Independence County (T11N-R4W-S32). This site is within the eastern limit of the Ozark Mountains (most eastern extent of Boston Mountains) near the Gulf Coastal Plain boundary. Habitat consisted of vegetation typical of upland hardwood forest in sandstone-limestone soils.

The entrance of mine shaft no. 1 faced to the northeast and measured (width x height) 2.6 m x 1.0 m. A straight shaft averaging 1.6 m x 1.8 m led to a room 2.4 m x 2.9 m. During the study period, this mine was the wettest, had the highest humidity, and the coolest air temperatures of the three. The opening of mine shaft no. 2 was 37 m from no. 1 and faced the east and measured 2.7 m x 1.3 m. The shaft was short and led to a room 5.0 m x 3.3 m. Mine shaft no. 3 was located 6.7 m from no. 2 and faced the southeast and its entrance measured 2.2 m x 1.3 m. A small shaft led to a room 1.5 m x 2.0 m. The shaft abruptly ended some 23 m into the mine. This mine was the driest, warmest, and shortest of the three.

On each visit, vertebrates were collected by hand, aquatic dipnet, or with Pilstrom tongs (Pilstrom, Fort Smith, AR). When possible, amphibian and reptile voucher specimens were collected, sexed, and measured for snout-vent length (SVL) and retained for deposition in the Arkansas State University Museum of Zoology (ASUMZ). Specimens of mammalian taxa were prepared as alcoholic vouchers and deposited in the Collection of Recent Mammals of Arkansas State University (ASU).

The probable ecological adaptation of each species in the mines was noted following terminology developed for facultative (accidental, troglobites, troglophilic) and obligate (troglobites) cave fauna by Barr (1963) and followed by McDaniel and Gardner (1977). Comments regarding status, life history, and distributional information within Arkansas are included.

Sixteen vertebrate taxa, including two salamanders, six frogs and toads, two lizards, one snake, one bird, and four mammals were found to utilize these mines. The majority of vertebrates were collected from mine shaft no. 1. No fish or troglobitic vertebrates were found in any of the three mines surveyed. An annotated listing of vertebrate fauna follows:

Annotated List of Vertebrate Fauna in Abandoned Mines at Gold Mine Springs

Class Amphibia
Order Caudata
Family Plethodontidae
Eurycea multiplicata griseogaster Moore and Hughes, 1941. Trogophile. Two adult graybelly salamanders (SVL = 42, 44 mm) were found in mine no. 1 on our first visit (25 December 1991) and two additional salamanders (SVL = 44, 47 mm) were collected on the last visit (13 March 1995). Heath et al. (1986) previously reported larval and adult many-ribbed salamanders, E. multiplicata multiplicata (COPE, 1869) from Ouachita mines. In addition, McAllister and Fitzpatrick (1985) reported neotenic E. m. griseogaster from Savoy Cave, Washington County. However, to our knowledge, this documents the first time the graybelly salamander has been reported from mine habitat. Specimens deposited as ASUMZ 18113-18114, 20145-20144.

Plethodon albagula Grobman, 1944. Trogophile. Numerous western slimy salamanders, including juveniles and adults, utilized all three mines as habitat. Breeding activity and brooding behavior was not observed. Heath et al. (1986) observed reproductive activity by P. albagula

Proceedings Arkansas Academy of Science, Vol. 49, 1995

184
et al. (1986) observed reproductive activity by *P. albagula* in abandoned mines in the Ouachita Mountains. This salamander is commonly found in caves of the Ozarks (McDaniel and Gardner, 1977), and was the most common salamander of these mines. Specimens deposited as ASUMZ 18018, 19827-19828.

Order Anura

Family Bufonidae

*Bufo americanus charlesmithi* Bragg, 1954. Accidental. Two adult dwarf American toads (38, 42 mm SVL) were collected on a single visit on 18 August 1995 within the entrance zone of mine no. 2. The toads may have used the mine as a water source during the summer. Bufonids have not been reported previously from Arkansas mine or cave habitat. Specimens deposited as ASUMZ 19854-19856.

*Pseudacris crucifer crucifer* (Wied-Neuwied, 1838). Accidental. A single adult male northern spring peeper (SVL = 38 mm) was collected several meters within mine no. 1 (transition zone) on 18 August 1993. McDaniel and Gardner (1977) previously reported several *P. c. crucifer* from an Ozark cave in Stone County. Typically an epigean species, this represents the first report of *P. c. crucifer* from mine habitat. Specimen deposited as ASUMZ 19228.

*Pseudacris triseriata* (Wied-Neuwied, 1838). Accidental. A single adult male western chorus frog (SVL = 27 mm) was collected on 18 August 1993 within the entrance zone of mine no. 1. Another epigean hydidae, this frog is reported from mine habitat for the first time. Specimen deposited as ASUMZ 19221.

Family Ranidae

*Rana clamitans melanota* (Rafinesque, 1840). Accidental or Trogloxene. Nine green frogs were collected on three separate occasions (23 December 1991, 18 August 1993, 17 September 1993) during the study period from all three mines. Specimens included four juvenile males (SVL range 35-46 mm), two adult males (SVL = 69, 71 mm), and three adult females (SVL range 66-73 mm). Two of these latter females collected on 18 August 1993 were gravid. Green frogs were collected from the transition to dark zones of the mines with *R. palustris*. Black (1973) reported *R. c. melanota* from the twilight zone of an Oklahoma cave, and Trauth and McAllister (1983) found a green frog in the entrance of Savoy Cave, Washington County, Arkansas. In addition, Grove (1974), in an unpublished thesis, reported *R. c. melanota* from Blanchard Springs Caverns in Stone County, Arkansas. Herein, we document a new record for *R. c. melanota* from mine habitat. Specimens deposited as ASUMZ 19185, 19222-19224.

*Rana palustris* Le Conte, 1825. Trogloxene or troglophile. The pickerel frog was the most common amphibian found to utilize the mines. Numerous *R. palustris*, including juveniles, adult males, and adult females (most of which were gravid) were observed from the transition to dark zones within all three abandoned mine shafts. Heath et al. (1986) also noted that *R. palustris* was the most common frog found in Ouachita mines. Further, McDaniel and Gardner (1977) provided records of *R. palustris* from Arkansas caves, including four sites in Independence County. In addition to the present study, *R. palustris* from the mines were utilized for parasitological analyses (see McAllister et al., 1995). Specimens deposited as ASUMZ 19193-19194, 19201-19217.

Class Reptilia

Order Squamata

Suborder Sauria

Family Phrynosomatidae

*Scoloporus undulatus hyacinthinus* (Green, 1818). Accidental. An adult male northern fence lizard was observed at the entrance of mine no. 2 on 2 October 1994. Several other specimens were seen in surrounding woodland habitat but not within the mine entrance. These lizards were probably attracted to the entrance in search of arthropods. McDaniel and Gardner (1977) suggested fence lizards seek shelter among rocks within the entrance of caves. Voucher specimen not retained.

Family Scincidae

*Eumeces laticeps* (Schneider, 1801). Accidental. A juvenile male broadhead skink (SVL = 70 mm) was collected on 18 August 1993 at the entrance of mine no. 1. McDaniel and Gardner (1977) reported five-lined skinks, *E. fasciatus* (Linnaeus, 1758) from entrances of Ozark caves. McAllister et al. (1994) reported the same lizard reported herein as a new host for a coccidian parasite. Specimen deposited as ASUMZ 19148.

Suborder Serpentes

*Agrisstodon contortrix contortrix* (Linnaeus, 1766). Trogloxene. A southern copperhead was found within the transition zone of mine no. 1 on 2 October 1994. Southern copperheads have been reported previously from Ouachita mines (Heath et al., 1986) and Ozark caves.
(McDaniel and Gardner, 1977; Dunivan et al., 1982). This is probably the most common snake found in mine and cave habitat. Specimen deposited as ASUMZ 19814.

Class Aves
Order Passeriformes
Family Trogloidyidae
_Troglohytes aedon_ Vieillot, 1808. Accidental. A house wren was collected within the twilight zone of mine no. 3 on 17 September 1993. A nesting site was not found although other bird species have been reported to either roost or nest in Arkansas caves (McDaniel and Gardner, 1977). This is the first report of a house wren from mine habitat. Voucher specimen not retained.

Class Mammalia
Order Chiroptera
Family Vesperilionidae
_Myotis austroriparius_ (Rhoads, 1897). Trogloxene. A southeastern myotis was collected on 3 September 1994 in mine chamber no. 1 along with several _M. septentrionalis_. Individuals of _M. austroriparius_ have been reported previously from Ouachita mines (Davis et al., 1955; Sealander and Young, 1955; Heath et al., 1986; Saugey et al., 1993) and Ozark caves (McDaniel and Gardner, 1977). Our collection site is at the extreme western edge of the species range in the Interior Highlands of the Ozarks. The species has been reported previously from Independence County (Sealander and Heidt, 1990) as well as Bradley, Calhoun, Cleveland, Columbia, Drew, Garland, Grant, Howard, Lafayette, Little River, Miller, Mississippi, Montgomery, Nevada, Ouachita, Pike, Sevier and Woodruff counties (Saugey et al., 1993). Specimen deposited as ASU 27181.

_Myotis septentrionalis_ (Trouessart, 1897). Trogloxene. Four northern myotis were collected on 3 September 1994 within a chamber of mine no. 1. Additional specimens were observed on several other occasions but not collected. The species has been reported commonly from Ouachita mines (Davis et al., 1955; Sealander and Young, 1955; Heath et al., 1986) but less frequently in Ozark caves (McDaniel and Gardner, 1977; Harvey and McDaniel, 1988). Northern myotis have been reported previously from Independence County (Sealander, 1979; Sealander and Heidt, 1990). Voucher specimens deposited as ASU 27182-27185.

_Plecotus australis_ Lesson, 1827. Trogloxene. A solitary eastern big-eared bat was observed on three visits (17 September 1993, 3 September 1994, 2 October 1994). Unlike other bats in these mines, it was always active and invariably flew further into the mines or out the entrances into other mines to allude capture when approached. On our last visit (13 March 1995), however, we collected a scrotal male _P. australis_ from mine no. 1. Although reported previously from caves (McDaniel and Gardner, 1977; Saugey et al., 1993), this is the first time _P. australis_ has been reported from mine habitat. Gardner and McDaniel (1978) reported _P. leucopus_ from a locale approximately 30 km to the NE in nearby Jackson County. Therefore, Independence County is a new county record for _P. australis_ and represents an extension of its range into the eastern Ozarks (Sealander and Heidt, 1990). This bat has also been reported from Arkansas, Bradley, Calhoun, Clark, Cleveland, Columbia, Craighead, Crawford, Cross, Dallas, Drew, Faulkner, Grant, Greene, Jackson, Lafayette, Lawrence, Little River, Nevada, Ouachita, Pope, Pulaski, Sevier and Union counties. Voucher specimen deposited as ASU 27250.

Order Rodentia
Family Muridae
_Peromyscus leucopus_ (Rafinesque, 1818). Trogloxene. A Peromyscus sp. was seen nesting in the twilight zone of mine no. 3 on 3 September 1994. On subsequent visits prior to 15 March 1995, the nest was still intact but the mouse was not present. On our last visit, we collected a scrotal male _P. leucopus_ from deep within mine no. 1. Although Heath et al., (1986) reported Texas mice, _Peromyscus attwateri_ from two Ouachita mines and McDaniel and Gardner (1977) reported a nursing _P. attwateri_ deep within an Ozark cave in Sharp County, there are no previous reports of _P. leucopus_ utilizing mine habitat. Voucher specimen deposited as ASU 27251.

At least 16 vertebrate taxa utilized the three abandoned mines at Gold Mine Springs. Of these taxa, 44% were reported previously from Ouachita Mountain caves by Heath et al. (1986), whereas 63% were reported by McDaniel and Gardner (1977) from Ozark Mountain caves. Heath et al. (1986) reported a total of 27 vertebrate taxa from 27 abandoned mines in the Ouachita Mountains. Interestingly, we report 16 taxa from three mines in the Ozark Mountains. Although not collected during the study period, larger mammals (coyote, opossum, raccoon, skunk) occasionally used the mines as foraging sites as evidenced by tracks observed within entrances. These mice were utilized by vertebrates seeking temporary or permanent habitat as well as those using them as breeding sites and summer or winter retreats.

In conclusion, new records are established for 11 vertebrate taxa using mine habitat and a new county record is documented for _P. rafinesquii_. Unfortunately, current landowner use suggests the future loss of this mine habitat for local fauna at Gold Mine Springs.

Acknowledgments.—We thank the Arkansas Game and Fish Commission for Scientific Collecting Permits.
nos. 775 and 1114, Dr. V. R. McDaniel for confirming mammal identifications, and J.T. McAllister, III, for assistance in collecting.

Literature Cited


Vertebrate Prey of Selected Arkansas Snakes

Stanley E. Trauth
Department of Biological Sciences
Arkansas State University
State University, AR 72467-0599

Introduction

All snakes are carnivorous and often represent the dominant predatory species in food chains of terrestrial and aquatic communities. Snake food habits, feeding behavior, and trophic ecology have been extensively documented (Mushinsky, 1987). Food lists on the dietary preferences of North American snakes can be found in virtually any study on snake ecology. Snakes often eat a variety of vertebrate prey (often including snakes themselves [e.g., see appendix in Greene, 1988]); vertebrates constitute the principal component of the diet in 95 of 116 snakes species (82%) reported by Mushinsky (1987). Only recently has the snake diet literature begun to emphasize foraging theory and the interrelationships between predator and prey (see review by Arnold, 1993).

Research on vertebrate prey of Arkansas snakes in limited to mostly anecdotal accounts (e.g., Trauth, 1982; Byrd et al., 1988; Trauth and Cochran, 1991) compared to the food habits information amassed for snakes typically inhabiting the southcentral United States. These diet data are summarized or referenced in the snake life histories of Wright and Wright (1957) or in recent herpetological textbooks (e.g., Ernst and Barbour, 1989; Ernst, 1992), in annotated state bibliographies (Texas–Dixon, 1987; Oklahoma–Carpenter and Krupa, 1989), in state herpetological books (Louisiana–Dundee and Rossman, 1989; Missouri–Johnson, 1987), and in various natural history studies conducted on snakes in states adjacent to or near Arkansas (e.g., see studies by Klimsta in Illinois and by Fitch in Kansas as cited in Smith [1961] and Collins [1993], respectively).

In the present study, we documented vertebrate prey of several Arkansas snake species through the dissection of museum specimens. Our primary objective was to generate new information on the food habits of several snake species found within the state. A dietary study such as ours contributes to an understanding of the following: 1) a snake’s habitat choice, 2) variation in annual and seasonal food consumption, 3) ontogenetic dietary shifts, 4) competition for available food resources, and 5) geographic differences in selected food. Finally, our food habits study represents a preliminary list for these snakes in Arkansas and adds to a database of knowledge on their life history.

Chris T. McAllister
Department of Biology
Texas Wesleyan University
1201 Wesleyan
Fort Worth, TX 76105-1536

Material and Methods

We analyzed the stomach contents of 14 species and subspecies of snakes collected in Arkansas and housed in the Arkansas State University (ASU) herpetological collection. A total of 510 specimens, most of which were collected over a 10-year span (1984-1993), was examined. The alimentary tract of each specimen was entered via a midventral incision; many of these animals had previously been necropsied to determine their reproductive condition (Trauth et al., 1994). Snout-vent length (SVL) and sex were recorded for all dissected snakes (as well as for some of the prey species). All prey items (including, in some cases, invertebrates) were placed in plastic bags or glass jars filled with 70% ethanol, retained as voucher specimens, and deposited in the ASU herpetological collection. For convenience, each species was grouped according to adult body size, mode of reproduction, and familial rank (see Trauth et al., 1994). A majority of the snake specimens utilized to compile Table 1 was collected during spring months (March-May). Common and scientific names of snakes followed Conant and Collins (1991).

Results and Discussion

Small Oviparous Colubrid Species.—The northern scarlet snake, Cemophora coccinea copei, is well known for its egg-eating habits (see Mushinsky, 1987; Trauth, 1993). Of the 18 specimens examined, we found lizard eggs (and/or eggshells) in three individuals (17%). One specimen had consumed six eggs, whereas the other two contained three and five eggs. In all cases, the eggs appeared to be those of the six-lined racerunner (Cnemidophorus sexlineatus).

Medium-sized Oviparous Colubrid Species.—Ernst and Barbour (1989) summarized the literature on food habits of the eastern hognose snake (Heterodon platirhinos). Although toads of the genus Bufo are favorite prey in this species, we found toads in only four of 78 animals (5%). Trauth (1982) reported the consumption of spotted salamanders (Ambystoma maculatum) from a snake collected near Yellville in Marion County.

The diet of the red milk snake (Lampropeltis triangulum syrphila) was reviewed by Williams (1988). We found...
# Table 1. Vertebrate prey items from the stomachs of 10 species of snakes collected in Arkansas. Abbreviations for snake species are followed by the total number of stomachs examined (in parentheses). *Thamnophis p. proximus* - TPP (77); *Masticophis f. flagellum* - MFF (36); *Lampropeltis getula holbrooki* - LGH (84); *L. c. calligaster* - LCC (28); *L. triangulum sylpila* - LTS (39); *Elaphe o. obsoleta* - EOO (66); *Coluber constrictor priapus* - CCP (46); *Agkistrodon c. contortrix* - ACC (87); *A. piscivor us leucostoma* - APL (66); *Sistrurus miliarius streckeri* - SMS (19). Snake species listed in this table have more than one type of prey item; see text for additional details and remarks.

<table>
<thead>
<tr>
<th>Class Osteichthyes</th>
<th>CCP</th>
<th>EOO</th>
<th>LTS</th>
<th>LCC</th>
<th>LGH</th>
<th>MFF</th>
<th>TPP</th>
<th>SMS</th>
<th>ACC</th>
<th>APL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order Perciformes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family Centrarchidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Lepomis cyanellus</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unidentifiable sunfish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class Amphibia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order Caudata</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family Ambystomatidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ambystoma maculatum larva</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family Plethodontidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Damognathus brimleyorum</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order Anura</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family Bufonidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Bufo sp.</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family Hyliidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acris crepitans blanchardi</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hyyla cinerea</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hyyla versicolor/chrysoscelis</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unidentifiable hylid sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family Ranidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Rana utricularia</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class Microhylidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Gastrophryne carolinensis</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Class Reptilia      |     |     |     |     |     |     |     |     |     |     |
| Order Sauria        |     |     |     |     |     |     |     |     |     |     |
| Family Phrynosomatidae |     |     |     |     |     |     |     |     |     |     |
| *Sceloporus undulatus hyacinthinus* |     |     |     |     |     |     |     |     |     |     |
| Class Osteichthyes  |     |     |     |     |     |     |     |     |     |     |
| Order Perciformes   |     |     |     |     |     |     |     |     |     |     |
| Family Centrarchidae |     |     |     |     |     |     |     |     |     |     |
| *Lepomis cyanellus* |     |     |     |     |     |     |     |     |     |     |
| Unidentifiable sunfish |     |     |     |     |     |     |     |     |     |     |
| Class Amphibia      |     |     |     |     |     |     |     |     |     |     |
| Order Caudata       |     |     |     |     |     |     |     |     |     |     |
| Family Ambystomatidae |     |     |     |     |     |     |     |     |     |     |
| *Ambystoma maculatum larva* |     |     |     |     |     |     |     |     |     |     |
| Family Plethodontidae |     |     |     |     |     |     |     |     |     |     |
| *Damognathus brimleyorum* |     |     |     |     |     |     |     |     |     |     |
| Order Anura         |     |     |     |     |     |     |     |     |     |     |
| Family Bufonidae     |     |     |     |     |     |     |     |     |     |     |
| *Bufo sp.* |     |     |     |     |     |     |     |     |     |     |
| Family Hyliidae      |     |     |     |     |     |     |     |     |     |     |
| *Acris crepitans blanchardi* |     |     |     |     |     |     |     |     |     |     |
| *Hyyla cinerea* |     |     |     |     |     |     |     |     |     |     |
| *Hyyla versicolor/chrysoscelis* |     |     |     |     |     |     |     |     |     |     |
| Unidentifiable hylid sp. |     |     |     |     |     |     |     |     |     |     |
| Family Ranidae       |     |     |     |     |     |     |     |     |     |     |
| *Rana utricularia* |     |     |     |     |     |     |     |     |     |     |
| Class Microhylidae   |     |     |     |     |     |     |     |     |     |     |
| *Gastrophryne carolinensis* |     |     |     |     |     |     |     |     |     |     |

| Class Aves           |     |     |     |     |     |     |     |     |     |     |
| Order Passeriformes  |     |     |     |     |     |     |     |     |     |     |
| Family Icteridae     |     |     |     |     |     |     |     |     |     |     |
| *Agelaius phoenicurus* |     |     |     |     |     |     |     |     |     |     |
| Class Mammalia       |     |     |     |     |     |     |     |     |     |     |
| Order Rodentia       |     |     |     |     |     |     |     |     |     |     |
| Family Muridae       |     |     |     |     |     |     |     |     |     |     |
| *Micritus ochrogaster* |     |     |     |     |     |     |     |     |     |     |
| *Microtus pinetorum* |     |     |     |     |     |     |     |     |     |     |
| *Mus musculus* |     |     |     |     |     |     |     |     |     |     |
| *Neotoma floridana* |     |     |     |     |     |     |     |     |     |     |
| *Ochomys nutalli* |     |     |     |     |     |     |     |     |     |     |
| *Oryzomys palustris* |     |     |     |     |     |     |     |     |     |     |
| *Peromyscus leucopus* |     |     |     |     |     |     |     |     |     |     |
| *Peromyscus maniculatus* |     |     |     |     |     |     |     |     |     |     |
| *Sigmodon hispidus* |     |     |     |     |     |     |     |     |     |     |
| Unidentifiable rodent |     |     |     |     |     |     |     |     |     |     |
| Order Lagomorpha     |     |     |     |     |     |     |     |     |     |     |
| Family Leporidae     |     |     |     |     |     |     |     |     |     |     |
| *Sylvilagus floridanus* |     |     |     |     |     |     |     |     |     |     |
| Order Insectivora    |     |     |     |     |     |     |     |     |     |     |
| Family Soricidae     |     |     |     |     |     |     |     |     |     |     |
| *Cryptotis parva* |     |     |     |     |     |     |     |     |     |     |

Proceedings Arkansas Academy of Science, Vol. 49, 1995
only lizards species (Table 1) in three specimens (8%). One of the prey items (C. sexlineatus) was not mentioned in the listing of natural foods by Williams (1988), although this species was reported by Knight and Collins (1977) in a milk snake from Kansas.

**Large Oviparous Colubrid Species.**—Clark (1949) and Fitch (1963a) provided the most detailed studies on food habits of the black rat snake (Elaphe obsoleta obsoleta); the investigations were conducted in Louisiana and Kansas, respectively. Both studies found mammals and birds to be the most abundant prey. We found voles, mice, rabbits, and red-winged blackbirds in 6% of our sample of mostly adult snakes.

The speckled kingsnake (Lampropeltis getula holbrooki) consumes a variety of vertebrates but usually prefers reptiles and especially reptilian eggs. A summary of prey species is shown in Table 1. We found three specimens (850, 1205, and 829 mm in SVL, respectively) whose stomachs contained 1, 2, and 10 snake eggs. One immature adult female (705 mm in SVL) collected in Clark County had eaten a Quachita dusky salamander; this may represent the first record for this prey item in the speckled kingsnake. A speckled kingsnake was observed eating a hognose snake (H. platirhinus) in Searcy County (G. L. Harp, pers. comm.); copperheads (Agkistrodon contortrix) have been taken by captive snakes. Thirteen percent of our sample contained vertebrate prey.

The food preferences of the prairie kingsnake (L. c. calligaster) have been reviewed by Ernst and Barbour (1989); mammals represent the most common prey. Only mammals (shrews, voles, and juvenile woodrats) were found in the stomachs of five specimens (18%). One of us (SET) observed predation on C. sexlineatus by a juvenile prairie kingsnake in eastern Oklahoma (Trauth, 1983).

The southern black racer (Coluber constrictor priapus) is an opportunistic feeder, preying on a variety of vertebrates as well as invertebrates. Among the most common vertebrate prey in our specimens were lizards (skinks) and snakes. Skinks were found in 24% of stomachs examined. However, invertebrates (crickets and grasshoppers) were also found in 24% of specimens. Fitch (1963b) summarized food for all subspecies of C. constrictor throughout its range in North America. Our study revealed similar prey items compared to other subspecies reported from different geographic regions.

Although Mushinsky (1987) made no reference to the food habits of the eastern coachwhip (Masticophis flagellum flagellum), Carpenter (1958) briefly reported on this species from Oklahoma. He found lizards and birds in the diet. Lizards were the primary prey, being found in all specimens containing food remains (33%). Cnemidophorus sexlineatus was the most common prey species. We have observed coachwhips on several occasions hunting for collared lizards (Crotaphytus collaris) in rock quarries and on cedar glades in Arkansas.

**Medium-sized Viviparous Colubrid Species.**—Amphibians represented the only food group recorded for two species of Thamnophis in our study. Prey of the eastern garter snake (Thamnophis sirtalis sirtalis) consisted only of toads (Bufo sp.) in the present study. Predation by this species on wood frogs (Rana sylvatica) was mentioned by Trauth et al. (1995). The western ribbon snake (T. p. proximus) consumed salamander larvae and anurans (Table 1). Only eight stomachs (10%) contained food remains. Ernst and Barbour (1989) surveyed the diet literature on these two species. Clark (1974) found that amphibians represented 92% of the diet in T. p. proximus.

**Small Viperid Species.**—The diet of the western pigmy rattlesnake (Sistrurus miliarius streckeri) consisted of reptiles (lizards and snakes). Food items were found in 4 of 19 stomachs (21%) examined in this study (Table 1). Trauth and Cochran (1991) reported a predatory interaction between this species and a four-toed salamander (Hemidactylium scutatum) in Garland County.

**Medium-sized Viperid Species.**—A variety of small rodents (Table 1) represented the only prey group found for the southern copperhead (Aghistron don contortrix contortrix). Nine percent of the stomachs contained food items. Woodland voles (Microtus pinetorum) were the most common mammal. Fitch (1960) provided a detailed summary on the food habits of copperheads.

We found fish, anurans, small mammals, and snakes as food items (Table 1) for the western cottonmouth (A. piscivor us leucostoma). In one instance, a cottonmouth (651 mm in SVL) was collected along a rice field near Newport, Jackson County, in the process of consuming a previously-killed and decapitated yellowbelly watersnake (770 mm in SVL). This type of scavenging has been previously reported in this species (Bern and Gibbons, 1991). Fifteen percent of the stomachs we examined contained prey items. Burkett (1966) provided a detailed listing of vertebrate prey in this species from studies conducted in states surrounding Arkansas.

**Large Viperid Species.**—Ernst (1992) furnished a comprehensive list of prey for the timber rattlesnake (Crotalus horridus). We examined eight specimens; one stomach contained two young gray squirrels (Sciurus carolinensis).

In summary, vertebrate food items of 14 species and subspecies of snakes were examined. The snake samples included medium-sized to large forms (both terrestrial and aquatic, but excluded Nerodia species). The samples comprised 10 genera (Aghistronod, Cemophora, Crotalus, Coluber, Elaphe, Heterodon, Lampropeltis, Masticophis, Sistrurus and Thamnophis) in two families (Viperidae and Colubridae). We found 34 different species of vertebrate prey. Anurans were the dominant prey of two species of Thamnophis and in H. platirhinus. Lizards were the domi-
nant food items in M. flagellum, L. triangulum sspilida, Coluber (C. constrictor priapus), and S. miliarius streckeri. The ground skink (Scincella lateralis) was the most utilized reptilian prey item. Snakes predominated in the diets of Lampropeltis (L. getula holbrooki) and A. piscivorus leucosoma, but were also found in M. flagellum and C. constrictor priapus. Mammals were obtained mostly in L. c. calligaster, E. o. obsoleta and A. contortrix; voles led as the dietary preference of these snakes. Reptilian eggs were found in the stomachs of Cemophora (C. coccinea), L. g. holbrooki and M. flagellum.

The food habits data presented herein represent a preliminary listing for these snakes; future studies would benefit by incorporating more snake species and by addressing invertebrate prey as well. Studies of ecoregional variation in dietary habits of snakes within Arkansas are currently being undertaken.

ACKNOWLEDGMENTS.—We thank the many students and colleagues who provided field assistance from 1984-94. Collection of snakes was under the authorization of the Arkansas Game and Fish Commission through scientific collection permits issued to SET.

Literature Cited


Herpetol. Soc. 30:46-51.


Egg Mass Characteristics of Terrestrial Morphs of the Mole Salamander, *Ambystoma talpoideum* (Caudata: Ambystomatidae), from Northeastern Arkansas and Clutch Comparisons with Other *Ambystoma* Species

Stanley E. Trauth, Robert L. Cox, Jr.1, J.D. Wilhide and Hilary J. Worley

Department of Biological Sciences
Arkansas State University
State University, AR 72467-0599

Introduction

Aquatic eggs and/or egg masses of many salamander species normally increase in mass by acquiring a considerable amount of water via osmosis immediately following oviposition (see Duellman and Trueb, 1986). Most of this water gain is restricted to an area between the vitelline membrane which immediately surrounds the ovum and the outer egg capsule. Within this region there can be as many as eight concentric capsular rings per egg (Saltle, 1963); as these capsules expand, a gelatinous appearance is bestowed upon the single egg and/or egg masses. Not only do egg capsules serve to protect the developing embryo from predation and physical harm, but they also are vital to successful fertilization of the egg and must be present for hatching to occur (Duellman and Trueb, 1986).

There are six species of ambystomatid salamanders that occur in Arkansas (Conant and Collins, 1991); of these, five species (*Ambystoma annulatum*, *A. maculatum*, *A. talpoideum*, *A. texanum*, and *A. tigrinum*) normally lay their eggs by attaching them to submergent vegetation in the form of masses or clusters, whereas the other species (*A. opacum*) deposits its eggs in a terrestrial nest at the edge of a pond or pool of water. Among the former species, only the mole salamander (*A. talpoideum*) has been shown to vary geographically by exhibiting two egg-laying patterns (see review in Semlitsch and Walls, 1990). Within the Mississippi River Valley ecoregion this species deposits eggs in the form of egg clusters (Shoop, 1960; Raymond and Hardy, 1990), whereas in the Atlantic Coastal Plain single eggs are attached to vegetation (Semlitsch and Walls, 1990). In addition, this species is polymorphic (exhibition paedomorphic and metamorphic forms) in Arkansas (Trauth et al., 1993) as well as in other parts of its range (see Scott, 1998).

The present study documents egg mass and clutch characteristics of terrestrial morphs of *A. talpoideum* in Arkansas. In addition, we compare similar egg mass traits of this species with another ambystomatid species, the spotted salamander (*A. maculatum*). Lastly, we summarize egg mass and/or clutch size of *Ambystoma* species in Arkansas.

1 (RLC-deceased)

Materials and Methods

Egg masses of the terrestrial morph of the mole salamander, *Ambystoma talpoideum*, were collected from two temporary ponds in Greene County, Arkansas, in December of 1988 and 1994. These seasonal, temporary ponds (abandoned gravel pits) differed markedly from those permanent ponds that typically contain paedomorphic individuals. Egg clusters (with embryos mostly in early stages of development) were taken to the laboratory and placed into fixative (10% formalin) within 24 hr after collection. All egg masses are housed in the Arkansas State University herpetological collection.

Laboratory procedures included the recording of mass (g) and number of eggs per egg mass. While measuring egg masses, individual masses were removed from fixative and blotted dry; mass was recorded with a triple-beam balance (to the nearest 0.1 g). Egg masses of the spotted salamander (mostly collected on 8 March 1988 from permanent ponds in Independence, Izard and Marion counties) were processed in a similar manner. (In order to support the contention that preserved egg masses actually gain mass following preservation nine egg masses of *A. maculatum*, collected on 28 January 1995, were weighed (massed) prior to preservation and then one month thereafter. In all cases, these egg masses gained at least 100% in total mass.) Mean values in Table 1 are accompanied by ± two standard errors.

Results and Discussion

The morphology of egg masses of metamorphic *A. talpoideum* is shown in Fig. 1. The globular nature of these egg masses supports the dichotomous pattern of egg mass structure for this species as discussed by Semlitsch and Walls (1990). The masses differed structurally from those of *A. maculatum* (illustrated by Gilbert, 1942) mainly by being more fragile. For example, upon collection in the wild, egg masses of *A. maculatum* are typically characterized by their turgidity or an ability to withstand manipulation. Egg masses of *A. talpoideum* also retain a globular appearance as viewed in recently-oviposited masses.
Fig. 1. Egg masses of the terrestrial morph of *Ambystoma talpoideum* collected in Greene County, Arkansas. A. Recently-oviposited egg mass (shown attached to a twig) with around 32 eggs. B. Egg mass with around 55 embryos nearing hatching. (developmental stage determined by embryonic stage) as well as in older masses whose embryos are nearing hatching (Fig. 1 A and B, respectively). The gelatinous capsules of each egg mass eventually break down or weaken in both species as embryos near hatching (Fig. 1B). The nature of the egg mass of terrestrial morphs of this species also differs sharply from those of the paedomorphs (observed in Arkansas) whose eggs are laid singly (sometimes attached to one another) and are very fragile (S.E. Trauth, unpubl.).

Table 1. Data on the number of eggs per egg mass (or clutch size) for *Ambystoma* species documented in Arkansas.

<table>
<thead>
<tr>
<th>Species</th>
<th>N</th>
<th>Average Egg Mass Size (± 2 SE)</th>
<th>Range</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>A. annulatum</em></td>
<td></td>
<td>14.0</td>
<td>4-31</td>
<td>Trapp, 1956</td>
</tr>
<tr>
<td><em>A. maculatum</em></td>
<td>75</td>
<td>148.7 (± 0.9)</td>
<td>20-334</td>
<td>This study</td>
</tr>
<tr>
<td><em>A. opacum</em></td>
<td>10</td>
<td>87.1</td>
<td>12-99</td>
<td>Trauth et al., 1989b</td>
</tr>
<tr>
<td><em>A. talpoideum</em></td>
<td>60</td>
<td>41.1 (± 1.0)</td>
<td>87-124</td>
<td>This study</td>
</tr>
<tr>
<td><em>A. texanum</em></td>
<td>34</td>
<td>33.1 (± 0.5)</td>
<td>12-99</td>
<td>Trauth et al., 1990</td>
</tr>
<tr>
<td><em>A. t. tigrinum</em></td>
<td>2</td>
<td>130.5 (± 1.5)</td>
<td>96-165</td>
<td>Trauth et al., 1990</td>
</tr>
</tbody>
</table>

Figure 2 illustrates a comparison of mass gain in egg masses (following preservation) of *A. talpoideum* and *A. maculatum*. Although data shown in Fig. 2 are not intended to actually represent a measure of mass gain of egg masses in the wild (nor do data in Fig. 2 signify or express any inherent osmotic quality of these egg clusters), the degree of intraspecific variation associated with egg mass size and maximum mass gain is intriguing. If we assume that osmosis is not encumbered or halted after preservation (see above), then each egg mass of equal egg number and size should presumably undergo a similar mass gain. A comparison of the two December collections (collected six years apart) for *A. talpoideum* (Fig. 2) revealed differing mass gains per egg mass of equal egg number. This was also observed for egg masses of *A. maculatum*. These differences suggest individual variation in ovipositing females and that this variation presumably is grounded either in the selective pressure on females ovipositing in temporary ponds vs. permanent ponds or in the inherent variability of reproductive and/or life-history characteristics associated with ovipositing females in any given population [as has been observed in many ambystomatid salamanders (e.g., see Walls and Altig, 1986)]. For instance, differences in mass in egg masses of similar size could be the result of the following types of variation: 1) variation in ovum size at ovulation within a female or between adult females of varying body sizes, 2) variation in egg size (with egg capsules) at oviposition.
within a female or between adult females of varying body sizes, 3) variation in the number of eggs oviposited per egg mass within a female or between adult females of varying body sizes, and 4) variation associated with the aquatic habitat (e.g., temporary vs. permanent ponds). It is uncertain whether variation in developmental stage at the time of collection has any influence on how the fixative affects the egg capsules; furthermore, the overall effects of formalin in altering osmotic phenomena inside egg capsules remains uncertain (but see Vitt et al., 1985).

Previous studies have documented variation in ovum size and number in Ambystoma. Shoop (1960) found that adult metamorphic female A. talpoideum ranging from 57 to 66 mm in snout-vent length (n = 14) contained from 226 to 401 vitelligenic ova. Walls and Altig (op. cit.) found ova diameters ranging from around 1.76 to 1.93 mm in A. talpoideum and from 2.2 to around 2.7 mm in A. maculatum. Semlitsch (1987) reported that adult paedomorphic A. talpoideum vary greatly in the number of ova produced per clutch and that this parameter was directly related to female body size. Furthermore, whether a pond is temporary or permanent has been shown to affect the size as well as number of eggs per clutch in A. maculatum (Woodward, 1982). Woodward (op. cit.) found that larger females in permanent ponds produced larger eggs but do not increase the number of eggs per clutch and that permanent pond females produced more eggs per clutch than do temporary ponds females. Partitioning of clutches could, therefore, result in both large and small females ovipositing similarly-sized egg masses; however, each egg mass could conceivably gain a different amount of water, because of egg size differences.

Our data in Fig. 2 also suggests that maximum mass values for egg masses exhibited by both salamander species are consistent with differences in egg size. For example, in A. talpoideum an egg mass of 14 eggs had a maximum mass of 44.6 g, whereas an egg mass of 75 eggs had a maximum mass of 192.6 g. Therefore, the average mass per egg for the former is 3.2 g, and the average mass per egg for the latter is 2.6 g. On the other hand, in A. maculatum an egg mass of 120 eggs had a maximum mass of 214.4 g, whereas an egg mass size of 299 eggs had a maximum mass of 391.6 g. Therefore, the average mass per egg for the former is 1.8 g, and the average mass for the latter is 1.1 g. These ranges suggest that the ability to gain mass is more pronounced in the smaller, more fragile egg capsules of A. talpoideum than in the larger eggs with firmer egg capsules of A. maculatum.

A summary of egg mass size (or clutch size as in A. opacum) for Ambystoma species collected in Arkansas is shown in Table 1. Because five of the six species of Ambystoma are aquatic egg-layers and because interspecific overlap in egg mass size occurs among several species, the field identification of a particular species' egg mass in geographic areas of sympatry can often be difficult, especially when several species are ovipositing in the same pond or ditch at the same time. Yet, there are species-specific differences in the annual timing of oviposition as well as preferred egg-laying habitats that can usually assist in assigning egg clusters to a species of Ambystoma. No reliable established suite of egg mass characteristics can easily separate species in some situations. In Arkansas, we suggest that egg masses with eggs numbering over 100 per mass (and oviposited in ponds) be considered to be those of either A. maculatum or A. tigrinum. Winter breeding of A. annulatum (not exclusively during the fall months; see Trauth et al., 1989a) combined with their similar egg mass size with A. talpoideum and A. maculatum can make distinguishing egg masses ranging from 25 to 100 eggs problematic. In this case, egg masses of A. maculatum can be separated from the other two based on the greater turgidity of the mass (in A. maculatum vs. A. annulatum) along with the possibility of the presence of a green algae in A. maculatum (Gilbert, 1942); separation of A. talpoideum from the other two would be based upon greater fragility of egg masses. In egg masses fewer than
25, as seen in *Ambystoma talpoideum* and *A. texanum*, a reliance on egg-laying habitat may be the best guide. Ditches and/or small temporary pools are commonly utilized by *A. texanum*, whereas *A. talpoideum* generally prefers ponds.

In summary, data on egg mass characteristics of the terrestrial morph of the mole salamander, *Ambystoma talpoideum*, were examined and compared to those of the spotted salamander (*Ambystoma maculatum*) collected elsewhere in Arkansas. We also provide a summary of egg mass traits for other *Ambystoma* species inhabiting Arkansas. Although the egg masses of *A. talpoideum* (terrestrial morph) are oviposited in fragile clusters, they can withstand collection, manipulation, and preservation while retaining their globular-like, structural morphology. By comparison, eggs laid by paedomorphs of this species are normally not found in clusters and are extremely susceptible to damage or loss of integrity upon handling. Average clutch size in *A. talpoideum* was 41.1 eggs (14-99; n = 60), whereas *A. maculatum* averaged 148.7 (20-334; n = 75). Mass (g) changes while in preservative in *A. talpoideum* and *A. maculatum* indicated that eggs of both species gained mass. The reliability of using preserved (museum) egg masses to provide information on selected reproductive characteristics in salamanders remains speculative and awaits further scrutiny.

### Literature Cited


The PROCEEDINGS OF THE ARKANSAS ACADEMY OF SCIENCE appears annually. It is the policy of the Arkansas Academy of Science that 1) at least one of the authors of a paper submitted for publication in the PROCEEDINGS must be a member of the Arkansas Academy of Science, 2) that only papers presented at the annual meeting are eligible for publication, and 3) that the manuscript is due at the time of presentation. In accordance with this policy, manuscripts submitted for publication should be given to the section chairman at the time the paper is being presented. Correspondence after this time should be directed to Dr. Stan Trauth, Editor-PAAS, Dept. Biological Sciences, Arkansas State University, State University, AR 72457-0699.

Each submitted paper should contain results of original research, embody sound principles of scientific investigation, and present data in a concise yet clear manner. The COUNCIL OF BIOLOGY EDITORS STYLE MANUAL, published by the American Institute of Biological Sciences, is an example of a convenient and widely consulted guide for scientists writers. Authors should strive for directness and lucidity, achieved by use of the active voice. Special attention should be given to consistency in tense, unambiguous reference of pronouns, and to logically placed modifiers. It is strongly recommended that all authors 1) inspect the existing format for feature articles and general notes in the PROCEEDINGS OF THE ARKANSAS ACADEMY OF SCIENCE and follow the format at which they are drafting their manuscript, and 2) submit their manuscript to another qualified person for a friendly review to appraise it for clarity, brevity, grammar, and typographical errors.

Preparation of Manuscript

The author should submit three copies of the manuscript, tables, and figures. Manuscripts must be double spaced (preferably typed with a carbon ribboned typewriter) on 8 1/2 x 11 inch bond paper with at least one inch margins on all sides. Do not staple pages together. Do not hyphenate words on the right-hand margin; do not submit word processed copy printed with justified right-hand margins. Do not submit copy in italics; underscore words to be set in italics. If co-authored, designate which author is to receive correspondence and at what address.

An abstract summarizing in concrete terms the methods, findings and implications discussed in the body of the paper must accompany a feature article. The abstract should be completely self-explanatory. A feature article comprises approximately six or more typewritten pages. A PROCEEDINGS printed page is equal to approximately three and one-half typewritten pages and the author is assessed a PAGE CHARGE (see Procedure section). A separate title page, including authors names and addresses should be included with the manuscript. Feature articles are often divided into the following sections: abstract, introduction, materials and methods, results, discussion, acknowledgments, and literature cited. These sections should be centered. Subheadings should begin at the left-hand margin, but more than one subheading should be avoided. A general note is usually one to five typewritten pages and rarely utilizes subheadings. A note should have the title at the top of the first page with the body of the paper following. Abstracts are not used for general notes.

Abbreviations: Use of abbreviations and symbols can be ascertained by inspection of recent issues of the PROCEEDINGS. Suggestions for uniformity include the use of numerals before units of measurements (5 m), but nine animals (10 or numbers above, such as 13 animals). Abbreviations must be defined the first time they are used. The metric system of measurements and weights must be employed.

The literature cited section for feature articles should include six or more references; entries should take the following form:


If fewer than six references are cited in a general note, they should be inserted in text and take these forms: (Jones, The adrenal cortex, Cambridge Univ. Press, p. 210, 1987); (Davis, J. Anim. Ecol., 2:232-238, 1933).

Tables and Illustrations: Tables and figures (line drawings, graphs, or black and white photographs) should not repeat data contained in the text. The author must provide numbers and short legends for illustrations and tables and place reference to each of them in the text. Legends for figures should be typed on a separate piece of paper at the end of the manuscript. Do not run tables in the text. Illustrations must be of sufficient size and clarity to permit reduction to standard page size (or 1/2 page); ordinarily they should be no larger than twice the size of intended reduction and whenever possible no larger than a manuscript page for ease of handling. Photographs must be printed on glossy paper. Sharp focus and high contrast are essential for good reproduction. Figures and labeling must be of professional quality. Notations identifying author, figure number, and top of page must be made on the back of each illustration. All illustrations must be submitted in duplicate. Tables must be of professional quality when submitted. Note preferred placement of figures and tables in the margins of the manuscript.

Review Procedure

Evaluation of a paper submitted to the PROCEEDINGS begins with a critical reading by the Editor. The paper is then submitted to referees for checking of scientific content, originality, and clarity of presentation. Attention to the proceeding paragraphs will greatly speed up the process. Judgments as to the acceptability of the paper and suggestions for strengthening it are sent to the author. If the paper is tentatively accepted, the author will rework it, where necessary, and return two copies of the revised manuscript together with the original to the Editor. Usually a time limit for this revision will be requested. If the time limit is not met, the paper may be considered to be withdrawn by the author and rejected for publication. All final decisions concerning the acceptance or rejection of a manuscript are made by the Editor.

When a copy of the proof, original manuscript, and reprint orders reaches the author, they should be carefully read for errors and omissions. The author should mark corrections on the proof and return both the proof and manuscript to the Editor within 48 hours or the proof will be judged correct. Printing charges accruing from excessive additions to or changes in the proofs must be assumed by the author. Reprint charges are placed with the printer, not the Editor. Page changes are $40 printed page or portion thereof. These changes and excessive printing charges will be billed to the author by the Academy of Science. A page charge will be billed to the author of errata.

ABSTRACT COVERAGE

Each issue of the PROCEEDINGS is sent to several abstracting and review services. The following is a partial list of this coverage.

- Abstracts in Anthropology
- Abstracts of North America Geology
- Biological Abstracts
- Chemical Abstracts
- Mathematical Reviews
- Recent Literature of the Journal of Mammalogy
- Science Citation Index
- Sport Fishery Abstracts
- Wildlife Review
- Zoological Record
- Review Journal of the Commonwealth Agricultural Bureau

BUSINESS AND SUBSCRIPTION INFORMATION

Remittances and orders for subscriptions and for single copies and changes of address should be sent to Dr. John Rickett, Secretary, Arkansas Academy of Sciences, Dept. of Biology, University of Arkansas, Little Rock, Little Rock, AR 72204.

Members receive one copy with their undergraduate membership of $15.00, regular membership of $30.00, sustaining membership of $35.00, sponsoring membership of $45.00 or life membership of $200.00. Institutional members and industrial members receive two copies with their membership. Annual subscription rates for 1989 are $25.00. Copies of most back issues are available. The Secretary should be contacted for prices.
TABLE OF CONTENTS

Secretary's Report and Financial Statement .................. 2
Program ....................................................... 11

FEATURED ARTICLES
JAMEL M. AL-KHAYRI, and EDWIN J. ANDERSON: Callus Induction and Plant Regeneration of Commercial Rice (Oryza sativa L.) Cultivars ........................................... 17


MOHANJEE S. BRAR, JAMEL M. AL-KHAYRI, and GERALD L. KLINGAMAN: Effect of Thidiazuron and Benzylaminopurine on In Vitro Shoot Proliferation of Carum (Dianthus carinophyllus L.) .......................................................... 30

NICHOLAS R. BROWN, BRIAN R. LOCKHART, PHILIP A. TAPPE, LYNEE C. THOMPSON, ROBERT C. WEIH, JR., and RICHARD A. WILLIAMS: A Conceptual Basis for an Index of Forest Integrity for Upland Coastal Plain Ecosystems ........................................ 34

CHRISTINE A. BYRD, WILSON H. HOWE, AMBER D. CLIMER, and W.J. BRAITHWAITE: Using Small-Geometry, Vertex Time Projection Chamber Measurements to Delineate the Distribution of Red-cockaded Woodpeckers in Independence County, Arkansas .................................................. 37

ROBERT CORDOVA, and BOBBY MAKIN: Arkansas' Wellhead Protection Program, with Discussion of Delineation Methodology ......................................................... 41

PEGGY RAE DORRIS, HENRY W. ROBISON, and CHRIS CARLTON: Spiders (Arthropoda: Aranea) From Deciduous Forest Litter of the Ouachita Highlands ........................ 45

T.E. EZELL and J.A. DARSEY: SCF-MO Conformational Analysis of Polycroconaine ........................................... 49

YANFEI GUO, BRIAN LOCKHART, and JAMES L. HODGES: Prediction of Leaf Area in Individual Leaves of Cherrybark Oak Seedlings (Quercus pagoda Raf.) ......................... 52

MOSTAFA HEMMATI, and STEVEN YOUNG: Proforce Waves: The Effect of Current Behind the Shock Front on Wave Structure ......................................................... 56

FRED HICKLING, WESLEY DAVIS, and HEATHER WOOLVERTON: Critical Energy of Torus Knots ......................................................... 60

HOLLY HILL, PEGGY RAE DORRIS, and LYNEE C. THOMPSON: Influence of Pine Silvicultural Systems on Spider Population Diversity in Independence County, Arkansas ....... 85

ANTHONY HOLT and GEORGE L. HARP: Dytiscidae (Coleoptera) of Jackson County, Arkansas ......................................................... 71

WILSON H. HOWE, CHRISTINE A. BYRD, AMBER D. CLIMER, and W.J. BRAITHWAITE: Optimizing Tracking Software for a Time Projection Chamber ................................ 75

DAVID H. H. ARLIOT, LEES LARRY A. OLSON: Recent Establishment of the Asian Tiger Mosquito (Aedes albopictus) in Independence County, Arkansas .......................... 80

JAMES E. JOHNSTON: Recreational and Angler Survey of the Buffalo National River, Arkansas ......................................................... 82

BRANDON KEMP, ROBERT ENGELKEN, ARIF RAZA, AREES SIDDIQI, and OMAR MUSTAFA: Diagnostics of CdTe Electrodeposition by Resist Potential Voltammetry ......... 87

R. KLUENDER, D. LORTZ, W. MCCOY, B. STOKES, and J. KLEPAC: Timber Felling Time, Costs, and Profitability in Arkansas ......................................................... 94

SIRIPONG MALASRI, and JENNIFER R. MARTIN: Construction Resource Allocation Using a Genetic Algorithm ......................................................... 99

G. DOUGLAS MALDON, A.A. ROLLEFSON, and W.J. BRAITHWAITE: Energy-Loss Particle Identification in 2-D Silicon Drift Detectors ......................................................... 104

S.E. MCCLUSKEY, and W.J. BRAITHWAITE: An Introduction to Monte Carlo Methods ......................................................... 105

WARREN G. MONTAINE: Cavity Protection Techniques for Red-cockaded Woodpeckers ......................................................... 115

KAZUHIKO MURAI, CARLOS A. SÁNCHEZ, and DONALD C. WOLD: Using Geant to Model Calorimeter Response for Electromagnetic Cascades from Nucleus-Nucleus Interactions in a Cosmic Ray Detector ......................................................... 121

RISA PARKER, and PEGGY RAE DORRIS: Additions to the List of Schizocosa (Family Lycosidae) for Arkansas ......................................................... 127

JAMES H. PECK and W. CARL TAYLOR: Checklist and Distribution of Arkansas Pteridophytes ......................................................... 130


ARIF RAZA, ROBERT ENGELKEN, BRANDON KEMP, AREES SIDDIQI, and OMAR MUSTAFA: Molten Salt Electrolytes for Electrodeposition of CdTe Films ......................................................... 143

SCOTT W. REEVE, and WAYNE A. WEIMER: Spectroscopic Temperature Measurements for a Direct Current Arcjet Diamond Chemical Vapor Deposition Reactor ......................................................... 149

QUAZI GALIB SAMDAMI, HAMEED A. NASEEM, and W.D. BROWN: Characterization of Cadmium Sulfide Films Deposited By Chemical Bath Method ......................................................... 155

CARLOS A. SÁNCHEZ, KAZUHIKO MURAI, and DONALD C. WOLD: Using FRITOF to Model Nucleus-Nucleus Interactions in a Cosmic Ray Detector ......................................................... 160

FRANZ L. SEFF, JOHN W. HAWLEY, and ALAN D. TOLAND: Hammett Correlations of Carbonyl 13C Chemical Shifts in a Series of N-(4-Substituted-ethyl)-5-Chloro-2-Nitroanilines ......................................................... 166

ALI M.S. SHAMS, DEWEY H. SIFFORD, and BOB D. JOHNSON: 5'-Nucleotidase and Thrombin-Like Activities of Selected Crotalid Venoms ......................................................... 169


FELIX TENDUKO: Retrieval of Atmospheric Turbulence Coefficient and Water Column Density from Solar Irradiance Data ......................................................... 177

H. WIEMAN, W.G. GONG, S. MARGETIS, M.T. BURKS, W.J. BRAITHWAITE, and A.A. ROLLEFSON: A Drift Chamber Utilizing Microstrip Readout for Testing a New Microchip Concept ......................................................... 181

GENERAL NOTES
CHRIS T. MCALLISTER, STANLEY E. TRAUTH, and LINDA D. GAGE: Vertebrate Fauna of Abandoned Mines at Gold Mine Springs, Independence County, Arkansas ......................................................... 184

STANLEY E. TRAUTH, and CHRIS T. MCALLISTER: Vertebrate Prey of Selected Arkansas Snakes ......................................................... 188

STANLEY E. TRAUTH, ROBERT L. COX, JR., J.D. WILHIDE, and HILARY J. WORLEY: Egg Mass Characteristics of Terrestrial Morphs of the Mole Salamander, Ambystoma talpoideum (Caudata: Ambystomatidae), from Northeastern Arkansas and Clutch Comparisons with Other Ambystoma Species ......................................................... 193