TABLE OF CONTENTS

Consolitated Minutes of the 100th Annual Meeting of the South Dakota Academy of Science ............................................................................................... 1
2015 Membership List........................................................................................................... 8
Presidential Address: Reflections On One Hundred Years
    of Service to the State by the South Dakota Academy of Science.
    Steven L. Matzner ........................................................................................................ 11

History of the South Dakota Academy of Science
Symposium Papers Presented at the 100th Annual Meeting of the South Dakota Academy of Science

A Concordance of Science Education Themes in the SDAS Proceedings:
    The First Hundred Years. C. M. Ezrailson .................................................................. 19
From Tabeau to SDOU: A Brief History of Ornithology in South Dakota
    with Special Reference to Works Published in the Proceedings of the South Dakota Academy of Science. David L. Swanson ......................... 29
A History of Botanical Exploration in South Dakota. Mark Gabel, Dave Ode, and Grace Kostel ........................................................................ 69
One Hundred Years of Geology and Hydrology Papers Published in the Proceedings of the South Dakota Academy of Science. Perry H. Rahn ................................ 85
Significant Contributions to Paleontology in 100 Years of the South Dakota Academy of Science. Ed Welsh and Sally Y. Shelton .................. 91
One Hundred Years of Valuable Scientific Records: What Critically Important Information Can We “Extract” from Our SDAS Proceedings that Informs Our Collective Future in South Dakota and the World? Nels H. Granholm ................................................................................ 105
A Brief History of the South Dakota Academy of Science Based on Minutes from the Annual Meetings—1915-2014. Robert Tatina .................. 113

Complete Senior Research Papers
Presented at the 100th Annual Meeting of the South Dakota Academy of Science

    Barbara Smith Grandstaff, Eric Deeble, and David C. Parris .................................. 127
Stratigraphic and Taxonomic Revision of a North American False Saber-toothed Cat Cub. Ed Welsh, Clint A. Boyd, Kurt Spearing, and Paul Z. Barrett ......................................................................................... 141
Reasons Anglers Did Not Respond to an Internet Survey and Evaluation of Data Quality. Larry M. Gigliotti and Kjetil R. Henderson .......... 155
Angler Satisfaction in South Dakota. Kjetil R. Henderson and Larry M. Gigliotti .................................................................................... 171
Rearing with Overhead Cover Influences Rainbow Trout Behavior.
    Kristen H. Becket and Michael E. Barnes .................................................................. 187
Re-Establishment of Finescale Dace (Phoxinus Neogaeus) in Mud Lake,
    Lawrence County, South Dakota. Jane Amiotte, Greg Simpson, and Michael E. Barnes ........................................................................ 195
Classification and Monitoring Plains Cottonwood Ecological Type in the Northern Great Plains. Daniel W. Uresk................................................................. 201
Model for Classification and Monitoring Green Ash Ecological Type in the Northern Great Plains. Daniel W. Uresk, Kieth E. Severson, and Jody Javersak........................................................................................................... 213
Prairie or Woodland? Reconstructing Past Plant Communities at Good Earth State Park Via Soil Core and Tree Ring Analysis. Craig N. Spencer, Mason D. Vansessen, Elizabeth A. Renner, and W. Carter Johnson ............................................................................................................. 227
Cloud Seeding as a Potential Water Management Tool in Western South Dakota. Andrew G. Detwiler and Paul L. Smith .......................................................... 237
Comparative Study of Thermally Treated Silicon Anode Nanostructures Based on Polyacrylic Acid and Polyaniline for Lithium Ion Battery Application. Michael McGraw, Praveen Kolla, Rob Cook, James Wu, Vadim Lvovich, and Alevtina Smirnova .................................................................................................................. 253
Identification and Characterization of Drought-Tolerant Alfalfa (Medicago sativa Subsp. falcata) Germplasm. Austin Hanson, Lan Xu, Arvid Boe, Patricia S. Johnson, Roger N. Gates, and Yajun Wu .................................................................................................................. 263
Identifying Promising New Falcata Alfalfa Populations for Use in Semi-arid Rangelands. Derek Kannenberg, Lan Xu, Arvid Boe, Roger N. Gates and Patricia S. Johnson ............................................................................................................. 273
Genome-Wide Identification of Disease Resistance Genes in Aegilops tauschii Coss. (Poaceae). Ethan J. Andersen, Samantha R. Shaw, and Madhav P. Nepal ............................................................................................................. 281
Morphological and Ecological Discrimination of Two Stenodipsis (Diptera: Cecidomyiidae) on Alopecurus arundinaceus, A. pratensis and Bromus inermis (Poales: Poaceae) in Eastern South Dakota. J. Manuel Perilla López, Paul J. Johnson, and Arvid Boe ............................................................................................................. 297
Water Geochemistry and Pressure Buildup in Drill Holes on the 4850-Ft Level at the Sanford Underground Research Facility. Larry D. Stetler ............................................................................................................. 317
Fermi’s Question. Perry H. Rahn and Thomas V. Durkin .................................................. 329

One Hundred Years of Physics in South Dakota: A Current Legacy
Symposium Abstracts of Papers
Presented at the 100th Annual Meeting of the South Dakota Academy of Science

Physics and the South Dakota Academy of Science. Joel Rauber................................. 339
Dark Matter and the Darkside in South Dakota. Drew Alton for the Darkside Collaboration .................................................................................................................. 340
NOvA: The Giant with Square Shoulders. L. A. Corwin .................................................. 341
Purification of Germanium Crystals by Zone Refinement: Theoretical and Experimental Approaches. G. Yang, Y. T. Guan, M. D. Wagner, G. J. Wang, H. Mei, and D. M. Mei ............................................................................................................. 342
Research Experiences for Physics Undergraduates in Novel Magnetic Materials at South Dakota State University. Parashu Kharel..........................343
Undergraduate Research in Atomic, Molecular, and Optical Physics at Augustana College. E. Wells..........................................................344
Motivation and Development of the MPC-EX Detector at RHIC-PHENIX. M. Levan and N. Grau.........................................................345
Nuclear Physics at Augustana: Phases of Luminous Matter. N. Grau ..............................................................346
The Sanford Underground Research Facility at Homestake. J. Heise.................................................................347
Characterization of Dislocation and Defects for Large High Purity Ge Crystals. Hao Mei, Guojian Wang, Yutong Guan, Gang Yang, Bruce Gray, and Dongming Mei...........................................348
An Update on LUX Research Performed at SDSMT. Douglas Tiedt .................................................................349
A Theoretical Model for Calculating Plasma Effects in Germanium Detectors. Wenzhao Wei, Jing Liu, and Dongming Mei..................................................350
Crystal Growth and Detector Performance of Ø12 Cm High-Purity Ge Crystals. Guojian Wang, Mark Amman, Hao Mei, Dongming Mei, Klaus Irmscher, Yutong Guan, and Gang Yang........................351
PIRE: A Global Consortium for Advanced Germanium Detectors and Technology. Dongming Mei .................................................................352
Low-Energy Recoils and Energy Scale in Liquid Xenon Detector for Dark Matter Searches. Lu Wang and Dongming Mei ..................................................353
Development of a P-Type Point-Contact Germanium Detector with an Amorphous Semiconductor Surface for Rare-Event Searches. J. Liu, D.M. Mei and R. D. Martin.................................................................354
The Physics Materials and Nano-Science (PMNS) Lab at South Dakota State University. Y. Huh.................................................................355
An Experimental Program in Neutrinos, Nucleon Decay and Astroparticle Physics Enabled by the Fermilab Long-Baseline Neutrino Facility. Barbara Szczersbinska.................................................................356

Abstracts of Senior Research Papers Presented at the 100th Annual Meeting of the South Dakota Academy of Science

A Novel Design for a High-Efficiency Phased Array Feed Digital Down-Link. L. Hawkins.................................................................361
Characterization of Diaporthe Species Infecting Soybeans (Glycine max L.) in South Dakota. A. Gebreil, A. Micijevic, A. Weber, L. Hyronimus, and F. Mathew.................................................................362
Detecting and Quantifying Soybean Stem Canker Pathogens (Diaporthe sp.) in Soil and Plant Samples Using Real-Time PCR. B. Kontz, S. Adhikari, P. Bartlett, T. Chase, S. Subramanian, and F. Mathew.................................................................363
Differential Response of Teosinte and Flint, Sweet, and Dent Corn Varieties to Weed Competition. S. A. Hansen, S. A. Clay, D. P. Horvath, and S. Flint-Garcia.................................................................364
Belowground Bud Bank of *Bromus inermis* in Response to Mowing Frequency Over Two Growing Seasons. Denise Olson, Lan Xu, Arvid Boe, and Nels H. Troelstrup, Jr. ................................................................. 365
Weather and Temporal Effects on Urban Common Nighthawk (*Chordeiles minor*) Activity During the Breeding Season. G. N. Newberry and D. L. Swanson ......................................................... 366
Phylogeny of Armadillos. A. Rockey, S. Mcclanahan, and A. Kiesow ....................................................... 367
Evaluating Cattle Introgression in Bison on the Pine Ridge Reservation. T. R. Vargas, A. Higa, F. Cain, and S. Sarver .................................... 368
Expression of ADH Gene in Populations with a High Frequency of Alcohol Dependency. A. Traufler and A. Kiesow .......................................... 369
Physical Habitat Characterization of Perennial Wadeable Streams in the Northwestern Great Plains of South Dakota. Lyntauscha C. Kuehl, Chad Kaiser, Katie N. Bertrand, and Nels H. Troelstrup, Jr. ..................................................... 370
Influence of Pactola Reservoir on the Aquatic Insect Assemblage of Rapid Creek. S. D. Cooper and N. H. Troelstrup, Jr. ..................................................... 371
Toxicity of Ammonia to Rio Grande Silvery Minnow Under Variable Exposure Regimes. K. J. Buhl ................................................................. 373
On-Site Toxicological Assessments of Point Source Discharges to the Rio Grande, NM, on the Silvery Minnow. K. J. Buhl ..................................................... 374
A Historicl Comparison of Native Unionidae Mussel Decline in Eastern South Dakota. Kaylee Faltys, Nels H. Troelstrup, Jr., Chelsey Pasbrig, and Mike Smith .......................................................... 375
Potential Use of Lectins to Identify Intact and Ruptured Trichostrongyle Nematode Eggs in Sheep Fecal Samples. Y. M. Al-Kappany, A. Sarah, and M. B. Hildreth ..................................................... 376
Attempt to Eliminate an Anthelmintic-Resistant Strain of *Haemonchus contortus* from a South Dakota Sheep Herd Using a Combination Treatment involving Three Anthelmintics Drug Classes. A. Sarah, L. D. Holler, S. Holler, and M. B. Hildreth ..................................................... 377
A Historical Perspective of Mosquito Surveillance in South Dakota. G. P. Vincent, C. D. Carlson, L. Kightlinger, M. C. Wimberly, and M. B. Hildreth ..................................................... 379
Daily Activity Pattern and Circadian Rhythm in a Nicrophorine Burying Beetle (*Nicrophorus marginatus*). Leah M. Hiller, April E. Parsons, Carrie L. Hall, and Daniel R. Howard ..................................................... 381
Verification of Direct Ingestion of Flame Retardant-Treated Consumer Polyurethane Foam by House Crickets (*Acheta domestica*) Using Light Microscopy. Grace Estridge and Michael Gaylor* ..................................................... 382

The Effects of Airborne Particulate Matter on Rat Neuronal Cells. M. E. Johnson and P. A. Mazzer


Forensic Screening of Hazardous Chemicals Present in Thermal Cash Register Receipts Collected from Businesses in the Vicinity of Dakota State University. Michele Rogers and Michael Gaylor


Bioelectrochemical/Membrane Technologies for Enabling Energy-Efficient Wastewater Reuse in Power Plants. Namita Shrestha, Venkataramana Gadhamshetty, and Gina Elmore

Engineering N₂-Fixing Cyanobacteria to Produce Ethanol Fuel from CO₂ and H₂O. Nate Braselton and Ruanbao Zhou

Characterization of Three N₂-Fixing Cyanobacterial Members of Chroococcales Isolated from the Bay of Bengal. Paramageetham Chinthala, Liping Gu and Ruanbao Zhou

Examination of Antibiotic Resistance in *E. coli* from Lake Herman, Lake County, SD, and Lab Strain B. Sherif El Gayar and Donna Hazelwood

Nitrogen Fixing Endophytes of a Non-Nodule Forming Legume. Tyrel Deutscher, Volker Brözel, Leslie Henry, and R. Neil Reese

Characterization of Liquid and Solid Phases Produced After Hydrothermal Treatment of Lignin in Sub- and Supercritical Environment. Abu Md Numan-Al-Mobin, Mike Mcgraw, and Alevtina Smirnova

Production of High-Value Organic Products by Lignin Laccase-Mediator System. Bin Yao, Praveen Kolla, and Alevtina Smirnova

Testing the Feasibility of Inexpensive, Real Time Carbon Dioxide Measurements Using Combustion Sources. Thomas King and Andrew Detwiler


The Language of Models in Hydrology: A Particuliar Case For South Dakota B. A. Shmagin

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**Research Papers Published by Title Only**

Presented at the 100th Annual Meeting of the South Dakota Academy of Science

Investigating the Use of Copper Photoredox Catalysts in an Enantioselective Reaction. Sarah A. Souder and Katrina H. Jensen. Chemistry Department, Black Hills State University, Spearfish, SD 57799

Radio-Telemetry Measurements of Stopover Behavior of Fall Migrant Yellow-Rumped Warblers (*Setophaga coronata*) in Missouri River Riparian Forests and Anthropogenic Woodlots. Ming Liu and David L. Swanson. Department of Biology, University of South Dakota, Vermillion SD 57069
Temperature, Clipping, and Drought Effects on Belowground Bud Outgrowth of Invasive Bromus inermis and Native Pascopyrum smithii. Jacqueline P. Ott¹,², Jack L. Butler¹, Yuping Rong¹, and Lan Xu¹. ¹Department of Natural Resource Management, South Dakota State University, Brookings, SD 57007. ²Forest and Grassland Research Laboratory, Rocky Mountain Research Station, U.S. Forest Service, Rapid City, SD 57002. ³Department of Grassland Science, Animal Science & Technology College, China Agricultural University, Beijing, China 100193


Forest Structure, Logging, and Introduced Plants in the Black Hills National Forest. J. L. Butler¹ and S. D. Wacker². ¹USFS Rocky Mountain Research Station Forest and Grassland Research Laboratory, Rapid City, SD 57702. ²Yellowstone National Park, WY. 82190

Transforming Undergraduate Biology Education at Augustana College. Steven Matzner, Jennifer Gubbels, and Carrie Hall. Biology Department, Augustana College, Sioux Falls, SD 57197

South Dakota and Chemistry: A Rich History. Miles Koppang¹ and Matthew Miller². ¹Chemistry, University of South Dakota, Vermillion, SD 57069; ²Chemistry and Biochemistry, South Dakota State University, Brookings, SD. 57007


Prey Availability and Diet Composition of Woodland Migrants at Natural Riparian Woodlands and Anthropogenic Woodlots of the Northern Prairie Region. Ming Liu and David L. Swanson. Biology Department, University of South Dakota, Vermillion, SD 57069.

Reviewers of Manuscripts

Michael Barnes—SDGF&P
Kevin Buhl—USGS
Michael Catalano—DWU
Michael Farney—DWU
Mark Gabel—BHSU
Nels Granholm—SDSU
Tim Mullican—DWU
William Roggenthen—SDSU
Craig Spencer—AC
Hoaran Sun—USD
Mark Gabel—BHSU
COMBINED MINUTES
EXECUTIVE COUNCIL MEETING
AND BUSINESS MEETINGS
100TH ANNUAL MEETING OF THE
SOUTH DAKOTA ACADEMY OF SCIENCE
FRIDAY AND SATURDAY, 10 AND 11 APRIL 2015
HOSTED BY SDAS EXECUTIVE COUNCIL
CEDAR SHORE RESORT
OACOMA, SD

EXECUTIVE COUNCIL MEETING

President Chun Wu opened the meeting at 12:45 pm, welcomed members of the Executive Council to the 100th Annual Meeting of the South Dakota Academy of Science at Cedar Shores Resort and noted that a quorum was present.

Reports:

The Secretary’s Report, Treasurer’s Report and Proceedings Editor’s Report were given by Donna Hazelwood, Jeff Palmer, and Bob Tatina, respectively. Members moved and seconded acceptance of the respective reports.

Old Business:

Fellows:

No Fellows were elected 2014.

SDAS web page:

The SDAS website http://www.sdaos.org is hosted by Miner Solutions owned by Shane Miner who is currently working for WGBH in Boston. Payment is made from the Proceedings Account. Tim Mullican will continue as the SDAS web master.

New Business

Committee reports

Proceedings of the South Dakota Academy of Science by Bob Tatina

Bob reported that the Proceedings Account is solvent. In addition to peer-reviewed papers, abstracts are also included in the Proceedings. The Proceedings are available on the SDAS webpage. Complimentary paper copies are provided to libraries.

A special centennial edition of the Proceedings of the SD Academy of Science by historian Michael J. Mullin’s Science in the Service of the State: A Centennial History of the South Dakota Academy of Science 1915-2015, will be available at the Centennial Meeting.

Bob noted the following due dates and deadlines for the 100th Proceedings: Manuscripts for publication are due 15 July. Submission of manuscripts for publication in the 100th Proceedings signifies that the manuscript has undergone the peer-review process two times, been edited accordingly and is accompanied by a written letter documenting how the reviewer’s comments were addressed. Finally, reviewers cannot be authors of the manuscript.

Auditing Committee, Mark Gabel and Donna Hazelwood

The materials provided by treasurer Jeff Palmer were reported to be very well organized, easy to follow, and in good order.

Poster Judging Committee by Dave Bergmann Lan, Xu, and Matt Miller

The name of the awardee is underlined.

AAAS undergraduate female awardee:
THE EFFECTS OF AIRBORNE PARTICULATE MATTER ON RAT NEURONAL CELLS. Megan E. Johnson*UG and Paula A. Mazzer. Department of Chemistry and Physical Sciences, Dakota Wesleyan University

AAAS undergraduate male awardee:
THE PREPARATION OF OXYMEN PERMEABLE SILOXANE MEMBRANES CONTAINING PERFLUORALKYSULFONES. M. Hockert*UG, T. Moodie*UG, A. Schwader*UG, and G. A. Hartgraves. Dakota Wesleyan University

Paper Judging Committee by Vicki Geiser, Gary Larson, and Brian Patrick

The name of the awardee is underlined.

1ST Place: SYNTHESIS AND CHARACTERIZATION OF Ti₂MNAL: A POTENTIAL SPIN GAPLESS SEMICONDUCTOR. Simeon Gilbert*UG, Ryan FuglsbyUG, Yung Huh and Parashu Kharel. Department of Physics, South Dakota State University

2ND Place: A HISTORICAL COMPARISON OF NATIVE UNIONDAE MUSSEL DECLINE IN EASTERN SOUTH DAKOTA. Kaylee Faltys* and Nels H. Troelstrup Jr., Chelsey Pasbrig, and Mike Smith. Department of Natural Resource Management, South Dakota State University.

3RD Place: ONE OR TWO STENODIPLOSIS (DIPTERA: CECIDOMYIIDAE) ON ALOPECURUS ARUNDINACEUS AND BROMUS INERMIS IN EASTERN SOUTH DAKOTA? Juan Manuel Perilla López*, Paul J. Johnson, and Arvid Boe. Insect Biodiversity Lab., Department of Plant Science, South Dakota State University
Resolutions Committee by Vicki Geiser

The Members of the Academy thank the following:
1) The Local Planning Committee The SDAS Executive Council; 2) we thank the local registration committee and Nancy Presuhn; 3) we thank the Graphic Artist and photographer Thomas Jones for the banners and taking photographs; 4) we thank Dr. Michael J. Mullin, Professor of History at Augustana College for supporting the SDAS; for writing the monograph, “Science in the Service of the State: A Centennial History of the South Dakota Academy of Science 1915-2015”, and for the plenary address: “The South Dakota Academy of Science: A Century of Challenges and Triumphs”; 5) special thanks to Bob Tatina for his continued excellence and dedication as editor of the Proceedings of the SDAS; 6) special recognition to Chun Wu for serving as SDAS President (2014-2015); 7) special thanks to the dedicated Donna Hazelwood, Secretary; 8) special thanks to the meticulous Jeff Palmer, Treasurer; 9) thanks to Tim Mullican for serving as WebMaster; 10) thanks to our Members-at-Large who have served for the last three years: Jack Butler, Mark Gabel, Paula Mazzer, and Brian Patrick; 11) we thank the Audit Committee: Mark Gabel and Donna Hazelwood; 12) we thank the Resolution Committee: Vicki Geiser; 13) we thank the Nominations Committee: Chun Wu, Donna Hazelwood, Dave Bergman, and Vicki Geiser; 14) we thank our Fellow Nominations Committee: Brian Patrick; 15) we thank our honored SDAS Fellows: Kenneth F. Higgins 1998, The late Chuck Estee1999, Carroll Hanten 2001, Emil F. Knapp 2001, Clyde Brasher 2003, Milton Hanson 2003, S. Laeticia Kiltzer 2003, The late Robert Looyenga 2003, Arlen Viste 2003, The late Everett White 2003, Perry H. Rahn 2004, Robert Stoner 2004, Maureen Diggins 2011, Gary Earle 2011, H.L. Hutcheson 2011, Waldimar “Wally” Klawiter Jr. 2011, Nels Granholm 2012, The late Audrey Gabel 2012, Mark Gabel 2012, Robert (Bob) Tatina 2012, Arvid Boe 2015, Gary Larson 2015, David Parris 2015, the late Norm Miller 2015, and Robert Roy Kintner 2015; 16) we thank Brian Patrick, Vicki Geiser, and Gary Larson for judging the second Student Oral Presentations contest; and Dave Bergmann, Xu Lan, and Matt Miller for judging the undergraduate student poster contest; 17) we thank Dale Droge for being in charge of computers and LCD projectors; 18) we thank the chairs of this year’s symposia: Frontier Physics and Applied Physics: Dongming Mei and Barbara Szczersinska; and History of Science: Robert Tatina and Nels Granholm; and lastly 19) we thank Cedar Shore Resort for providing an excellent venue for the 2015 meeting.

Nomination committee Chun Wu, Donna Hazelwood, Dave Bergman, and Vicki Geiser by Dave Bergmann

The Executive Council provided for election the following slate of nominees:

Second Vice-President: Tim Mullican, DWU

Member-at-Large 2015-2017
Jack Butler, USDA Forest Service
Mark Gabel, BHSU biology
Paula Mazzer, DWU
Brian Patrick, DWU
Passing of the Academy Hammer
Outgoing President Chun Wu passed the SDAS Hammer to Incoming President Steven Matzner
The Presidential Address by Steven Matzner “Bridging the Divide: Can religion and science be complimentary, not confrontational?” was well received by the members of the Academy.

Upcoming SDAS Meetings:
2016 Meeting—101st Annual Meeting hosted by University of Sioux Falls 8 and 9 April. Contact: George Mwangi
102nd Annual Meeting hosted by Dakota Wesleyan University 2017.
103rd Annual Meeting hosted by SDSU 2018.
104th Annual Meeting hosted by MMC 2019.
106th Annual Meeting hosted by BHSU 2021.

Executive Council Fall Meeting 2015: Al’s Oasis, Oacoma, SD, Sat 12 Sept. 20115

Adjournment
Brian Patrick moved and Mark Gabel seconded adjournment of the 99th Annual SDAS Meeting.

Recap of the 2015 SDAS Centennial Meeting:
Two Symposia were presented Friday, A two-part Physics Symposium, Frontier Physics and Applied Physics, and a History of Science Symposium: A Century of South Dakota Scientists and Their Science. Saturday, a total of 36 papers and 30 posters were presented. One hundred eighty-three individuals attended the meeting.
TREASURER'S REPORT—2015

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Respectfully Submitted,
Jeffrey S. Palmer
SOUTH DAKOTA ACADEMY OF SCIENCE
PROCEEDINGS EDITOR’S REPORT 2015

Report for the year from April 1, 2014 to March 31, 2015.

1. The following libraries were mailed a complimentary paper copy: AC, BHSU, DSU, DWU, MMC, NSU, OLC, SDSMT, SDSU (2 copies), UND, USD (2 copies), Am. Mus. Nat. Hist., U of WA and the Booth Fish Hatchery.

2. The following indexing/abstracting services and institutions were mailed complimentary paper copies: Chemical Abstract Services, AcadSci., Inc., Cambridge Scientific Abstracts, GeoRef Library, Baywood Publishing (Anthropology), Thompson Scientific (Biosis).

3. The following non-member institution were sent paper copies: Linda Hall Library (Kansas City, MO) 1 copy; Curran and Associates (Red Hook, MA) 2 copies.

4. Electronic files of the 2014 Proceedings have been sent to Miner Solutions for publishing to the SDAOS website.

5. For the 2014 Proceedings:
   No. of paper copies printed = 40
   No. of pages = 220
   No. of full papers published = 14
   No. of abstracts published = 29
   No. of titles only published = 15
   No. paper copies distributed to libraries, abstracting services, individuals, etc. = 29

   Electronic files of were provided to Shane Miner of Miner Solutions for uploading to the SDAS website.

   192 pages invoiced @ $20.00 per page = $3840.00 ($3840.00 paid)
   5 set of reprints = $450.00 ($450.00 paid)
   3 copies sold @ $15.00 = $45.00 ($30.00 paid)
   One over payment of $10.00 was credited to author’s account
   Total invoiced = $4335.00 (Total paid = $4330.00)
   Costs for 2014 Proceedings and Annual Meeting Program = $4097.22
   Net profit = $4330.00 - $4097.22 = $232.78

6. First call for papers sent out early February; second call sent out 1 March.

7. 2015 Schedule of Events was printed and distributed.

8. Proceedings Ledger

   Beginning Balance (4/1/2014)  8596.00

   INCOME
   Page Charges & Reprints  $8220.00 (Invoiced $8220.00)
   Subscriptions  $60.00 (Invoiced $75.00)
   Total Income  $8280.00

   EXPENSES
   Postage  344.57
   Supplies  31.13
   Formatting & Printing  5323.28
   Webhosting  1200.00
   Meeting Expenses  707.67
   Total Expenses  $7606.65

   Ending Balance (3/31/2015)  $9269.35

Submitted by
Robert Tatina, Editor

Kenneth F. Higgins 1998
Chuck Estee 1999
No nominations 2000
Carroll Hanten 2001
Emil F. Knapp 2001
No nominations 2002
Clyde Brashier 2003
Milton Hanson 2003
S. Laeticia Kiltzer 2003
Robert Looyenga 2003
Arlen Viste 2003
Everett White 2003
Perry H. Rahn 2004
Robert Stoner 2004
No nominations 2005
No nominations 2006
No Nominations 2007
No Nominations 2008
No Nominations 2009
Maureen Diggins 2011
Gary Earle 2011
H.L. Hutcheson 2011
Waldimar “Wally” Klawiter Jr. 2011
Nels Grandholm 2012
the late Audrey Gabel 2012
Mark Gabel 2012
Robert (Bob) Tatina 2012
No Nominations 2013
No Nominations 2014
No Nominations 2015
### ANNUAL MEETING ROTATION SCHEDULE

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### 2015 MEMBERSHIP LIST

- **Alton, Andrew**
  - AC
- **Andersen, Ethan**
  - SDSU
- **Archambault, Gary**
  - USD
- **Bahr, Samantha**
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- **Gabel, Mark**
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- **Garette, Shawn**
  - OLC
- **Gayer, Sherif**
  - DSU
- **Gaylor, Michael**
  - DSU
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*Senior Member
**Student Member
***Non-member Attendee
PRESIDENTIAL ADDRESS

REFLECTIONS ON ONE HUNDRED YEARS OF SERVICE TO THE STATE BY THE SOUTH DAKOTA ACADEMY OF SCIENCE

Address to the South Dakota Academy of Science
South Dakota State University, Brookings, SD
April 11, 2015

Steven L. Matzner
Augustana College
Sioux Falls, SD

Have you ever wondered how you came to be at a particular place and time? What myriad of seemingly innocent events conspired to land you in your current situation? Prior to 1975, the “Presidential Address” was given by the outgoing president rather than the incoming president; outgoing president Jack Saunders suggested changing that practice in his 1975 address and in 1976 the incoming president gave the address. Without that change, I could be sitting with you in the audience, comfortably thinking I have a whole year yet to worry about this speech. On the other hand in 2013, the South Dakota Academy of Science was canceled because of the “freak ice storm” in Sioux Falls. This prevented the vote on electing a new president, resulting in Gary Larson being one of the relatively few people who were president for two consecutive years. Without that ice storm, I would have given my presidential address last year and would also be comfortably sitting in the audience right now. Of course, if I really want to place “blame” on my current situation, I don’t have to look any further than a couple of chemists. In 2011, I did not attend the Academy meeting for the very good reason that I was on sabbatical in New York with my family. Dr. Miles Kopang was on the executive committee and they needed a 2nd vice-president and apparently he thought of me. Now, at this point he could have contacted me or sent me an email, but that is NOT what happened. No, Dr. Kopang called a fellow chemist, my wife Dr. Jetty Duffy-Matzner, and my wife has a LONG history of “volunteering” me for things. Those are just a sample of the web of interesting events that has conspired to result in my having the honor of giving the presidential address for the 100th anniversary of the South Dakota Academy of Science.

When I teach photosynthesis, I usually talk about the eighteenth century English clergyman/scientist Joseph Priestley. He reported that he “accidently hit upon a method of restoring air that had been injured by the burning of candles”. He was burning candles in an enclosed glass container “which would injure the air” (the candle would go out). He found that putting a living sprig of mint into the container with the injured air for 10 days (I suspect he forgot about it) would “restore the air”, and that this restored air would “not be at all inconvenient to a mouse”. Let’s think about that for a second. He obviously had some experience
in knowing that the injured air WAS inconvenient to the mouse. I don’t think he would have received IRB approval for this. For his work however, Priestley was awarded a medal that stated “For these discoveries we are assured that no vegetable grows in vain…, but cleanses and purifies our atmosphere.”

I like this story because the work of Priestley illustrates the importance of scientific discovery as service to humanity. This theme of service has long been a theme of the Academy. In perusing presidential addresses, I would say that about 1/3 of the addresses had a theme of service to the state of South Dakota, to our country and/or to humanity. In his 1916 address, the first president of the Academy, Dr. Hilton Ira Jones noted that “Scientists work for appreciation more than money and I find that that is the very thing that is generally lacking in most of the schools of the state.” He went on to say that in South Dakota the “call is to real work with real things—to solve the bread and butter problems of a state.” Gregg Evans continued with this theme in his 1937 address saying that “the great Pasteur made his name immortal by solving the immediate, necessary problems of his community and state. We cannot all be Pasteurs, but we must do, through the years to come, all in our power to solve the grave problems facing our state.

How exactly did the early Academy envision serving the state of South Dakota? In her 1973 address, Sister Veronica Fasbender of Mount Marty College summed up the three main goals of the early Academy as “the upbuilding and industrialization of the state, the development of resources for the improvement of science teaching, and advising the governor and state legislature in scientific matters. Indeed, as N.E. Miller’s address in 1980 stated, the “early years were filled with inventories of the state’s resources and lofty expectations for the use of these resources for the betterment of all.” For example, J.W. Parmley’s 1921 paper on “The undeveloped possibilities of electricity in South Dakota”, called hydroelectric power “the one great development project in our state today.” It wasn’t long however, before calls for the development of the state’s resources were supplanted by calls for conservation of the state’s resources. In his 1934 article, “The return of the deserts”, J. Gladen Hutton passionately stated his concern for the issue of soil conservation, “for 25 years I have been crying out against this ruinous process, but in most cases have been met with gibes and jokes and even sneers, on the part of the people who should be concerned with the welfare of the people of the commonwealth. They have said “oh the soil will always be with us. We can study it when we have more money, when the taxes are not needed for something else.” Concern for the environment has been a notable theme in several presidential addresses. James Schmulbach suggested in his 1977 address that the South Dakota Academy of Science should consider being the “legal guardian of the South Dakota Environment”. In 1982, Theodore Van Bruggen said “Ecology will ultimately engulf economics. We must move away from the values of growth, profligacy, and exploitation typical of “economic man”, toward sufficiency and frugality.” One can hope that on the issue of climate change today that our political leaders (and I use the term leaders loosely) will understand that the long term environmental costs must trump short term economic gains. As was illustrated in the March 17 Argus Leader article “School science standards ignite debate”, we are not even to the point of debating how to solve the problem
of climate change, we are still fighting the battle in the state of South Dakota over whether climate change and evolution even exist as real topics to teach.

The Academy has long been embroiled in issues related to education in the state of South Dakota. Of about 66 presidential addresses that I perused, 22 or about 1/3 were directly about some aspect of teaching. In his 1939 address, Ward Miller stated that teaching science was also about making good citizens. He stated that “science contributes not only to a student’s technical background, but as well to his cultural background for serviceable citizenship.” He also noted that we are asked to do this for an “increasing number of students” and “without corresponding increase in funds.” An issue that perhaps still resonates today. Despite all efforts being focused on the war, in his 1942 address, Henry Lowsma found it important to remind the Academy of the importance of teaching. He said that “at the present time our scientific efforts will be directed toward winning the war. During this period our youth will continue to grow. Their training cannot be neglected.” Lowsma also said, just a few years before dropping atomic bombs on Hiroshima and Nagasaki, that “the products of science may be used either for man’s benefit or woe”. Prophetic words.

In 1960, V.R. Nelson eloquently summed up the importance of science teaching. “Let us join together to raise the teaching profession to its rightful place of pre-eminence in American life. Let us impress the public with the importance of science to the security, economy, and health of our nation.” Charles Vaughn echoed these sentiments in 1962 saying “the greatest responsibility of the Academy is to the people, especially the youth of today.”

Most recently Gary Larson in his 2012 address highlighted the inadequate funding for K-12 education in South Dakota and noted that South Dakota was last in teacher pay. South Dakota is still last in teacher pay and the problem appears to be getting worse. In the April 2, 2015 article “Teacher openings: Here’s the perfect storm”, the Argus Leader reported that there were more teacher openings in March (by about 100) than in any month in the last 7 years and that job openings typically peak in April.

Perhaps our greatest success in the last 100 years has been the effect that the Academy has had on fostering collegiality and collaborations among South Dakota science teachers and researchers. Personally several of my research collaborations have been the result of timely encounters at the academy. In his opening address, Dr. Hilton Ira Jones noted that “there have been a few great hermit scientists” but “I know of no first rate ones that still survive”. He went on to say “the pall of this country to me has always been the interminable stretch of miles that lay between me and anyone else that knew enough of the problem I was working on to appreciate what I was trying to do or to sympathize.” I think we can all relate to that. He went on to say that “prolonged isolation and lack of initiative produce stagnation and mental atrophy.” “Few scientists do good research without outside stimulus.” To break down isolation and stimulate research is the second great function of an academy like ours.” Aside from some lean years from 1928-1934, the South Dakota Academy of Science has consistently produced a proceedings each year. The proceedings are all online at the SDAOS website.
which made putting together this talk so much easier and pleasurable. This was no small endeavor and is an important accomplishment.

If breaking down isolation and stimulating research has been perhaps our greatest success, the dream of the early founders of the South Dakota Academy of Science as advising the governor and state legislature on scientific matters has been perhaps greatest unrealized expectation. N. E. Miller summed up the Academy’s unrealized expectations in his 1980 address by saying “the history of the academy is a bittersweet tale of muted aspirations whose outline is still discernible as one reads the proceedings.” It would not be hard to become disillusioned with our lack of progress on being consulted on scientific issues by the public and with our state government. I read with relish the presidential address of Charles Estee in 1957 who said “Perhaps it is time that we caused a little trouble. Perhaps it is time that we members of the scientific community use the Academy to state in a firm clear voice that we as scientists speak for the age in which we live; to demand that we be heard, for unless we stress the facts of our existence in this world today-unless we publicize the dependence of our very form of government upon our scientific technology-tomorrow our troubles as a nation may be far greater than those today. And as we hear the cries of those who deplore our age of science, who despair at the necessity of dealing with truth, of gathering, analyzing and justifying facts, perhaps we as individuals and as a society should cause just a little trouble and demand that our side likewise be heard.” We as scientists often lament our ability to communicate to politicians and the public about important issues. It is true that as scientists we could improve our message, but it also doesn’t matter how good the message is if no one is listening. As stated by Jack Saunders in his 1975 address “several President’s, Ballew among them, have announced to state government the availability of the academy to provide assistance by way of research or as an advisory body,” and “the state government hasn’t come to us for help!” The Academy is probably the most highly educated and largely ignored group within the state. I find it ironic that in a state where the teaching of evolution is objected to largely on religious grounds, that the history of the Academy in being a voice on scientific issues within the state has similarities to Old Testament prophets. From warning of environmental degradation to the funding of education, the Academy has been like a voice crying in the wilderness, largely unheeded, unheard. I am reminded of Jeremiah, speaking for the Lord telling the people of Judah “your ancestors refused to listen. They were stubborn, and whenever I wanted them to go one way, they always went the other. You have ignored me and become even more stubborn than your ancestors ever were. I am reminded also of Nehemiah, who wrote “you brought them into the land” and “blessed their nation”. “In spite of this they rebelled and disobeyed your laws. They killed your prophets who warned them.” Perhaps it is my upbringing, but I actually find this comparison comforting. Yes, it is discouraging when no one is listening, but our obligation to speak the truth about important matters is no less diminished.

What can we expect in the next 100 years? I expect the Academy to continue to advocate for best science teaching practices. I also expect that we will continue to be limited by funding. Somethings never seem to change. I expect the Academy to continue to provide a venue for the presentation of research. But
the recent declines in both full author papers and memberships require us to reconsider how we do that. I became involved with the Academy because of the mentorship of faculty at Augustana. Those of us involved with the Academy need to be mindful of recruiting the next generation of scientists. There is pressure on younger scientists to publish in journals with a higher impact factor and attend national meetings rather than a regional meeting. Perhaps we can reach out to citation indices to try and make South Dakota Academy of Science a more attractive publication venue. Also, networking and collaborating with other scientists within the state has its value. It can be as difficult to maintain an effective long distance research collaboration as it is to maintain a long distance romantic relationship. The recent participation of NIH BRIN supported undergraduate researchers significantly increased membership numbers and livened up the proceedings. We need to continue to reach out and connect with our fellow scientists in the state involved with NIH INBRE, NASA EPSCoR and NSF EPSCoR to look for opportunities where the Academy can be a resource for these groups. In particular, we need to ensure the Academy is a venue for undergraduate research to be presented.

I expect that scientists and the Academy will continue to speak the truth on issues such as climate change and evolution. Recently, I have been co-teaching classes on the ethics and economics of food. I have come to have grave concerns about an agricultural system that is increasing relying on trying to maintain monocultures. As Charles Estee stated, “perhaps it is time that we caused a little trouble”. I expect we will continue to struggle with getting the public and politicians to listen to us. But our obligation to engage the public and speak the truth about important scientific matters is no less diminished. Thank you.

RESOURCES

History of the South Dakota Academy of Science
Symposium Papers
presented at the
100th Annual Meeting
of the
South Dakota Academy of Science
A CONCORDANCE OF SCIENCE EDUCATION THEMES IN THE SDAS PROCEEDINGS: THE FIRST HUNDRED YEARS

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ABSTRACT

Several common science education themes are apparent in the articles and addresses contained in the last 100 years of the Proceedings of the South Dakota Academy of Science. These themes run parallel to issues and challenges arising in South Dakota at the time. Selected from the many themes found in the Proceedings, those examined here include papers whose emphasis is on 1) the need for science education of the public, 2) specific effective science teaching methods, and 3) certain philosophies of teaching and learning based on existing contextual factors. In the final section of this paper, some unresolved issues and challenges are addressed. Additionally, some thoughts on plausible solutions are explored.

INTRODUCTION

From the very beginning, the Proceedings of the South Dakota Academy of Science reflected considered opinions about not only the structure of teaching science, but also the attendant methods and the impact on student learning resulting from various approaches. Insightful and powerful teaching practices were described in at least 24 of the articles. The first example is an abstract in the first issue (1916p85) of the Proceedings: “The Relationship between Equipment and Efficient Science Teaching,” by A. B. Carr.

The science education themes gleaned from the abstracts, articles and Presidential Addresses are certainly as relevant today as they were 100 years ago. It seems incredulous that society’s trappings and technologies have so radically changed, but that the important issues and concerns surrounding the science education of each generation’s students and the best methods of teaching have scarcely been altered. The insights of teachers and professors in the last century have barely evolved – how can that be?

Not only do similar ideas and challenges recur throughout the Proceedings, but also many of the proposed solutions are similar, if not the same. Some commentary is added here to suggest reasons for many of our continued educational dilemmas, despite concerted efforts of decades of well-educated and dedicated teachers at all levels leading up to today.
The frequency of the articles supporting the three themes selected from the Proceedings for this paper are shown in Figure 1 and include: 1) examples of articles with an emphasis on the need for science education of the public, 2) illustrations and recommendations of specific and proven science teaching methods, and 3) promotion of certain philosophies of teaching and learning based on specific contextual factors at the college and secondary levels.

There were so many excellent papers and ideas that appeared throughout the Proceedings which made it very difficult to select the few that I highlight here. I ask the reader (who may have authored a paper not selected) to not take offense if his or hers is not among them.

**SCIENCE EDUCATION OF THE PUBLIC**

More than twelve articles in the Proceedings dealt with the topic of science education of the public in a major way, with many more mentioning the challenges in getting the public to accept scientific points of view and to delve into the heart of a science issue instead of buying into surficial or politically expedient positions on science and science education issues.

L. K. Akeley from the Department of Geology at the University of South Dakota, in his SDAS Presidential Address (1921p65) decried the “futility of enlisting” on the part of the general public any “intelligent appreciation of scientific research.” Akeley further maintains “the restricted and educated public that ought to be an intelligent supporter…can be swept off its feet by newspaper propaganda.” This argument sounds no different than today’s mostly scientifically bereft political climate. Speaking to the attempt to “popularize Einstein’s theories, as he visited the US, in 1919, Akeley pronounced:
The recent efforts made by the magazines and newspapers in the direction of popularizing science have shown the utter futility of ever enlisting any intelligent appreciation of scientific research on the part of the general public. (Akeley 1921)

In his SDAS Presidential Address, Sven G. Froiland (1964p36), from the Department of Biology at Augustana College posited:

Not everyone, by any means, really understands what science and technology represent. As a matter of fact, not everyone really understands the difference between a scientist and a technician... the relationship of the general public to the scientific world, the responsibility of the scientist and the lack of communication between the humanist and the scientist and even the morality of the scientist!! (Froiland 1964)

Dr. Froiland goes on to discuss that “gross misunderstandings” by the public about science and scientific work are not surprising as most of the public has little formal science background to bring to bear on these issues. Hence, much misrepresentation of scientific conclusions, suspicion and distrust of science and scientists on the part of the public can (and does) occur.

This process seems to have accelerated during the 2000’s as the public remains suspicious that global warming is some sort of hoax. This is the result of sustained resistance by certain political candidates to remedies that might affect businesses directly impacted by enhanced environmental protection measures. Legislation in many states has been written to refute that the global warming effects on our planet are caused by human endeavor. The South Dakota Science Standards committees in writing new standards in 2012-2014 were charged by the state legislature NOT to attribute any environmental impact as due to human activity in any of the wording in these standards.

In his SDAS Presidential Address (2005p13), Robert Tatina of Dakota Wesleyan University biology department, reiterated and further highlighted the issue of scientific literacy among the general population. Citing data from the National Science Foundation and the National Science Board, he delineated the ways in which a “general lack of understanding about how science works” proliferates in American society. He offers several reasons for this problem – including textbooks that lack depth and do not incorporate clear explanations of basic science principles, the structure of our school systems and the lack of funding and science required in the general curriculum both pre-college and in teacher preparation programs – especially among the elementary pre-service teachers.

There is a pervasive acceptance of pseudoscience. From the Science & Engineering Indicators 2004, about 50% of the US population believes in ESP, about 40% believe that astrology to be at least somewhat scientific, and about 30% believe in lucky numbers (National Science Board, 2004). (Tatina 2005)
Gary Larson, professor of biology at South Dakota State University, in his SDAS Presidential Address (2012p17) addressed the issue that our legislators and governors often do not understand the needs of science in South Dakota. He maintains that the SD K-12 educational system is “jeopardized” by inadequate state financial support and listed several causes for this precarious situation, among them: “reforms” suggested by Governor Daugaard which amounted to additional cutting of the already emaciated state education budget. This trimming was supposedly justified by “low test scores” and higher per pupil funding as compared to 1971 (with no adjustments for inflation). Not addressed was the abysmal teacher pay—49th (in 2012) among all states. It is now 50th and several thousand dollars lower than all of our surrounding states.

A one-time teacher bonus was suggested by the governor as a solution to the problem of accelerating teacher shortages. Because twenty percent of the state’s share of the money is passed through from the federal government, South Dakota spends, on average, $1600 less than what has been determined to be the lowest sustainable per pupil funding.

First, South Dakota cannot hide a poor environment for teachers. The state’s record of education funding and how teachers are treated in South Dakota is online for all to discover and…unless and until teachers and school administrators are valued as professionals, we will lose top educators to other states. South Dakota must compete for good educators rather than penalize the good ones it has. (Larson 2012)

Dr. Larson also cites the state legislature’s adding of layers of “accountability” measures to our overburdened and ill-supported schools. He urges an overhaul of the financial underpinnings of funding for education and that citizen’s urge politicians to finally increase the SD state-based share of funding for our public schools.

SUGGESTED METHODS OF EFFECTIVE SCIENCE TEACHING

At least 24 Proceedings articles addressed specific teaching practice and include methods with a discussion of factors in practice that impede deep and sustained science learning. Several representative examples are highlighted here.

In his paper, J. G. Hutton (1929p53) espoused the responsibility of the scientist to become an effective teacher, “…to shape the philosophy of college students” so that it encompasses a more scientific perspective. Dr. Hutton encourages the science instructor to bridge the gap between what the student already knows with the theories of science presented – so as not to “lose” the student and “reduce the intensity of the growing pains.” He saw this important function of the scientist as a “moral duty.”
It is possible so to present the facts of science that the student will be so jarred and shocked and confused that he experiences great anguish of soul and may even develop a radical and unsocial philosophy. Facts and theories should be presented according to the ability of the student to assimilate them without disaster to himself. Hutton (1929)

In his Presidential Address (1939 p11) Ward L. Miller, from the botany department of South Dakota State College, examined “Teaching Techniques in the Light of New Demands Made Upon Science.” In his address, he asked many questions, including: “how can the teaching of science to an ever increasing number of students be continued when there is no corresponding increase in room or equipment?” He suggested that students were entering college for reasons different than those in the past and he lamented that many were not serious students and had “varying capacities.” He maintained that the solution to the enlarging student body was substituting the “lecture-demonstration method” of teaching for the laboratory method.

Dr. Miller lamented that “making every student learn the same way” was at the heart of the problem and neglected those who would become scientists as well as those who needed a more “hands-on” approach to really develop a scientific way of thinking and to acquire skilled laboratory techniques. His plea for students to “understand” over “memorizing facts” also speaks to the educational environment today, especially in public schools where “teaching to the test” has fundamentally changed the way the sciences (and other subjects) are taught. Dr. Miller reiterates his aims:

But, I believe understanding to be the important aim for the great majority of beginning students; and I can teach understanding better with the demonstration method than I can with the individual laboratory method…All are better satisfied. (Miller 1939)

In the Proceedings (1957 p151), Kenneth V. Olson, from Northern State Teachers College in Aberdeen, presented findings from his unique controlled mixed methods study “An Experimental Evaluation of a Student-Centered Method and a Teacher-Centered Method of Biological Science Instruction for General Education of College Students (p181).” He outlined and defined four “pivotal” objectives of science teaching as the following:

1. Acquisition of factual information in science.
2. Understanding and application of the principles of science.
3. Understanding and application of the elements of the scientific method together with its associated attitudes, and
4. Skill in the basic tools peculiar to a specific science.

Dr. Olson centered his research questions on two conflicting methodologies as evidenced in the title of his paper. He found that even though students in both methods increased in knowledge of subject matter and scientific thinking abil-
ity, students in the teacher-centered group performed better on subject matter questions than those in the student-centered group. Nonetheless, there were no differences between methods in student performance on “some inductive aspects of scientific thinking.”

His findings, however, yielded some surprising results. Looking at the mean initial and final scores on student performance and comparing boys and girls, he found that girls performed significantly higher than boys in both methods on their “ability to recall and apply biological facts and principles.” Boys, on the other hand, performed significantly higher in the teacher-centered method than in the student-centered method on this ability. I might add that students were far more familiar with the teacher-centered method so that there may have been a learning effect at play here with the student-centered method. More scientists might well reserve drawing conclusions from experience and instead apply their science backgrounds to the determination of teaching method success through controlled studies such as this one. Such experimental methods are commonly used in science education studies today.

In his Presidential Address (1987p15), Marvin Seines, a high school physics teacher, gives an object lesson as he illustrates the qualities of excellent high school science teaching and maintains, “The textbook alone is not science or the curriculum.” He makes the case that science learning does not end with graduation, but that it must be a process of “life-long learning.” Defining science as both a “body of knowledge and a process of investigation,” Mr. Seines describes the teacher as the “catalyst in the educational process.” But, he pleads...
for support (also seen in the tight budgets of today) not only financial, but also in awareness by legislators and other state officials that there is inherent danger in ignoring math and science education. Demanding improvement doesn't support, but hinders the teacher, where there is not also a coherent plan with clearly elucidated solutions.

SDAS President Lynn Hodgson, of the Department of Mathematics and Natural Sciences at Northern State University, in her Presidential Address (1992p17), “Priming the Pump,” (p18) describes a math and science “pipeline” to produce more scientists and science teachers. Her goal is science literacy for all students with a continuous pipeline of well-educated students who then pursue math and science careers. Her pipeline is illustrated in Figure 2.

All students enter school (at the bottom of the pump), become (hopefully) scientifically literate in the primary and secondary grades. Then, after high school, differentiate in their choices of profession or enter higher education. Today, math and science teachers, especially in secondary schools, will typically hold graduate degrees in science and/or science education.

PHILOSOPHIES OF TEACHING AND LEARNING
BASED ON CERTAIN CONTEXTUAL FACTORS

At least 18 of the articles in the Proceedings contained philosophies of teaching that embraced certain predetermining factors that might impact a student’s ability to learn certain subjects and processes. These articles include one by W.W. Tuttle (1920p27), who tied the ability to learn how to type to certain “native traits.” He devised a controlled study to measure the degree to which students possessed those traits (or not). Native skills of an efficient typist, according to Mr. Tuttle included:

1. Quick motor action.
2. A keen sense of rhythm.
3. Ability to pay attention and be accurate.
4. A well developed memory span.
5. Ability to follow directions.
6. Ability to carry on the process of substitution. (Tuttle 1920)

When trait test results were compared with typewriting task success, certain attributes were found not to be necessary for typing, but useful for other tasks related to learning. These included: sense of rhythm, ability to follow directions, and memory span.

Note: care should be taken when drawing conclusions based on “native skills,” since much can be learned with practice despite an initial showing of lack of skill. Wise and experienced teachers suggest that patience and hope spring eternal and may be rewarded with success in the end.

W.H. Batson of the University of South Dakota, in his article, “Measuring Human Ability” (1922p18), compared the necessity of a standard system of measurement in science to the necessity of developing a reliable intelligence
test – to “measure human ability.” With any instrument, there should be some understanding of its capabilities and limits because decisions made on the basis of standardized tests of all kinds can be destructive if the tests are not put into context with other factors.

On the whole it appears that the effort to replace opinion by measurement in our rating of work in various levels of education and even in determining ability or capacity for activities outside of school will increase and spread… There are many fantastic and even deceptive procedures parading behind the banner of educational science. Alleged scales are reported and used which measure the fact in question about as well as the noise of the thunder measures the voltage of the lightning. (Bateson 1921)

Early attempts at development of measures of intelligence as predictors of student success as well as determining the value of students’ ability to learn yielded conclusions that were fraught with misinformation, error and downright bigotry and sexism. Little understanding of the impact of developmental differences over time among students was considered.

By 1945, the predictions made by W.H. Batson in the Proceedings in 1922 had already come to fruition – more and more complex measures of student achievement were being used to assess which students were superior and so determined scholarship and the ability to do college level work. Batson’s second article on the subject was included in the 1946-47 Proceedings. In this paper, he delves deeply into the nature of the tests, the objectives met by giving them, as well as how they were administered and graded. He includes a detailed report of findings for the period 1935-1944, illustrating tremendous increases in the number of schools participating in the testing program that encompassed questions on English, Social Studies, Science and Mathematics.

At that time, 32 percent of high school graduates went on to attend college compared with 43 percent of those who qualified for the final scholastic examination based on the scores of their first test. However, prediction of these students’ success in college was not convincing – as grades are only incidentally a predictor of success. After college matriculation, no correlation between test scores and success is evident.

**SCIENCE EDUCATION IN SOUTH DAKOTA: UNRESOLVED ISSUES AND CONTINUING CHALLENGES**

This author, from the School of Education at the University of South Dakota, previously wrote about the history of science education in the *Proceedings* paper (2012p167) entitled “Public School Science Curriculum in Context: The Impact of Standard Reforms During the Last Two Hundred Years.” In the conclusion of that paper the following appeared:
At a hearing early in 2007, Senator Edward Kennedy suggested that the way forward in science education lies in our knowledge of the past. He reminded us of events that have been forgotten in the present push for standards reform, “We did it after the Sputnik launch, [in 1957] when we trained a new generation of Americans in math and science. And we inspired millions more to greater and greater innovation when President Kennedy challenged us to send a man to the moon” (Abramson 2007). In 1958, Congress had passed the National Defense Education Act that gave a new science curriculum an infusion of more than a billion dollars when it passed. (Ezrailson 2012)

As long as society changes and science education is then again “reformed,” educational funding, as seen historically, will continue to be one of the biggest obstacles to science education quality and uniformity in South Dakota. Additionally, tension between the general public and science will continue, inviting political diatribe and new testing measures to again replace real and lasting reform. Tension and competition among colleges and online entities will increase, as the role of the “brick and mortar” college and university becomes more undefined and tenuous.

Perhaps, if the roots of today’s challenges were examined with an historical lens, having an appreciation for the issues addressed, then an understanding of the solutions that had been attempted and worked, as well as those that had failed, might help us to formulate better remedies. As a result, the next generations of science education reforms, programs and partnerships between schools and colleges could blossom to yield excellent results.

This paper has drawn from our earliest beginnings and traced a path through papers addressing some persistent issues: the need for science education of the public, a look at specific and effective science teaching methods, and examined certain philosophies of teaching with their mitigating contextual factors. Some thoughts on possible solutions are offered and include: 1) educating ourselves (scientists and teacher) thoroughly on the issues (respecting all perspectives) to look for common ground and common language that the public will understand; 2) working together to prioritize steps to be taken (construct a timeline and action items) and to begin to spread our common message – consistently and persistently; 3) opening a continuous, and mutually respectful dialogue between all invested parties to formulate a strong message that includes achievable benchmarks and clear goals and; 4) most importantly, celebrating and publicizing (continuously) our successes and achievements to the public!
FROM TABEAU TO SDOU: A BRIEF HISTORY OF ORNITHOLOGY IN SOUTH DAKOTA WITH SPECIAL REFERENCE TO WORKS PUBLISHED IN THE PROCEEDINGS OF THE SOUTH DAKOTA ACADEMY OF SCIENCE

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ABSTRACT

The history of ornithology in South Dakota can be divided into several general periods. The initial natural history forays into what was to become South Dakota, including the Lewis and Clark expedition, occurred during the first half of the 1800s and form a period of exploration. During the latter half of the 1800s, sponsored government surveys traversed western North America, including the western Dakotas, while settlement predominated in the east, and ornithological efforts focused on a more complete catalogue of birds within particular regions. Efforts of a number of individual ornithologists during the late 1800s and first half of the 1900s built upon these initial studies to provide more complete catalogues of birds of particular regions within the state. It was also during this period that the first comprehensive treatments of the statewide avifauna appeared. A seminal event in the ornithological history of South Dakota was the founding of the South Dakota Ornithologists’ Union in 1949 and this organization still strongly supports bird research in the state. Ornithology content published in the Proceedings generally reflects these historical trends. Efforts to more precisely define the status and distribution of birds in the state remain an important focus of Ornithology, and such content occurs in the Proceedings from its inception until today. More recent years have witnessed the diversification of bird studies in South Dakota and this is also reflected in publication trends in the Proceedings. Early ornithology content published in the Proceedings focused on history, natural history notes, and poultry science. Major foci of ornithology content in the Proceedings from 1960-1989 included contaminant effects, habitat associations and ecology. Habitat associations and ecology remained prominent ornithology topics in the Proceedings during the last quarter-century, but conservation and management, climate change and physiology have increased in coverage.

Keywords

Ornithology, history, South Dakota, Audubon, Maximilian of Wied, South Dakota Ornithologists’ Union, South Dakota Academy of Science
INTRODUCTION

The study of birds in South Dakota has a long and rich history, which can be conveniently categorized into several distinct periods based on the background knowledge and technology available for studying birds, the funding sources supporting these efforts, and the topics on which ornithological studies focused. Recognizing that other classification schemes are possible, I’ve divided the history of ornithology in South Dakota into four periods. Early bird study in South Dakota usually was part of larger exploratory excursions into the state which focused on documenting natural history and describing the culture of the resident indigenous peoples. I call this the Period of Exploration and it extended roughly from 1800-1850.

During the latter half of the 1800s was a period of government-sponsored surveys of natural history, geology, and natural resources in the western part of the state and settlement in eastern South Dakota. Ornithological studies during this period focused on refining knowledge of the status and distribution of birds in the state. These topics continued to be a major focus of bird study in the state in the period from 1900-1950, where a number of professional ornithologists and amateur bird enthusiasts greatly refined the knowledge of the status and distribution of birds in the state through more in-depth surveys of the birds within smaller geographic areas (e.g., counties, topographical regions). During this period the first comprehensive avifaunal treatments of the birds of South Dakota also occurred. The founding of the South Dakota Ornithologists’ Union (SDOU) toward the end of this period, in 1949, was an important event for promoting ornithological research within the state, a role in which the SDOU is still very active.

More recent advances in technology, as well as increasing availability of government and university funding for research, have expanded the study of birds within the state to a wide diversity of topics. Consequently, I call the period of ornithology in South Dakota since 1950 the Period of Ornithological Diversity. In the remainder of this paper, I’ll highlight some of the more noteworthy advances in ornithological study within the state during each of these periods, as well as focus on the role of the South Dakota Academy of Science and its publication, *Proceedings of the South Dakota Academy of Science* (hereafter *Proceedings*), in advancing and disseminating knowledge about birds, both in South Dakota and more broadly.

PERIOD OF EXPLORATION (1800-1850)

Early bird study (prior to 1850) in the geographic region that was to become South Dakota occurred along the Missouri River and its surrounding habitats, as the river formed a conduit for travel and commerce during this period. The earliest exploratory expeditions were by representatives of fur trade companies scouting the area for commercial possibilities, but also included the government-sponsored Lewis and Clark expedition. Following these earliest expeditions, several important privately funded exploratory parties penetrated the Missouri
River region in the Dakotas to describe the natural history as well as the culture of the indigenous people inhabiting the region.

The first written mention of a bird in South Dakota was by Jean-Baptiste Truteau, who traveled up the Missouri River with a scouting party for the Missouri Company in 1794 (Krause 1956). The party wintered at a post they built south of Pickstown, in current Charles Mix County, South Dakota. Truteau’s journal mentions that the party shot Wild Turkeys (Meleagris gallopavo) for sustenance over the winter. No other birds were specifically mentioned in the journals, but this mention provides a single datum for the historical distribution of turkeys in the region (Krause 1956), and, interestingly, this site is close to the northwestern extent of the historical range of the Eastern subspecies of the Wild Turkey (M. g. silvestris) in North America (Speller et al. 2010).

Pierre-Antoine Tabeau accompanied Régis Loisel and a party from the Missouri Company up the Missouri River to a trading post at Cedar Island (current Stanley or Lyman Co., SD) in 1803, serving as narrator for the party and keeping a journal (Abel 1939). The party departed upriver from the mouth of the Missouri on 22 June 1803 and wintered at the Cedar Island post from 1803 to 1804 (Krause 1956). Tabeau apparently continued living among the Arikaras on Cedar Island after Loisel departed in the spring of 1804, finally traveling downriver in April of 1805 with the crew sent downriver by Lewis and Clark from the Mandan villages (Abel 1939). Tabeau was the first to describe a portion of the avifauna of South Dakota for reasons other than table fare, so this narrative really provided the first true ornithological information on bird distribution within the region that was to become South Dakota. Tabeau’s bird list includes Black-billed Magpie (Pica hudsonia), which were noted as picking at saddle sores on the backs of horses, Golden Eagle (Aquila chrysaetos) and Wild Turkey, the latter of which he notes that they seldom occur above the mouth of the Niobrara River (Krause 1956). He also mentions, without noting the precise location along the expedition route, that “the plovers in the autumn and the spring and the pheasants in every season are abundant” and that “The hawk, the merlin, the crow, the owl and others are very common” (Abel 1939, p. 88). These quotations illustrate some of the difficulty in extracting ornithological information from the journal narratives of these early explorers. Bird common names were not codified until later (American Ornithologists’ Union 1886), so bird names were often quite variable among different authors. In addition, in this era when good descriptions required shooting the bird and describing it in hand, along with scientific training to recognize what features were important to note, descriptions of birds observed were often incomplete or rudimentary, which makes unambiguous identification difficult or impossible.

The next exploration of the Missouri River region which provided information on birds of the region was the Lewis and Clark expedition in 1804-1806. Part of the charge of the Lewis and Clark expedition was to record the natural history of the regions through which the expedition passed, including a catalog of the birds observed. Lewis and Clark passed through the middle Missouri River region, defined here as from Omaha north to the North Dakota/South Dakota border, from 27 Jul-14 Oct on the upstream journey, and from 23 Aug-7 Sep 1806 on the downstream journey (Moulton 1986, 1987, 1993). Thus, they observed
birds in the region during the late summer, after the breeding season for most birds in the region, and during fall migration, rather than during the spring and early summer breeding season when birds are typically easier to detect (Tallman et al. 2002). Nevertheless, the Lewis and Clark expedition produced a large leap forward in ornithological knowledge of the American West, and 134 species of birds can be identified with certainty from the journals (Holmgren 1984a,b). Of these, by my count from the journals, 57 species occurred along middle Missouri River region during the dates of passage.

Lewis and Clark are given credit for the first scientific descriptions of 25 bird species or subspecies, including 4 from middle Missouri River region – Sharp-tailed Grouse (*Tympanuchus phasianellus*), Interior Least Tern (*Sternula antillarum athalassos*), Common Poorwill (*Phalaenoptilus nuttallii*), and Black-billed Magpie. The explorers first noted Interior Least Tern near the mouth of the Soldier River in current Washington County, Nebraska. This subspecies is now listed as federally endangered, but still nests regularly on unvegetated sandbars of the Missouri and Cheyenne rivers in South Dakota (Thompson et al. 1997, Tallman et al. 2002). Sharp-tailed Grouse were first noted on 12 September 1804 in current Charles Mix County, South Dakota. One bird was captured and sent back alive to President Thomas Jefferson from the Mandan villages, along with many natural history specimens and other materials, but this individual did not survive the trip (Moulton 1987). Black-billed Magpie was first noted near the mouth of American Crow Creek (current Lyman Co., SD) on 16 Sep 1804. The party eventually captured four magpies and sent them back to Jefferson from Fort Mandan; one survived the trip and was kept by Jefferson as a pet for some time afterward, serving as the model for Alexander Wilson’s painting in his American Ornithology (Holmgren 1984c). The final new species new to science was the Common Poorwill, of which Lewis and Clark found a torpid individual near the mouth of the Cannonball River, just north of the South Dakota border in current Sioux County, North Dakota, on 17 October 1804. The circumstances surrounding this observation demonstrate clearly that Lewis was an experimentalist, as his response to finding the dormant bird was to scramble its heart and lungs with his pen-knife and then see what happened. What happened, as noted in the journals, was that the bird “lived upwards of two hours,” to which Lewis correctly concluded that “this fanominon [phenomenon] I could not account for unless it proceeded from the want of circulation of the blood” (Moulton 1987, p. 178).

Thus, Lewis was not only the first to describe Common Poorwill, but also the first to discover torpor (a state of dormancy where body temperature drops to save energy) in birds, a phenomenon that would not make its way into the mainstream ornithological literature until the 1940s, when Jaeger (1948, 1949) also found that poorwills use torpor. Interestingly, even though many birds use nocturnal torpor or hypothermia as a strategy for saving energy, usually under conditions of cold or food scarcity, the Common Poorwill is the only bird known to hibernate, that is to remain dormant for periods longer than a single night (Woods et al. 2005).

One other noteworthy record from Lewis and Clark is their mention of the now-extinct Passenger Pigeon (*Ectopistes migratorius*) in Lyman County,
South Dakota on 16 September 1804. This species formerly bred in woodlands throughout eastern North America west to Kansas, northwest to Alberta, and across southern Canada (Blockstein 2002) and occurred as a migrant and uncommon nesting species in South Dakota (Tallman et al. 2002). Lewis and Clark noted it on several occasions, from St. Louis to the Lemhi River, Idaho, including the Lyman County, South Dakota, record where Clark notes that “almost every species of wild game is fond of the acorn … turkies, ducks, pigegians …” (Moulton 1987, p. 77).

Following the Lewis and Clark expedition, the fur trade dominated commerce in the region for many years, but the trappers generally added little to our knowledge of birds in South Dakota. During the early 1800s, however, several privately funded expeditions considerably advanced the knowledge of birds in the region. The first of these was by the 26-year old Duke Paul Wilhelm of Württemberg in 1823. Duke Wilhelm was a nephew to King Frederick of Württemberg, and as such was a member of the ruling house of this Prussian Kingdom, presently part of a state in southern Germany. He traveled widely in North America from 1822-1824, including the trip up the Missouri River (Wilhelm 1973). Duke Wilhelm had some scientific training during his schooling, which prepared him well for this expedition, the purpose of which was to document the natural history of the region and the cultures of the indigenous people along the Missouri River. Duke Wilhelm applied scientific names to the observations of species in his journals, which reduced, but did not completely eliminate confusion over species descriptions. As an interesting historical side-note, Baptiste, the son of Sacagawea and Toussaint Charbonneau (interpreter for the Lewis and Clark expedition) who was born at Fort Mandan during the winter of 1805 and later adopted by William Clark, accompanied Duke Wilhelm back to Germany in 1824 and remained there under the Duke’s supervision until 1829 (Wilhelm 1973). Duke Wilhelm made another expedition up the Missouri River to its source in 1829 and 1830 (Wilhelm 1973), but to my knowledge, no ornithological material survives from this trip.

Like Lewis and Clark, Duke Paul Wilhelm traveled upriver in 1823 by the relatively slow keelboat, although he often disembarked and traveled overland for long periods as well. Consequently, the party covered the distance from St. Louis to current Chamberlain, South Dakota over a relatively long period, from May through November of 1823 (Wilhelm 1973). The party was in South Dakota from mid-August to early September and had planned to proceed farther up the river than the location of present-day Chamberlain, but they were forced to turn around by rumors of roaming bands of Arikaras that were hostile to intruders. Thus, Duke Paul Wilhelm, like Lewis and Clark, also observed birds in South Dakota during the late summer after the breeding season and during the early fall migration period. He recorded approximately 46 species of birds on the Missouri River expedition (Wilhelm 1973). Prior to entering South Dakota, at the mouth of the Niobrara River, Duke Wilhelm mentions Sharp-tailed Grouse and a “large, pretty grosbeak, brown with yellow underbelly with white spotting, lives either singly or in small flocks in these parts, and seems to frequent the wild cherry trees of the prairie” (Wilhelm 1973, p. 346), perhaps a juvenile or female Black-headed Grosbeak (*Pheucticus melanocephalus*). Specific mention of birds
from South Dakota in Duke Wilhelm’s journals are relatively few, but include Cliff Swallow (*Petrochelidon pyrrhonota*), Mississippi Kite (*Ictinia mississippiensis*), swans (perhaps Trumpeter Swan, *Cygnus buccinator*, a former nesting species in eastern South Dakota, now reintroduced in western South Dakota and several areas in the Midwestern and eastern U.S.; Tallman et al. 2002, Mitchell and Eichholz 2010), and American White Pelican (*Pelecanus erythrorhynchos*). The Mississippi Kite record, a specimen collected by Duke Wilhelm on 30 August 1823 from the Bijou Hills, current Brule County, South Dakota, is particularly noteworthy. This specimen served as the model for Alexander Wilson’s painting of this species in American Ornithology. Only seven records of Mississippi Kite exist for South Dakota, and all other records of the species are of spring migrants from May (Tallman et al. 2002; [http://sdou.org](http://sdou.org)). The final mention of birds from South Dakota occurred from the mouth of the Big Sioux River on 6 September 1823, where Duke Wilhelm noted that Wild Turkey and the now-extinct Carolina Parakeet (*Conuropsis carolinensis*) “seem rarely to cross this boundary, but appeared in huge flights farther downstream” (Wilhelm 1973, p. 373).

The next privately funded expedition up the Missouri River was that of the party of Prince Alexander Phillip Maximilian of Wied in 1832–1834. This expedition added considerably to the early ornithological knowledge for South Dakota. Prince Maximilian was the eighth of ten children of Friedrich Karl, Count of Wied-Neuwied, a Prussian principality, now in west-central Germany. He received some training in the sciences from the anthropologist Johann Friedrich Blumenbach at the University of Göttingen and the explorer-naturalist Alexander von Humboldt (Schach 1994, Noll 2011). At the time of the trip up the Missouri River, Maximilian was 50 years old and had considerable previous experience as a naturalist, having conducted an expedition to document the flora, fauna and indigenous peoples of Brazil in 1815–1817 (Noll 2011).

His party traveled by the steamboat *Yellowstone* under the auspices of the American Fur Company and so proceeded at a much faster rate than previous natural history expeditions (Schach 1994). The party made it upriver as far as Ft. Union at the mouth of the Yellowstone River and then retreated downstream to winter at Fort Clark, north of present-day Bismarck, North Dakota, from November 1833 through April 1834 (Witte and Gallagher 2010). Maximilian’s personal party consisted of only two people other than himself, the artist Karl Bodmer, now justifiably famous for his iconic historical portraits of the Missouri River region and indigenous peoples, and the hunter-taxidermist, David Dreidoppel, on loan from his brother to support Maximilian’s travels in North America (Schach 1994). Maximilian’s expedition up the Missouri River, like his previous expedition to South America, focused on documenting the natural history and native cultures of the region (Noll 2011, Witte and Gallagher 2010).

The party passed upriver through South Dakota from 8 May – 13 June 1833, so they were the first of the early natural history expeditions to encounter birds during spring migration and the early part of the breeding season, when birds are in full breeding plumage and are singing and displaying. From my perusal of the journals (Witte and Gallagher 2010), Maximilian made specific mention of 66 bird species for South Dakota. Noteworthy records include Swallow-tailed Kite (*Elanoides forficatus*), a curlew on the prairies near the mouth of the James
River, the now-extinct Passenger Pigeon, and Common Raven (\textit{Corvus corax}). The Swallow-tailed Kite was observed near the mouth of the Big Sioux River on 8 May 1833. Only one record for this species since 1910 exists for South Dakota, although it was apparently more common prior to 1910 (Agersborg 1885, Tallman et al. 2002, \url{http://sdou.org}). Maximilian mentions that his party observed a curlew of the genus Numenius on 11 May and several pairs of curlews on 12 May 1833, both observations occurring on the prairies above the river bluffs between the James and Niobrara rivers. Witte and Gallagher (2010) suggest that these sightings refer to the Long-billed Curlew (\textit{Numenius americanus}), which is reasonable since they nest on mixed grass prairies and arrive on breeding grounds in the Great Plains by mid-April (Tallman et al. 2002), and Audubon also saw them in this area in early May (Audubon 1960). This area is currently east of their range in South Dakota, but they formerly also nested in the southeastern part of the state (Tallman et al. 2002), although they were rare in southeastern South Dakota by the 1880s (Agersborg 1885). Another possibility is the now-extinct Eskimo Curlew (\textit{Numenius borealis}), which was formerly a common spring migrant through eastern South Dakota during the early to mid-May time period when Maximilian observed these birds (Agersborg 1885, Tallman et al. 2002). Common Raven is now a very rare species in South Dakota, averaging fewer than two reports per year, with most records from the fall and winter, but it was formerly more common prior to the disappearance of bison (Tallman et al. 2002, \url{http://sdou.org}).

The last of these major privately funded expeditions was by the famous ornithologist-naturalist-artist John James Audubon, who traveled up the Missouri River from May through October of 1843 (Audubon 1960, Rhodes 2004). The traveling party of five consisted of the 58-year old Audubon, John Bell as taxidermist, Isaac Sprague as artist, Lewis Squires as assistant, and Edward Harris, who helped fund the journey (Stevens 1943). The Audubon party traveled upstream as passengers on the American Fur Company’s steamboat \textit{Omega}, so progress was rapid and it took only 49 days from St. Louis to reach Fort Union at the mouth of the Yellowstone River, which was a record at the time (Stevens 1943). The downstream trip was on a Mackinaw barge, the \textit{Union}. Audubon’s focus was on documenting the natural history of the region, principally cataloging the birds and mammals. Audubon described a total of five new bird species on the Missouri River expedition, including Bell’s Vireo (\textit{Vireo bellii}), Sprague’s Pipit (\textit{Anthus spraguei}), Le Conte’s Sparrow (\textit{Ammodramus lecontei}), Baird’s Sparrow (\textit{Ammodramus bairdii}), and Common Poorwill, the species observed by Lewis and Clark, but not sufficiently described for scientific purposes.

The party traveled through the region to become South Dakota from 14 May through 3 June on the upstream trip and from 1 September to 1 October on the downstream trip, so Audubon was able to observe South Dakota birds during spring migration, the early breeding season, and fall migration. He listed approximately 72 birds from South Dakota, two of which were new to science and several with ranges that were different at that time than today. The two new species that Audubon collected and described from South Dakota were the Le Conte’s Sparrow, from Cedar Island (the same Cedar Island on which Tabeau wintered in 1803) on 22 May 1843, and the Common Poorwill, from some-
where between the mouth of the Moreau River and Fort Pierre on 7 September 1843. Le Conte’s Sparrow currently is a rare to uncommon nesting species of moist grasslands in the northeastern and north-central portions of South Dakota (Tallman et al. 2002). Audubon collected the poorwill during fall migration, which he noted in the journals (Audubon 1960), and the date mentioned is within the main fall migratory period for this species in South Dakota (Tallman et al. 2002). Audubon also observed the now-extinct Carolina Parakeet and Passenger Pigeon within South Dakota.

Several other noteworthy records, either of rare species or species with different ranges than the present day, were also provided by Audubon in the journals (Audubon 1960). A Common Raven, currently only of casual occurrence in the state (Tallman et al. 2002), was observed on 14 May near the mouth of the Big Sioux River. On 16 May, Audubon collected a Henslow’s Sparrow (Ammodramus henslowii), which is a rare grassland migrant and breeding species in the state that is more common farther southeast in North America (Tallman et al. 2002). Audubon collected several Evening Grosbeaks (Coccothraustes vespertinus) on 28 May at Fort George (in current Presho County). Evening Grosbeaks are currently a rare breeding species restricted in the state to the Black Hills (Tallman et al. 2002). Audubon also mentions in the journals that he heard a Pileated Woodpecker (Dryocopus pileatus) near the mouth of the Big Sioux River on 1 October. Pileated Woodpecker is currently a rare permanent resident and breeder in northeastern South Dakota, with only a very few records of wandering birds in the southeastern part of the state (Tallman et al. 2002). Audubon also makes mention of a Fork-tailed Hawk on 20 May near the mouth of the James River. The identity of this bird is not certain, but it could be a Swallow-tailed Kite, of which only one has been documented in the state since 1910, but this was a species also noted by Maximilian.

Two papers from the Proceedings nicely summarize the ornithological impact of these early explorations. Krause (1956) provides a detailed summary of the ornithological information gleaned from the journals of those expeditions before Audubon, and states that “Before 1794 our knowledge of the avifauna of South Dakota amounted to little or nothing … By 1834, forty years later, we had considerable information on at least 31 species of birds and some data on their distribution” (p. 201). Over (1922) provides an overview of the Audubon expedition and the birds he recorded and provides a nice commentary describing the single-mindedness of Audubon as a naturalist - “… Audubon had no interest in anything except birds and mammals, of which he saw and recorded many different species” (p. 44). By the end of this Period of Exploration, a solid foundation of knowledge regarding the status and distribution of birds of the region had accumulated, upon which later ornithological studies would capitalize.
PERIOD OF GOVERNMENT SURVEYS
AND SETTLEMENT (1851-1900)

Coues (1874) reviewed bird data collected by several U.S. Army, U.S. Geological Survey and Pacific Railroad expeditions from the 1850s through the early 1870s to western North America, including the entirety of the Missouri River drainage, which is the region of focus of his book. These expeditions include those supervised by G.K. Warren in the mid-1850s to the Upper Missouri, Yellowstone, Platte and Niobrara rivers and the Black Hills and W.F. Raynolds in 1859 to map the area between Fort Pierre and the headwaters of the Yellowstone River. Also included is the analysis of specimens collected by J. Stevenson, H.D. Smith, and C. Hart Merriam (of ecological life zones fame) on 1870 and 1872 expeditions to the region under the supervision of Ferdinand V. Hayden, to whom the introduction to the book is addressed as Geologist in Charge of the U.S. Geological Survey of the Territories. The focus of this handbook is status, distribution and habitats for the species listed, although Coues (1874) also comments on unfamiliar plumages, behavior, nesting details and phenology of the annual cycle for some species. Coues (1874) makes specific mention of 125 species from the region to become South Dakota (Whitney et al. 1978), so the number of species recorded from South Dakota has, for the first time, exceeded the century mark.

Also during this period was the expedition led by George Armstrong Custer to the Black Hills in 1874, where gold was discovered, which led to the penetration and settlement of the Black Hills by Euro-Americans in violation of the 1868 Treaty of Fort Laramie. George Bird Grinnell accompanied the expedition while he was a graduate student at Yale University and served as the naturalist, making most of the bird observations for the expedition report by William Ludlow (1875). The Custer Expedition left Fort Lincoln, near current Bismarck, North Dakota, on 2 July. The party entered South Dakota and explored the Cave Hills in current Harding County on 11 July. On 20 July the expedition entered the Black Hills from the northwest and spent until 16 August in the Black Hills, departing from Bear Butte on that date and returning to Fort Lincoln on 30 August, so they experienced the late breeding season and post-breeding periods for most birds in the Black Hills. A total of 110 species of birds was mentioned in the report (Ludlow 1875). Some of the more interesting or noteworthy records included the White-winged Junco (Junco hyemalis aikeni), a subspecies largely endemic to the Black Hills (Pettingill and Whitney 1965, Tallman et al. 2002) which Ludlow (1875, p. 90) calls “the most common bird in the more elevated portions of the Black Hills,” a statement which may still be true to this day. Ludlow (1875) also mentions the Clay-colored Sparrow (Spizella pallida) as abundant, but Chipping Sparrow (Spizella passerina) as “nowhere abundant” (p. 90). Clay-colored Sparrow is now restricted as a breeding bird to northeastern South Dakota, although it is a statewide migrant, whereas the Black Hills may serve as the epicenter of Chipping Sparrow abundance in North America (Tallman et al. 2002). Whether this difference in population trends for the two species in the Black Hills results from habitat or other changes or identification challenges – late summer and juvenile plumages of Chipping and Clay-colored
sparrows are very similar and plumages of some species in the region over the entire annual cycle were not completely known at that time (Coues 1874) – is not known. The party also saw Common Raven regularly throughout the expedition, and I’ve already mentioned that this is a very rare species in South Dakota at the present day.

This period was also defined by the settlement of the eastern portion of Dakota Territory, which provided opportunity for people to begin to learn the birds of the areas in which they lived, and the initial descriptions of regional avifaunas began to appear toward the end of this period. An excellent example was that of Gabriel S. Agersborg, a college-trained physician and veterinarian from Vermillion who also served as the first teacher in the Vermillion School District after it was organized in 1867 (Stalheim 1987). Agersborg (1885) described the status and distribution of birds in southeastern South Dakota, covering the area from Yankton County east to Union County and north to Minnehaha County, in an annotated checklist format, listing a total of 215 currently recognized species. Other examples of early regional avifaunas appearing during the late 1800s include those of B. Knickerbocker (Chilson 1968) and C.E. McChesney (1879), both of whom studied the avifaunas of northeastern South Dakota. Publications such as these proliferated during the early to mid-1900s and greatly expanded local and regional knowledge of the status and distribution of birds within the state.

REGIONAL SURVEYS AND STATEWIDE AVIFAUNAS (1901-1950)

One of the most prominent ornithologists in the state in the early 1900s was Stephen Sargent Visher, Assistant State Geologist of South Dakota from 1910-1913, who later went on to a distinguished career as a Professor of Geology and Geography at Indiana University (Rose 1971). He completed several regional avifaunal studies during the period he served as Assistant State Geologist, mostly from western South Dakota (Visher 1909, 1912a,b, 1914), but also from Sanborn County in the east-central part of the state, where he grew up (Visher 1913), and Clay County in the southeast (Visher 1915). Numerous other regional avifaunas also appeared during this period and such publications continued into the 1950s and 1960s, prominent examples including Stephens and Felton’s (1955) treatment of the birds of Union County and Pettingill and Whitney’s (1965) monograph on the birds of the Black Hills.

The first statewide treatments of the avifauna of South Dakota also occurred during this period. The first were by William H. Over, Professor at the University of South Dakota, and Craig Thoms, and were published as monographs by the University of South Dakota Press (Over and Thoms 1921, 1946). The first edition (Over and Thoms 1921) covered 288 species. The count for the second edition (Over and Thoms 1946) had grown to 331 species. The South Dakota Ornithologists’ Union undertook the publication of a new treatment of the birds of the state, authored by an appointed checklist committee and published in 1978 (Whitney et al. 1978). The official state list for South Dakota stood at 377 species in this publication. Two more editions of the South Dakota Orni-
thologists’ Union-sponsored book have since appeared, one in 1991 (SDOU 1991) covering 395 species, and one in 2002 (Tallman et al. 2002) covering 414 species. The current official South Dakota bird list contains 434 species, seven of which are listed as hypothetical status because of uncertain origins or because they are single observer sight records without additional corroborating evidence (http://sdou.org).

THE SOUTH DAKOTA ORNITHOLOGISTS’ UNION

Founded in 1949, the South Dakota Ornithologists’ Union (SDOU) is an organization whose stated purpose is to “encourage the study of birds in South Dakota, and to promote the study of ornithology by more closely uniting the students of this branch of natural science” (Chapman 1950). The SDOU has been, and continues to be, very active in promoting bird study within the state and producing publications summarizing our knowledge of the status and distribution of South Dakota birds. The quarterly journal of the SDOU, South Dakota Bird Notes, has been published continuously since 1949 and published content has greatly advanced our knowledge of the where and when of bird occurrence in the state. The SDOU is still very active in promoting the study of birds within South Dakota and hosts spring and fall meetings each year to encourage networking of professional and amateur ornithologists within the state. Among other activities, the SDOU supports scholarships for students interested in pursuing careers in ecology and ornithology and provides grants supporting bird study within the state.

A detailed summary of the formation and objectives of the SDOU is provided in a paper in the Proceedings of the South Dakota Academy of Science by Herman Chapman (Chapman 1950). Chapman includes quotes from several nationally famous ornithologists regarding the formation of the SDOU. The late Roger Tory Peterson, perhaps the most widely known ornithologist in the history of ornithology in the United States, is quoted as saying that SDOU “… should serve an extremely important function in stimulating field work in the state, and particularly in drawing attention to some of the problems of bird distribution that remain to be solved in the state.” Chapman (1950) also quotes the late Olin Sewall Pettingill, author of the first widely used textbook for college ornithology courses (and the text I used when I took ornithology as a sophomore in college in 1981), as saying “For a long time I have hoped to see the creation of such an organization in South Dakota because in no other prairie state, except Nebraska, are the resident ornithologists sufficiently well organized to promote the study of birds on a broad regional basis.” Thus, the South Dakota Academy of Science and the South Dakota Ornithologists’ Union have been collaborating organizations from the beginnings of SDOU.
ORNITHOLOGICAL DIVERSITY (1951-2015) AND
PUBLICATION TRENDS IN THE PROCEEDINGS OF
THE SOUTH DAKOTA ACADEMY OF SCIENCE

Since the 1950s, ornithology, as a field of study, has diversified and moved from a focus on status and distribution of birds within particular geographic areas (although this is still a continuing topic of study) to a diverse set of topics and research questions. Indeed, birds often serve as important models for the study of broader biological themes, such as ecology, evolution, genetics, population biology, behavior, physiology, developmental biology, and neuroscience, among other topics. The number of ornithology publications has exploded worldwide in recent years, and this is also true for bird study in South Dakota. T.C. Stephens, in the earliest ornithology article published in the Proceedings (Stephens 1918), focused on the bibliography of ornithology in South Dakota up until that time. He listed a total of 49 publications from 1858-1919, which included government survey publications, regional avifaunas (counties, reservations, etc.), notes on the distribution of various species, and other individual species notes (occurrence, nesting). Most of the focus of these early publications was on the status and distribution of birds within the state. In contrast, a search of Google Scholar on 24 February 2015 using the terms “Birds South Dakota” showed the number of publications increasing by an order of magnitude from relatively stable levels prior to the 1960s to current levels exceeding 2000 publications per year (Figure 1).

![Graph showing the number of publications per decade from 1930s to 2010s](image)

Figure 1. Number of publications (# of Hits) per decade since the 1930s from a Google Scholar search including the terms "Birds South Dakota" on 24 February 2015. The number of hits for the 2010s was calculated by multiplying the number of hits in the 2010-2014 period by 2. Note the exponential increase in the number of publications.
Some other interesting recent trends in ornithology publication are reflected by changing publication patterns for ornithology content in the Proceedings. Prior to 1990, publication by species category was split fairly evenly between poultry/game birds and non-game birds, but since 1990, publications on non-game species have comprised almost three-quarters of all bird studies published in the Proceedings (Figure 2). This change is likely explained, at least partially, by increased recent interest in biodiversity conservation, as well as increased focus on basic rather than applied bird study. Publication types have also undergone considerable change in the Proceedings, although some of this is likely related to biases in searches through the online version of the Proceedings (e.g., papers by graduate students were historically not published in the Proceedings, so this creates some bias toward full papers in early years). Nevertheless the trends are strong, so they likely reflect real differences, despite the biases in the search data. Before 1995, all ornithology publications identified by a search of the Proceedings data base were full papers. From 1995-2004, full papers made up 60% of all ornithology content and abstracts comprised the remaining 40%. From 2005-2014, full papers made up only 36% of published ornithology content, with abstracts and titles comprising the remaining published content (Figure 3). This trend likely results from increased emphasis in current academic evaluations on broad dissemination (e.g., coverage in multiple search engines and publication indices) and impact factors calculated from numbers of citations. This emphasis functions to encourage publication in broadly disseminated journals with high impact factors, and away from more regional journals with lower distribution and generally lower impact and lower numbers of citations.

Figure 2. Presentations by bird species category from South Dakota Academy of Science meetings published in the Proceedings of the South Dakota Academy of Science (includes full papers, abstracts and titles). Data on numbers of presentations were from a search of ornithological literature published in the Proceedings through 2014 provided by Editor Robert Tatina.
Ornithology content published in the *Proceedings* also shows some interesting changes through time (Figure 4) that reflect overall trends in bird research (Bautista and Pantoja 2000, Vihervaara et al. 2010, Altshuler et al. 2013). Status and distribution studies have remained fairly constant over time, comprising between 10 and 20% of all ornithology content published in the *Proceedings* over all periods (Figure 4), suggesting that this topic still is an important topic of research in ornithology, particularly as it relates to changes in abundance and distribution of birds as a function of land-use and climate change impacts on species (e.g., Swanson and Palmer 2009, Bedford et al. 2013, Sohl 2014). Indeed, South Dakota just recently completed its second Breeding Bird Atlas project (2008-2013) to document and track current bird distributions throughout the state for comparisons with the first South Dakota Breeding Bird Atlas completed 20 years ago (Peterson 1996). Studies of bird-habitat associations have become increasingly important in recent years along with the increasing interest in biodiversity conservation (Altshuler et al. 2013), and bird-habitat association studies published in the *Proceedings* have increased from no studies prior to 1960 to almost 30% of all ornithology content since 1990 (Figure 4). Studies on environmental contaminants and their impact on birds increased dramatically in the 1960s and 1970s after the publication of Rachel Carson’s *Silent Spring* in 1962, creating a “Silent Spring Effect” in ornithology publication. This trend is also evident in papers published in the *Proceedings*, with studies on contaminants and parasites forming over 20% of all published ornithology content in 1960-1989, but less...
than 5% of content in any other period (Figure 4). With the increased interest in biodiversity conservation, the shift in focus away from applied agricultural studies, and the shift toward publication in more specialized higher-impact journals, publications on poultry science in the Proceedings have plummeted from 25% of all content before 1960 to no studies since 1990 (Figure 4). Life history, ecology, physiology, conservation and management, and climate change studies have also all increased from no coverage prior to 1960 to form substantial fractions of ornithology content published in the Proceedings since 1990 (Figure 4). These publication data offer strong evidence that ornithology content in the Proceedings is following the same trend toward increasing diversity of themes that is also present in the ornithological literature at large (Bautista and Pantoja 2000, Altshuler et al. 2013).

I will use the remainder of this paper to review some significant ornithology topics covered in the Proceedings and to highlight a few specific studies dealing with this content. I do not intend for this to be a comprehensive review of all ornithology content in the Proceedings, but I instead want to highlight some of the

Figure 4. Trends in ornithology content published in the Proceedings of the South Dakota Academy of Science, including articles, abstracts and titles. Data were from a search of ornithological literature published in the Proceedings through 2014 provided by Editor Robert Tatina.
themes and studies that I believe are the most interesting or the most important to South Dakota ornithology. I focus my comments on full papers published in the *Proceedings*, rather than on Abstracts and Titles, which are most often published in full form elsewhere.

Grassland, wetland and woodland habitats are all important for birds in South Dakota (Bakker 2003a), and a number of studies published in the *Proceedings* document important aspects of bird-habitat relationships. Because of its location in the northern Great Plains and substantial remaining grassland habitats, South Dakota is an important region for grassland birds, and this group of birds is showing the most significant recent population declines among all bird groups in North America (Hill et al. 2014). The Conservation Reserve Program, authorized in 1985 (Luttschwager and Higgins 1992), is an important government program facilitating the presence of grasslands on the landscape of South Dakota, and several studies published in the *Proceedings* since 1985 examine impacts of CRP on grassland birds. These studies include Luttschwager and Higgins (1992), who found that a high diversity of birds use both strip and block CRP grassland patches. Leddy et al. (1997) compared bird abundance and species richness on CRP grasslands, pasturelands and croplands and documented higher bird densities and species richness in CRP fields than in other habitat types. Although CRP fields tend to have positive effects on grassland birds, vegetative characteristics may differentially impact different species. For example, Bahm et al. (2011) studied CRP fields in eastern South Dakota and found that Dickcissel (*Spiza americana*) abundance was negatively correlated with dead vegetation and litter depth, but Sedge Wren (*Cistothorus platensis*) abundance was positively correlated with the same variables, whereas Savannah Sparrow (*Passerculus sandwichensis*) abundance was negatively correlated with percent cover of live vegetation.

Among other published studies in the *Proceedings* relating to grassland birds, Bakker (2003b) reviewed research on the impacts of woody vegetation encroaching on grasslands, including site-level to landscape-level studies, finding that such woodlands negatively impact grassland bird occurrence, density and/or nesting success for grasslands birds. Another grassland habitat type that is restricted within the state to the northwest and southwest corners is sagebrush grasslands (Tallman et al. 2002). Lewis and Higgins (2010) used a landscape-level approach to find that Horned Lark (*Eremophila alpestris*) occurrence was negatively correlated with increasing proportions of hayfields on the landscape and that Brewer’s Sparrow (*Spizella breweri*), which is restricted in South Dakota to sagebrush habitats as a breeding species (Tallman et al. 2002), showed increasing occurrence with increasing proportions of sagebrush pastures on the landscape. These studies collectively illustrate a recent trend in ornithology and ecology, enabled by the development of Geographic Information Systems (GIS) technology, where bird-habitat association studies now explicitly incorporate larger-scale (i.e., landscape) habitat variables in addition to local-scale characteristics that dominated these types of studies until recently.

Wetlands are another extremely important habitat for numerous bird species, but represent another example where available habitats have declined dramatically within the state (Bakker 2003a). Much of the early research on birds and wetlands was driven by concern over waterfowl numbers because of hunting...
considerations, but recent research has focused more broadly on wetland bird communities, including non-game species. A number of studies published in the *Proceedings* have dealt with wetland birds. Two examples from the 1970s include McCrow (1974) who studied American White Pelican (*Pelecanus erythrorhynchos*) populations and trends in the state and Flake et al. (1977) who studied site-level habitat relationships of waterfowl on stock ponds in the northwestern part of the state. Thirty years later, May et al. (2008) also studied habitat relationships and productivity of waterfowl on stock ponds in western South Dakota, but this study explicitly included a landscape focus, again demonstrating the recent change from site-level to landscape-level focus of bird-habitat studies. Demonstrating the recent trend toward studies of non-game wetland birds, Swanson and Liknes (2009) documented the first nesting of Great-tailed Grackle (*Quiscalus mexicanus*) in the state from a wetland in Clay County, and examined range expansion trends in this species. As a final illustration of a general trend in ornithological studies, in this case pertaining to wetland birds, Higgins (2010) studied waterfowl population trends from specific wetland sites in the Northern Prairie region by repeating surveys initially completed 20-30 years ago at these same sites (Higgins 2010). Such studies are becoming more common in ornithology as the historical baseline data for these studies are now available and concern over population trends in various bird groups continues to mount.

Woodland habitats are rare in the northern Great Plains, but are disproportionately important for birds, harboring higher species richness and abundance of birds than any other habitat (Peterson 1996, Bakker 2003a). Habitat associations between birds and different types of woodlands have been the focus of a few studies published in the *Proceedings*. One example is the study of Coughlin and Higgins (1993), who documented that riparian habitats along the main channels of rivers offered better habitat than those along their tributaries for Wood Duck (*Aix sponsa*) nesting. Historically, riparian habitats in South Dakota had a variety of successional stages, but with the damming and current flow regulation patterns on many of these rivers that reduce the flooding necessary for generating early successional habitats, this habitat is declining (Dixon et al. 2012). In another *Proceedings* paper, Liknes et al. (1994) found that early and late successional cottonwood forest habitats along the Missouri River produced similar bird densities, but early successional habitats harbored greater species richness, highlighting the importance of early successional habitats to overall bird diversity in these riparian systems.

Disease and contaminant studies of birds were common topics of studies in the *Proceedings* in the 1960s through the 1980s, as part of the previously mentioned Silent Spring effect. One example dealing with disease is Fuller et al. (1968), who described a mass mortality event for water birds at Platte Lake, Aurora Co., possibly due to botulism. Another example, this one dealing with contaminant effects, is Solomon et al. (1973) who experimentally treated Ring-necked Pheasant (*Phasianus colchicus*) hens with 2,4-D or polychlorinated biphenyls (PCB), finding that treatment of hens did not result in increased abnormalities in embryos.

Bird migration has long been a topic of ornithological interest and a number of studies dealing with migration have been published in the *Proceedings*. In an early paper suggesting important bird study needs in South Dakota, Habeger
(1959) mentioned the need for migration (migration paths and weather effects) and breeding bird abundance (population trends) studies as two primary topics needing study in South Dakota. Ornithologists in South Dakota have done yeoman’s work in addressing these topics, with efforts examining breeding bird abundance including the two Breeding Bird Atlas projects. Several papers in the Proceedings have also studied different aspects of migration. For example, Timken and Anderson (1968) studied age and sex ratios of migrating Blue-winged Teal (Anas discors) in eastern South Dakota, finding different sex ratios between northeastern and southeastern South Dakota, with more males in the southeast. Spring raptor migration in Moody County, South Dakota, was studied by Gabbert and Schneider (1998). These authors found that peak abundance of raptors occurred during the first week of April, with a steady decline in numbers continuing until early June, thus establishing a phenology of spring migration for this group of birds.

Winter is a prominent part of life in South Dakota, so naturally the behavior and physiology of birds in winter has been a topic of study in the Proceedings, particularly as it relates to the state bird, Ring-necked Pheasant. For example, Sather-Blair and Linder (1980) demonstrated that pheasants preferentially used large wetlands with tall (> 1 m) surrounding vegetation for winter cover. In addition, Purvis et al. (1999) found that pheasants provided with supplemental food plots within their winter home ranges did not have larger fat stores, suggesting that food was widely available in all occupied habitats. These authors did find, however, that winter fat stores were positively related with fat stores in spring, thus demonstrating carry-over effects that might impact reproductive fitness.

Research on climate change and its impacts on flora and fauna has exploded recently and publications on this topic in the Proceedings have followed suit. Two recent examples include the papers by DeJong and Higgins (2012) and Bedford et al. (2013). DeJong and Higgins (2012) measured volumes of duck eggs from South Dakota present in museum collections to examine trends in egg size and their association with climate change over the past 150 years. They found that egg volumes changed over time in five of 14 species measured, but these changes were related to drought severity index, rather than directly to temporal changes in temperature, with eggs generally being larger during drought conditions than during moist conditions. Bedford et al. (2013) systematically surveyed Icterids (New World blackbirds and their relatives) during spring migration from 1995-2012 at Oak Lake Field Station, Brookings County, and their data suggest generally earlier spring arrival with recent warming.

One final ornithological study category occurring in the Proceedings is the study of the ecology of individual species. One example of such studies is for the Upland Sandpiper (Bartramia longicauda), an iconic grassland species. Two publications in the Proceedings have focused exclusively on Upland Sandpipers (Kaiser 1979, Gardner et al. 2008) and both highlight the importance of native grasslands and wetland complexes to the breeding ecology of this species. One other noteworthy example of a single-species study is the recent paper by Palmer and Javed (2014) on American Dippers (Cinclus mexicanus) in the Black Hills, where they modeled population trends based on annual survival of marked birds. Dippers have a small, restricted population in South Dakota, being limited to a
few fast-flowing clear streams in the northern Black Hills (Tallman et al. 2002). Palmer and Javed’s (2014) models predicted high probabilities of population declines for South Dakota dipper populations over the next 25 years, so they recommended that conservation efforts focus on actions to increase reproductive rates, such as increasing provision of artificial nest sites.

ACKNOWLEDGMENTS

First, I want to thank Bob Tatina, Editor of the Proceedings, for the invitation to present at the symposium on the History of South Dakota Science at the centennial meeting of the South Dakota Academy of Science. Bob organized a fantastic symposium for this meeting, and he also conducted the literature search for ornithology titles in the Proceedings. I also thank Jeff Palmer and Molly Rozum, who provided constructive comments on a previous version of this manuscript. In addition, I want to thank South Dakota ornithologists, in general, for their fine and dedicated work and their collegiality, and the members of the South Dakota Ornithologists’ Union for remaining true to the vision of the organization to “encourage the study of birds in South Dakota, and to promote the study of ornithology by more closely uniting the students of this branch of natural science.” Finally, I want to thank the members of the South Dakota Academy of Science for tirelessly pursuing new knowledge and serving the state of South Dakota in this regard.

LITERATURE CITED


A CENTURY OF ACADEMY OF SCIENCE PUBLICATIONS WITH RELEVANCE TO SOUTH DAKOTA’S WILD VERTEBRATE FAUNA AND FOSSILS

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ABSTRACT

We examined the titles, abstracts, and texts of all past volumes of the Proceedings of the South Dakota Academy of Science to determine how many articles contained information on wild vertebrate fauna species or on fossil evidence of prehistoric vertebrate fauna that have resided within the state at one time period or another. Frequency data are presented on the occurrence of species or fossil evidence of South Dakota’s vertebrate fauna reported in various articles published in the Proceedings of the South Dakota Academy of Science. However, quantification to the species or genus levels of taxonomy for some wild fauna groups and prehistoric fauna fossils was limited or absent, in part, due to sample sizes or limited expertise in specimen collection, preservation, and identification methodologies. Despite these limitations, several thousand wild fauna and fossil specimens that contain taxonomic labeling plus some collection location and habitat information currently exist in various repositories within South Dakota or elsewhere and are available for further research or study.

Keywords

Paleontology, vertebrate fauna, fossil vertebrates, South Dakota

THE PALEONTOLOGICAL TAXA RECORDED FROM SOUTH DAKOTA

Although all fossil organisms antedated the establishment of political boundaries, it is useful to estimate the number of fossil taxa from South Dakota, if only to reveal the vast importance of paleontology to its citizens. Beyond being im-
portant as both an earth science and a life science, paleontology has traditionally inspired young people to pursue careers in science generally. A fine example was Glenn Lowell Jepsen, born in Lead and a youthful resident of Rapid City, who ultimately became a distinguished professor at Princeton University, but began his scientific interest by collecting White River fossils.

There are fundamental principles that governed the fossil record as we see it, and these are much different from performing a census of the living fauna. For practical purposes, the only animals represented in the fossil record will be those with durable body parts, such as calcareous shells, chitinous exoskeletons, and bones. Major phyla that lack durable anatomy are virtually unknown as fossils. Taphonomy, the science that views the passage of organisms from the biological record to the geological record, works against soft-bodied organisms. In terms of prehistory, the stratigraphic systems with a fossil record begin with the Cambrian Period, which is the earliest age for organisms with calcareous shells, approximately 600,000,000 years ago. This period and all subsequent periods are represented in the geology and fossil records of South Dakota, emphasizing the towering importance of the state to the science of paleontology.

Another factor in the fossil record is the importance of facies, the aspects of the geologic record that reflect depositional environments. Intuitively one expects fossils to be confined to sedimentary rocks, but these vary according to their depositional formation, limiting our view of past life. For example, one of the most interesting fossil species to be described from South Dakota was the early fossil snake (*Coprophis dakotaensis*), which as the name implies, was found in fossil dung of Oligocene age. It probably lived (and was consumed by a predator) in an environment seldom represented in the fossil record, for only one specimen has ever been found (Parris and Holman 1978).

Although we have not checked the printed record exhaustively, it may be assumed that the vast majority of fossil species recorded from South Dakota have been cited in the Proceedings of the South Dakota Academy of Science. Those that have not are at least collectively recognized herein. Some groups have been subjected to a thorough census during recent years, but others have never been counted. In our prior work on the fossil fishes of South Dakota (Parris et al. 2005, 2007), we found about one hundred species to have been published, although not all were individually named in those papers. Similarly, in our review of the fossil waterfowl (Parris and Higgins 2010, 2014), we found about five species to be present in the regional prehistoric record, and the totality of South Dakota fossil birds would amount to about twenty species. Both of these groups, fishes and birds, would have major taphonomic factors affecting their preservation as fossils, as both birds and fishes have rather fragile skeletons which are easily destroyed with little chance of preservation.

That said, we begin our estimate of numbers of fossil taxa by reviewing the published record of the Cambrian Period, represented in South Dakota within the classic Deadwood Formation. It is the earliest of the periods of the Paleozoic, the Era of “Early Life”. The paleontology of the Deadwood Formation is particularly well studied, and is primarily an assemblage of trilobites and some other calcareous fossils (Lochman 1964). This so-called “shelly” fauna is one facies, but early Paleozoic rocks may also have another facies, which is typically found
in dark-colored shales and consists primarily of floating colonial animals called graptolites. In the Deadwood Formation, both kinds of animals have been found more or less together, thus giving a fairly good coverage of the population of that early time, about thirty distinct species. If this is presumed to represent Paleozoic fossils of an epoch, a likely scenario, then we can multiply the number of well-described epochs by thirty and get an estimate of the number of described taxa, especially for South Dakota, where paleontology has been thoroughly described. There are about ten Paleozoic formations, depending on what stratigraphic classification is used, yielding an estimate of perhaps 350 taxa that have likely been described, represented primarily by fossil invertebrates:brachiopods, mollusks, and arthropods. The Paleozoic fossil vertebrates of South Dakota are represented primarily by fishes (Parris et al. 2007).

The Mesozoic, the Era of “Middle Life”, also has a very substantial fossil record that occurs in the Triassic, Jurassic, and Cretaceous Periods. The Cretaceous is especially well represented in South Dakota, and is the Period in which the dark-colored shales, with their distinctive gumbo derivatives, were deposited. The most widespread is appropriately named the Pierre Shale Group (after Fort Pierre, actually), and is colloquially referred to as the South Dakota State Rock. The seven formations that make up the Pierre Shale Group have been studied extensively since the time of Lewis and Clark, and the South Dakota School of Mines and Technology has collected fossils in them continuously during the past forty years. As with almost all of the Paleozoic record, the Mesozoic record is primarily composed of marine environments that most residents do not intuitively associate with South Dakota. South Dakota presently has northern plains terrestrial environments that are inhospitable to most terrestrial lizards; only a few are known in the state (Kiesow 2006). But during the Late Cretaceous Period, the vertebrate fossil record of lizards is dominated by huge marine genera called mosasaurs, and South Dakota is one of the places most noted for producing spectacular fossil specimens of them (Russell 1967). More than a dozen species are known, most of which have been cited one or more times in publications of the South Dakota Academy of Science.

The Pierre Shale also has a substantial record of fossil invertebrates, including the ammonites, abundant cephalopods that are very useful in biostratigraphy, along with clams and snails. A particularly well-studied unit within the Pierre Shale Group is the De Grey Formation, which has accounted for about 35 mollusk species, as noted by Fox (2007). Since there are eight formations in the Pierre Shale Group, it may be estimated that more than 250 taxa are represented in the Pierre Group among Cretaceous formations. As there are more marine Cretaceous formations other than the Pierre Group, about twenty in all, plus a very fossiliferous non-marine formation, the dinosaur-bearing Hell Creek Formation, it is quite reasonable to estimate that at least 500 Cretaceous species have been reported from South Dakota. As with each formation of the Pierre Shale Group, the underlying Niobrara Chalk Formation has an accurate census of 31 species (Martin et al. 1998).

The South Dakota Academy of Science has been actively involved with Mesozoic individual species records as well. The Sundance Formation from the Jurassic age has a significant fossil fauna of invertebrates and vertebrates, including the
first ichthyosaur record, which was reported in the Proceedings of the South Dakota Academy of Science a few years ago (Parris and Grandstaff 2000).

The Cenozoic Period, “the Era of Modern Life”, is noted for its record of mammalian fossils, of which many accounts were published in a White River formation monograph many years ago (Scott et al. 1941). At that time, about 230 vertebrate species were recognized, and many others have been added since then. Even if the aspect of taxonomic splitting had been greater at that time, it is still reasonable to consider that new additions to the described fauna would maintain the number of species at well over 200, divided among three middle Cenozoic time units as in the case of the aforementioned *Coprophis*. Other vertebrate classes and invertebrates are also present in the White River Group. Since thirteen other Cenozoic formations are represented in South Dakota, all with fossil records, an estimate of 500 Cenozoic species is quite reasonable.

The Pleistocene Period of South Dakota, the so-called Ice Age, was exhaustively studied not long ago (Pinsof 1986). In that review, one hundred species of vertebrates were reported, including sixteen fishes, four amphibians, ten reptiles, three birds, and sixty-seven mammals. A few additional species of invertebrates would add to this record, which again makes it reasonable to assume that the overall number of vertebrate and invertebrate fossil species recorded from all of the geologic formations in South Dakota exceeds one thousand.

PALEONTOLOGY IN SOUTH DAKOTA ACADEMY OF SCIENCE PROCEEDINGS

As the state of South Dakota has world-renowned fossil resources, it would seem to be inevitable that museum collections of fossils would be maintained here, and also that the South Dakota Academy of Science would publish many paleontological reports. That is indeed the case; in fact, the earliest report in the Proceedings seems to have been a description of two significant fossil mammals from Slim Buttes by Kingsley (1919), which accurately predicted the importance of those Harding County sites. Various geological reports by Rothrock and others dealt with the overall geological record of the state, also forming the basis of paleontological research.

The Museum of Geology at the South Dakota School of Mines and Technology had major interests in paleontology, notably in the White River Badlands. After the Second World War, with the arrival there of James Reid MacDonald and Morton Green, published reports from the Museum increased, including submissions to the South Dakota Academy of Science. They were not the only ones, however. The report of Bolin (1952) on the microinvertebrates of the Niobrara Chalk Formation was especially significant, as it noted more than 60 species that are of great biostratigraphic value, although lacking the high profile of dinosaurs. The report of Johnson (1966) performed a similar feat for microvertebrates, adding new phyla to the White River fossil faunas that had escaped earlier detection because of their small size.

When James E. Martin joined the faculty at the Museum of Geology, he continued to present paleontological papers at the South Dakota Academy of Science and was an active member of the Academy, once serving as President.
While he and his students and other associates have continued to publish in the Proceedings to the present-day, the summary symposium about their collective researches in the Pierre Shale Group was a particularly memorable feature of the 2004 annual meeting of the Academy.

Based on the results from a rapid assessment of all the titles, abstracts, and texts that were published in the Proceedings from 1915 through 2014, we located a minimum of 42 full papers and 38 units of titles plus abstracts for a total of 79 publications relating to fossil vertebrate fauna (Table 1). The first mention of a vertebrate fossil was of a fossil fish (Lexiousaurs) on page 18 of an article about the “Natural History in the Missouri Valley” by Will Powers in the 1924 Proceedings (Vol. 9). The first full paleontological paper published in the Proceedings was authored by E.J. Bolin [1952 (Vol. 31): 190-193] and dealt with microfossils. The first full paper with relevance to vertebrate fauna fossils was authored by J. R. MacDonald and Morton Green in the 1954 (Vol. 33: 47-49) Proceedings and was titled “The Pliocene Vertebrate Fauna of South Dakota”. Thus, the first full paper concerning vertebrate fauna fossils in the Proceedings occurred 40 years after the Academy was founded in 1915.

Full papers on vertebrate fossils became more frequent beginning with the 1960s (Table 1) and have been relatively constant per decade during the 1980-2014 period. Publications of titles plus abstracts have been most frequent during the 1992-2014 period (Table 1).

A rough estimate of the numbers of fossil taxa (Invertebrates 110, Fishes 70, Amphibia 10, Reptilia 60, Birds 10, Mammals 120) that were cited and/or enumerated in Academy presentations and publications from 1915-2014 reflects the strength and weaknesses of the fossil record as a whole, as well as the principal emphases of South Dakota paleontology.

Table 1: Decadal frequency of published papers and abstracts concerning vertebrate fauna fossils in the Proceedings during 1915-2014.

<table>
<thead>
<tr>
<th>Decade</th>
<th>Full Papers</th>
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<th>Abstracts Only</th>
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<tr>
<td>1915-1925</td>
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<td>1926-1936</td>
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<tr>
<td>2003-2014</td>
<td>9</td>
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<td>31</td>
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<td>40</td>
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<tr>
<td>Totals:</td>
<td>41</td>
<td>+</td>
<td>38</td>
<td>=</td>
<td>79</td>
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Based on the results from the same rapid assessment of the Proceedings published during 1915-2014, we identified a minimum of 306 full papers and 159 units of titles plus abstracts for a total of 465 publication accounts relating to eight non-fossil wild vertebrate fauna groups that occurred in South Dakota dating from the late 1700s A.D. through 2014 (Table 2).

Of the 465 published accounts involving the 8 groupings of vertebrates, 153 were of birds (Table 3), 139 of fishes (Table 4), 109 of mammals (Table 5), 13 of turtles (Table 6), 32 of amphibians (Table 7), 13 of snakes (Table 8), 5 of lizards (Table 9), and 1 of skinks (Table 10).

Of the 8 vertebrate groups, there were no publications (full papers or abstract article) for any of the fauna groups in 14 years of Proceedings, including 1915, 1921, 1923, 1925, 1926, 1939, 1948, 1949, 1952, 1953, 1960, 1985, 1986, and 1988. In 1976 there were no full papers and only one abstract article relative to native vertebrate fauna.

Several factors were likely responsible for the paucity of papers about wild fauna groups in South Dakota. For example, during the first decade of the Academy, farm crop damage by insects was the focus of several papers. Then, during the drought of the 1930s, funding for field studies and/or agency/university staffs was likely reduced with low levels of funding continuing at the onset of and throughout the duration of WWII and the Korean conflict.

During the early 1960s, several major changes occurred with university departments, including additional staffing and a significant increase in graduate studies involving South Dakota’s natural resources. For example, at SDSU, the Wildlife and Fisheries staff separated from the Biology/Zoology Department to establish a Wildlife and Fisheries Department, and this new department was augmented with the establishment of two USDI Cooperative Research Units; one Wildlife unit and one Fisheries unit. Similar changes in staffing and departmental courses were also occurring at other institutions of higher learning in South Dakota.

The 1960s also brought on several environmental programs that affected wildlife, landscapes and citizens at mega scales, including but not limited to the Clean Air and Clean Water Acts, the Endangered Species Act, the USDA’s Soil Bank Program, and the US Fish & Wildlife’s Small Wetlands Program, which had its beginnings in South Dakota.

The paucity of papers in the 1980s was likely related to staff retirements and the hiring of new faculty at various universities and colleges. With new faculty and the recruitment of new graduate students, there is usually a delay of two to three years before research is completed and papers are produced for publication.

Also, beginning with the 1980s, there was a stronger emphasis for faculty and agency researchers to publish more articles per year and to publish in journal outlets of higher ranking and higher impact merits (e.g. the frequency of times the article is cited in other articles) in order to achieve set thresholds in promotion standards. The 1980s was also the decade in which personal computers and statistical programs enabled individuals to manage larger and more complicated...
data sets in less time, resulting in faster outputs of articles for publication. This facilitated greater ease of conducting seminars and training workshops, and promoted greater capacity for instant communication and transfer of concepts, data and publications among other researchers via emails etc., all of which have resulted in more publications (full papers and abstract articles) in the Proceedings during the 1990s and the first 15 years of the new millennium.

Considering all of the above, it is apparent that during the past century the South Dakota Academy of Science and its Proceedings have provided many substantial publications that have enhanced our understanding of the State's native vertebrate fauna and fossils. It is also apparent from our review of the Proceedings that scientific studies and education efforts within our state could be greatly enhanced during the next century according to the following three themes of approach.

While researching articles in the Proceedings of the past century (1915-2014), we noticed three readily apparent themes: (1) a lot of scientific research and general observations and collections have been published and/or archived with regard to South Dakota's prehistoric and post-prehistoric flora and fauna. However, the bulk of the publications and a significant portion of the collection items (e.g. fossil flora and fauna; reference and/or teaching collections of plants and animals) are scattered throughout North America and in some foreign countries; (2) even though several private, non-profit, and public agencies, institutions, and associations periodically provide status reports and/or inventory results relative to various flora and fauna within the State, it is very apparent that large gaps still exist in collections and data bases, both temporally and spatially; and (3) apparently, there is no overall master plan available nor is there a dedicated source of annual funding with relevance to a master plan that would support future inventories and demographic status ratings of the State's flora and fauna (prehistoric and currently). Nor is there a single comprehensive compilation of former reference materials and/or reference guides to the locations of SD flora and fauna specimens that occur in various repositories, personal and teaching collections such as museums and universities in South Dakota and elsewhere. For example, in a March 27, 2015 communication, Dr. Robert Timm of the University of Kansas in Lawrence reported that their records indicate that 2,103 vertebrate specimens from South Dakota were archived in their collections, including 780 birds, 669 mammals, 582 herps (reptiles and amphibians), and 72 fish.

Some recent examples lend support that an overall statewide inventory of natural resources, their distributions and the former inventory efforts and publications concerning current populations of native flora and fauna is possible. For example, in a recent effort, Lewis (2014) located over 600 publications about South Dakota's waterfowl (ducks, geese, and swans) that had been published since the late 1800s. Hoagstrom et al. (2006), during river surveys, found that 35 species of fish had declined from one or more river drainages, 8 former fish species had become extinct from the State, and 10 other fish species are currently listed as state or federal threatened or endangered in status. Agency records also show that 9 species and 2 subspecies of birds and 7 species and 1 subspecies of mammals and 12 species of fish species were extirpated from the state at one time or another (Table 11).
In addition to the thousands of scientific publications, numerous examples of field guides exist relative to South Dakota’s wild fauna, including but not limited to the State’s fishes (Neumann and Willis 1994), mammals (Higgins et al. 2000), amphibians (Fischer et al. 1999), turtles (Bandas and Higgins 2004), amphibians and reptiles (Kiesow 2006), plus many more. Occasionally, some comprehensive, specific area surveys, such as the first “Bio-Blitz” (Higgins et al. 2005) that was conducted at Oakwood State Park in Brookings County in 2003, are jointly performed as public learning exercises and flora and fauna inventories. In summary, we believe that unified inventories of the State’s natural resources, past, present and future and their distribution and status have merit and are possible pending the development and coordination of a plan, a leadership commitment, and some support funding.

Table 2: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to wild vertebrate fauna of the post fossil era.

<table>
<thead>
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<th>Group: Vertebrate Fauna Groups: Post Fossil Era</th>
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<td>Decade</td>
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<td>Birds</td>
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<td>Fish</td>
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<td>Lamprey Eel*</td>
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<td>Mammals</td>
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<tr>
<td><strong>Totals:</strong></td>
</tr>
</tbody>
</table>

*An eel-like primitive fish that may or may not be classified as a true fish.*
Table 3: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to birds.

<table>
<thead>
<tr>
<th>Group: Birds</th>
<th>Decade</th>
<th>Full Papers</th>
<th>+</th>
<th>Abstracts Only</th>
<th>=</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>4</td>
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<tr>
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<tr>
<td></td>
<td>1937-1947</td>
<td>5</td>
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<td></td>
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<tr>
<td></td>
<td>1970-1980</td>
<td>19</td>
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<td></td>
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<td>1981-1991</td>
<td>3</td>
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<tr>
<td></td>
<td>1992-2002</td>
<td>25</td>
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<td>20</td>
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<td></td>
<td>2003-2014</td>
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<td>Totals:</td>
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<td>103</td>
<td>+</td>
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<td>=</td>
<td>153</td>
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</tbody>
</table>

*One paper in this decade also mentioned a lamprey which is an eel-like fish.*

Table 4: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to fish.

<table>
<thead>
<tr>
<th>Group: Fish</th>
<th>Decade</th>
<th>Full Papers</th>
<th>+</th>
<th>Abstracts Only</th>
<th>=</th>
<th>Total</th>
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<tbody>
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<td></td>
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<td></td>
<td>0</td>
<td></td>
<td>33</td>
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<td></td>
<td>1926-1936</td>
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<td>6 (1) *</td>
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<td></td>
<td>2003-2014</td>
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<tr>
<td>Totals:</td>
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<td>95</td>
<td>+</td>
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</table>
Table 5: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to mammals.

<table>
<thead>
<tr>
<th>Group: Mammals</th>
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</thead>
<tbody>
<tr>
<td>Decade</td>
</tr>
<tr>
<td>1915-1925</td>
</tr>
<tr>
<td>1926-1936</td>
</tr>
<tr>
<td>1937-1947</td>
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<td>1948-1958</td>
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<td>1981-1991</td>
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<tr>
<td>2003-2014</td>
</tr>
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<td>Totals:</td>
</tr>
</tbody>
</table>

Table 6: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to turtles.

<table>
<thead>
<tr>
<th>Group: Turtles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decade</td>
</tr>
<tr>
<td>1915-1925</td>
</tr>
<tr>
<td>1926-1936</td>
</tr>
<tr>
<td>1937-1947</td>
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<tr>
<td>1948-1958</td>
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<tr>
<td>1959-1969</td>
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<td>1981-1991</td>
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<tr>
<td>1992-2002</td>
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<tr>
<td>2003-2014</td>
</tr>
<tr>
<td>Totals:</td>
</tr>
</tbody>
</table>
Table 7: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to amphibians.

<table>
<thead>
<tr>
<th>Group: Amphibians</th>
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</thead>
<tbody>
<tr>
<td>Decade</td>
</tr>
<tr>
<td>1915-1925</td>
</tr>
<tr>
<td>1926-1936</td>
</tr>
<tr>
<td>1937-1947</td>
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<td>1959-1969</td>
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<td>1970-1980</td>
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<td>1981-1991</td>
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<tr>
<td>2003-2014</td>
</tr>
<tr>
<td>Totals:</td>
</tr>
</tbody>
</table>

Table 8: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to snakes.

<table>
<thead>
<tr>
<th>Group: Snakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decade</td>
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<tr>
<td>1915-1925</td>
</tr>
<tr>
<td>1926-1936</td>
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<tr>
<td>1937-1947</td>
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<td>1948-1958</td>
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<td>1959-1969</td>
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<td>1992-2002</td>
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<tr>
<td>2003-2014</td>
</tr>
<tr>
<td>Totals:</td>
</tr>
</tbody>
</table>
Table 9: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to lizards.

<table>
<thead>
<tr>
<th>Group: Lizards</th>
<th>Decade</th>
<th>Full Papers</th>
<th>+</th>
<th>Abstracts Only</th>
<th>=</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
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<tr>
<td></td>
<td>1992-2002</td>
<td>0</td>
<td></td>
<td>1</td>
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</tr>
<tr>
<td></td>
<td>2003-2014</td>
<td>0</td>
<td>3</td>
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<tr>
<td>Totals:</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
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<td>5</td>
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</table>

Table 10: The number of published articles per decade in the past century (1915-2014) of the Proceedings that had relevance to skinks.

<table>
<thead>
<tr>
<th>Group: Skinks</th>
<th>Decade</th>
<th>Full Papers</th>
<th>+</th>
<th>Abstracts Only</th>
<th>=</th>
<th>Total</th>
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<tr>
<td></td>
<td>2003-2014</td>
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</tr>
<tr>
<td>Totals:</td>
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<td></td>
<td></td>
<td>0</td>
<td>=</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 1: Wild fauna extirpated from South Dakota complied in April 2014 with the assistance of John Carreiro, Gene Galinat, Casey Heimerl, John Kanta, Silka Kempema, Andy Lindbloom, and Chelsey Pasbrig at South Dakota Game, Fish and Parks; Scott Larson at U.S. Fish and Wildlife Service; Jacob Kerby at the University of South Dakota; Katie Bertrand at South Dakota State University; and Nancy Drilling at the Rocky Mountain Bird Observatory.

<table>
<thead>
<tr>
<th>Number of species or subspecies extirpated before 1915</th>
<th>Number of species or subspecies extirpated after 1915</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birds: 10</td>
<td>Birds: 1</td>
</tr>
<tr>
<td>Bald Eagle (<em>Haliaeetus leucocephalus</em>)</td>
<td>Peregrine Falcon (<em>Falco peregrinus</em>)</td>
</tr>
<tr>
<td>Osprey (<em>Pandion haliaetus</em>)</td>
<td></td>
</tr>
<tr>
<td>Carolina Parakeet (<em>Conuropsis carolinensis</em>)</td>
<td></td>
</tr>
<tr>
<td>Passenger Pigeon (<em>Ectopistes migratorius</em>)</td>
<td></td>
</tr>
<tr>
<td>Sandhill Crane (<em>Grus canadensis</em>)</td>
<td></td>
</tr>
<tr>
<td>Blue Grouse (<em>Dendragapus obscurus</em>)</td>
<td></td>
</tr>
<tr>
<td>Common Raven (<em>Corvus corax</em>)</td>
<td></td>
</tr>
<tr>
<td>“Giant” Canada Goose (<em>Branta canadensis maxima</em>)</td>
<td></td>
</tr>
<tr>
<td>Eastern Wild Turkey (<em>Meleagris gallopavo silvestris</em>)</td>
<td></td>
</tr>
<tr>
<td>Trumpeter Swan (<em>Cygnus buccinator</em>)</td>
<td></td>
</tr>
<tr>
<td>Mammals: 6</td>
<td>Mammals: 2</td>
</tr>
<tr>
<td>Grizzly Bear (<em>Ursus arctos</em>)</td>
<td>Gray wolf (<em>Canis lupus</em>)</td>
</tr>
<tr>
<td>Black Bear (<em>Ursus americanus</em>)</td>
<td>Black-footed Ferret (<em>Mustela nigripes</em>)</td>
</tr>
<tr>
<td>Elk (<em>Cervus canadensis</em>)</td>
<td></td>
</tr>
<tr>
<td>Audubon’s bighorn sheep (<em>Ovis canadensis auduboni</em>)</td>
<td></td>
</tr>
<tr>
<td>River otter (<em>Lontra canadensis</em>)</td>
<td></td>
</tr>
<tr>
<td>American marten (<em>Martes americana</em>)</td>
<td></td>
</tr>
<tr>
<td>Fishes: 0</td>
<td>Fishes: 12</td>
</tr>
<tr>
<td>Silver Lamprey (<em>Ichthyomyzon unicuspis</em>)*</td>
<td></td>
</tr>
<tr>
<td>Mooneye (<em>Hiodon tergisus</em>)</td>
<td></td>
</tr>
<tr>
<td>Silverband Shiner (<em>Notropis shumardi</em>)</td>
<td></td>
</tr>
<tr>
<td>Northern Hogsucker (<em>Hypentelium nigricans</em>)</td>
<td></td>
</tr>
<tr>
<td>Black Buffalo (<em>Ictiobus niger</em>)</td>
<td></td>
</tr>
<tr>
<td>Slenderhead Darter (<em>Percina phoxocephala</em>)</td>
<td></td>
</tr>
<tr>
<td>Bowfin (<em>Amia calva</em>)</td>
<td></td>
</tr>
<tr>
<td>Blackchin Shiner (<em>Notropis heterodon</em>)</td>
<td></td>
</tr>
<tr>
<td>American Eel (<em>Anguilla rostrata</em>)</td>
<td></td>
</tr>
<tr>
<td>Banded Darter (<em>Etheostoma zonale</em>)</td>
<td></td>
</tr>
<tr>
<td>Mimic Shiner (<em>Notropis volucellis</em>)</td>
<td></td>
</tr>
<tr>
<td>Mottled Sculpin (<em>Cottus bairdi</em>)</td>
<td></td>
</tr>
</tbody>
</table>

Total: 16                                            Total: 15

*An eel-like fish.*
LITERATURE CITED


A HISTORY OF BOTANICAL EXPLORATION IN SOUTH DAKOTA

Mark Gabel1*, Dave Ode2, and Grace Kostel1
1Herbarium
Black Hills State University
Spearfish, SD 57799
2South Dakota Department of Game, Fish and Parks
Pierre, SD 57501
*Corresponding author: mark.gabel@bhsu.edu

ABSTRACT

Botanical exploration in South Dakota has been occurring for over two centuries. It is clear that American Indians in the area had an extensive knowledge about plant species and their uses. We used existing literature, herbarium specimens and electronic databases to document the history of botanical exploration in the state. The first scientific collections date to 1804 and were followed closely by additional voyages up the Missouri River. As the European-Americans increased in numbers, they also explored areas away from the Missouri River. Military expeditions frequently had a scientific officer charged with natural history observations and collections. The first expedition devoted to plant exploration in South Dakota was by Rydberg in 1892. The first statewide checklist of plant species was assembled by Saunders in 1899, and was followed three decades later by Over’s checklist. It was not until 1976 that a true state-wide flora was authored by VanBruggen, introducing the modern age of plant exploration in South Dakota.

Keywords
Black Hills, botany, Great Plains, plant collection, South Dakota

INTRODUCTION

Any discussion of botanical exploration in South Dakota must begin with recognition that American Indians were experts at recognizing plant groups and accepted uses for those plants. Abel (1939) reported in a narrative of Tabeau’s expedition to the upper Missouri that numerous native fruits and vegetables were used by American Indians in 1803-1805, but no known scientific collections of plants were made. When Lewis and Clark passed through South Dakota on their 1804-1806 adventure, they noted cultivated species including corn, beans, squash, watermelon, pumpkins, and tobacco (Ronda 1984). Traditional uses of plants by indigenous people have been better documented than on any other continent (Ford 1986). Uses by American Indians for plants in South Da-

METHODS

For this study we examined the existing literature on botanical exploration in South Dakota including the archives of the South Dakota Academy of Science (2015). We also used data bases for locating specimens collected by botanical explorers in South Dakota including those at MO, NY, RM, PH, US, PUL, and BHSC (acronyms follow Thiers (continuously updated)). This work does not contain references to vegetation management, livestock grazing, agronomy, forestry or other applied disciplines of botany.

RESULTS

The trip of Meriwether Lewis and William Clark in 1804-1806 from St. Louis to the Pacific coast and back has been described by numerous authors (Ambrose 1996; McKelvey 1955; Moulton 2002). The journey is important to this study because it is the first known expedition that collected plant specimens for scientific purposes in South Dakota. Reveal et al. (1999) reported that of 232 known plant specimens at least 26 specimens were collected from within the current boundaries of South Dakota.

In March of 1811 Wilson Price Hunt departed St. Charles, Missouri, leading a party of fur trappers on an expedition that more or less retraced the route of Lewis and Clark. The Hunt Expedition was funded by J. J. Astor of the American Fur Company (McKelvey 1955). On the expedition were two English botanists, Thomas Nuttall and John Bradbury. Nuttall was working for Benjamin Barton (Professor at the University of Pennsylvania). Bradbury was funded by the Liverpool Philosophical Society. The botanists traveled to the Arikara villages (near the current city of Mobridge, SD) with Hunt, reaching that area on 12 June 1811. Nuttall continued to the Mandan villages (in present day North Dakota) by boat. Bradbury proceeded on foot to the same location.

Bradbury left the Hunt party on 17 July 1811 and returned to St. Louis by the 29th of July. Bradbury became ill with a fever about 10 days after his arrival in St. Louis (McKelvey 1955) and remained there until the 4th of December 1811 when he left for New Orleans. On this journey he was an observer of the New Madrid earthquakes (15 – 21 December 1811), including two major seismic events occurring on 16 December with earthquakes that have been estimated to have ranged from magnitude 7.2 to 8.1.

Nuttall’s exact route is unknown since he apparently did not keep a journal. He returned to St. Louis in October of 1811 and learned of the potential of a war between England and the United States. He left straightaway for New Orleans and on to England, taking his plants with him.
Bradbury left New Orleans for New York on 20 January 1812. His plant collection was apparently shipped to England before he departed and arrived safely in Liverpool. Due to further delays, Bradbury was unable to leave for England until after the war of 1812.

Meanwhile, in England Frederick Pursh had obtained access to some of the plant specimens collected by the Lewis and Clark expedition, some of Nuttall’s plants, and Bradbury’s plants. Pursh (1813) published the results of his studies, negating the possibility of a botanical publication by Bradbury. Bradbury became most famous for a travelogue of his adventures in the New World published in 1817. Nuttall returned to the United States and published his own study of plants in 1818.

A publication that has caused some confusion is frequently referred to as “Fraser’s Catalogue” that was published in 1813. It is more properly titled “Catalogue of New and Interesting Plants Collected in Upper Louisiana and Principally on the River Missourie.” The document is primarily a list of plants with very few descriptions. Due to the scarcity of the “Catalogue”, Greene (1889) reprinted the list and attributed the authorship to Nuttall (1813). The lack of descriptions has mostly limited its value for species names, but the list clearly predated Pursh’s (1813) publication by several months.

Joseph Nicollet was a French citizen who was hired by the United States to explore and map the Mississippi River Valley. Nicollet (1843) made two expeditions, in 1838 and 1839, and hired at his own expense Karl Geyer, a German botanist, to collect plants. The first expedition included travels in far eastern South Dakota, including the Big Sioux River, Lake Preston, Lake Poinsett, Lake Traverse, and Big Stone Lake.

The second trip left St. Louis on 04 Apr 1839 and after a slow trip on the steamboat Antelope, arrived in Ft. Pierre on 12 Jun 1839 (roughly 18 miles per day). In a letter to W. J. Hooker, Geyer (1840) stated that they surveyed the Missouri “as high up as the Little Missouri and almost the whole of that immense country between the Missouri and the Mississippi.” The plants from Geyer’s collections were identified by Torrey (1843). The 1839 trip included the James River, Brown County and what is now Marshall, Day, and Roberts Counties of South Dakota.

Ferdinand V. Hayden was known primarily as a geologist from his work in western North America. He was also a physician and an enthusiastic naturalist (Hayden 1867, 1875). Hayden first came to what is now South Dakota during the summer of 1853. On that expedition, sponsored by James Hall of Albany, New York, Hayden collected fossils in the White River Badlands as well as plants. The following year Hayden, sponsored by Spencer F. Baird, Assistant Secretary of the Smithsonian Institution, travelled up the Missouri River and wintered at Ft. Pierre. From there he went on to explore the upper Missouri and the Yellowstone Rivers (Foster 1986). In 1856 and 1857 Hayden accompanied the Lt. G. K. Warren expeditions into Nebraska and the Dakotas. In 1859 Hayden traveled with the Captain W. F. Raynolds expedition, mapping the area between Ft. Pierre and the Yellowstone River. Plants from the upper Missouri were identified by Engelmann (1863). Hayden’s plant collections are currently located in the U.S. National Herbarium, the Philadelphia Academy of Science, the New York
Botanical Garden and the Missouri Botanical Garden. The latter has the largest collection of Hayden's specimens, approximately 457 Hayden collections, with nearly 100 of those from South Dakota.

One of the most noted expeditions to South Dakota was that of G. A. Custer in 1874, which included about 1000 men and 115 wagons. The person serving as botanist and a correspondent for a St. Paul newspaper on that expedition was A. B. Donaldson, a former faculty member of the University of Minnesota (where he taught Rhetoric and English literature). Donaldson collected a limited number of specimens while in South Dakota, and sent them to John Coulter, a botanist at Hanover College (Shaner and Harby 2008). Coulter (1874) listed 74 plant species in a preliminary publication, but noted that about 80 species were collected. In a later publication Coulter (1875) published a slightly different list with the same number of species. Coulter moved to Wabash College in 1879 (Masson 1994) and apparently took the Donaldson collections with him. Later the New York Botanical Garden acquired the Wabash collection (Holden 1993). Of the 74 or 80 specimens collected by Donaldson, 42 are currently at the New York Botanical Garden. More recently, 11 specimens from Donaldson were located at the Purdue University Herbarium (Shaner and Harby 2008). Between 21 and 27 specimens collected by Donaldson are still apparently missing. It was noted that unidentified species from Coulter were sent to T.C. Porter (Philadelphia Academy of Science). The specimens have not been relocated, but currently only 42,000 specimens of 1.4 million in their collection have been databased.

N.H. Winchell, a faculty member at the University of Minnesota, served as a geologist on the Custer expedition. In addition to producing the first geological map of the Black Hills, he listed species of trees and shrubs he observed (1875), but apparently made no collections.

In 1875 Walter P. Jenney and Henry Newton accompanied the Lt. Colonel Richard Dodge expedition of about 400 soldiers to the Black Hills. The Dodge expedition was charged with scientific observation, removing miners who had illegally trespassed into the Black Hills and to approach the American Indian tribes about purchasing the Black Hills. The Newton and Jenny report (1880) listed 175 species of plants from the Black Hills that were identified by Asa Gray at Harvard.

W. H. Forwood graduated from medical school in 1861 and was soon a field surgeon in the Civil War. In the period from 1879-1883 Forwood served as medical officer and naturalist for three expeditions commissioned by General Phillip Sheridan. He collected numerous specimens from the areas that became South Dakota, Wyoming and Montana. He was probably present, at least for a short time, at Fort Meade in 1887 because there are numerous collections from that post. Specimens collected by Forwood are present at Harvard, the New York Botanical Garden, and the Missouri Botanical Garden. Forwood later became Surgeon General.

Per Axel Rydberg was born in Sweden and immigrated to the United States in 1882. He received his B.S. from the University of Nebraska and the following year (1892) received a commission from the United States Department of Agriculture to explore the Black Hills. After completing his exploration of the Black
Hills, Rydberg went to New York to work on a Ph.D. at Columbia University. In the summer of 1897 Rydberg travelled to Montana and Wyoming to make plant collections in the first field program expedition of the New York Botanical Garden. He also made at least some collections in South Dakota on that trip. In 1899 he was employed as one of nine permanent staff members, and eventually became the first Curator at New York. Another collecting trip in 1926 brought him to South Dakota. Results from his work in South Dakota include the Flora of the Black Hills (1896) and the Flora of the Prairies and Plains of Central North America (1932, published posthumously). Rydberg had a very strong influence on botany in South Dakota.

DeAlton Saunders was a faculty member at what is now South Dakota State University and published the first checklist of plants of South Dakota (1899). The checklist included about 1100 species and was compiled from collections by Saunders in eastern South Dakota and Rydberg in the Black Hills.

Steven Sargent Visher grew up in Sanborn County, South Dakota, and was largely homeschooled. He obtained a B.S. in botany and an M.S. in geology from the University of Chicago, an A.M. in zoology from the University of South Dakota and a Ph.D. from the University of Chicago (Harris, 1968). He was said to be an avid naturalist and a quick study. While in South Dakota he conducted major studies in the Black Hills, Harding County and the Pine Ridge area. Many of his plant collections were identified by Aven Nelson at the University of Wyoming. Results of his work (1909, 1912a, 1912b, 1913a, 1913b, 1914) in South Dakota were published in various journals.

Herman E. Hayward is primarily known in South Dakota for his collections in the Black Hills in 1926 and 1927. During that time he collected about 1600 specimens which resulted in a publication on the flora of the Black Hills (1928). Hayward was associated with the Milwaukee Public Museum and his collections are housed at that institution.

W. H. Over was a person of diverse interests, publishing articles on fish, mammals, birds and especially archaeology. In 1923 he wrote a booklet on trees and shrubs of South Dakota. He is better known for his 1932 publication, a briefly annotated checklist of about 1769 species of the flora of South Dakota.

In 1931 A.C. McIntosh published his botanical survey of the Black Hills. The work includes sections on geology, soils, climate, paleobotany and ecology. These sections are followed by a checklist of the vascular plants with very brief comments about 1300 species.

Claude Barr published about 100 horticultural articles from the 1930s to 1970s that showed a great deal of taxonomic insight. A bibliography and summary of his work can be found in Barr’s 1983 book.

Two botanists who were prodigious collectors but did not publish extensively (Table 1) were F. L. Bennett of Black Hills State University and Charles A. Taylor Jr. of South Dakota State University. Bennett collected extensively from the 1920s to the 1940s, while Taylor collected primarily from 1949 into the 1990s.
DISCUSSION

In the period from 1800 – 1976 approximately 85 publications dealing with botanical exploration in South Dakota were published (Table 1). Of those 36 or 42% were published in the Proceedings of the South Dakota Academy of Science (Figure 1). It should be noted that many of the earlier publications were more general works that included plants from within the boundaries of South Dakota and that the Proceedings were not published until 1916. The later works are often more confined to the state. Since 1916, 64% of the publications on botanical exploration in the state have appeared in the Proceedings.

General trends observed in this study include the change from the study of plant species using only alpha taxonomy (morphology, anatomy, ecology etc.) to systematics (cytotaxonomy, numerical taxonomy, isozymes, and molecular analyses as well as alpha taxonomy). Another trend is the decentralization of taxonomic knowledge. Earlier collectors usually sent their specimens to experts for identification. Today, nearly all collectors identify their own specimens with the possible exception of species new to the region or specimens in very difficult groups. Taxonomists today usually hold advanced degrees in botany whereas previously workers were generalists.

Another trend is that botanical resources are more widely distributed. There are more herbaria today, as well as labs that can be used for the systematic study of plant species. Over the recent decades prices for systematic study are generally lower and the techniques more efficient.

Travel to field sites in the modern era is much easier than it was anytime previously. Roads have improved, maps have improved and vehicles have improved. Better data are obvious on plant specimen labels. Early locality data on many specimens would often reveal only very general information such as “Dakota Territory.” The importance of better data slowly became apparent. Legal descriptions were eventually used to describe township, range and section numbers. In the 1990s legal descriptions were supplemented or replaced by latitude/longitude data easily obtained from global positioning system units.

Figure 2 shows the number of plant species listed in the statewide publications. The actual number of specimens present in the state has probably not decreased from the time of Over (1932) to the publication by Van Bruggen (1976). The delineation of species has undoubtedly changed. Rydberg was frequently characterized as a “splitter,” or a taxonomist who defined species very narrowly based upon small differences. More recently, most botanists have taken a broader view of species, partially due to better communication among botanists and broader access to specimens. Important changes have resulted from a greater standardization of taxa due to the partial completion of the Flora of North America (Flora of North America Editorial Committee 1993+). Finally, widespread distribution of plant data has been increasing due to the use of electronic databases, some of which include label data as well as images of specimens.
Figure 1. Number of publications by decade reporting on botanical exploration in South Dakota. Hatched bars are articles published in the Proceedings of the South Dakota Academy of Science.

Figure 2. Number of species recorded in statewide checklists or floras of South Dakota. Saunders (1899) and Over (1932) were influenced by Rydberg’s nomenclature. Floras by Van Bruggen (1976, 1985, and 1996) used a more modern terminology. The 2017 estimate is based on current work for an ongoing revision of the flora.
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ONE HUNDRED YEARS OF GEOLOGY AND HYDROLOGY PAPERS PUBLISHED IN THE PROCEEDINGS OF THE SOUTH DAKOTA ACADEMY OF SCIENCE

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ABSTRACT

In 2015 The South Dakota Academy of Science celebrated one hundred years of publication of the Proceedings. This paper is written as part of the historic contributions to the Academy, focusing on the nearly two hundred papers dealing with geology and hydrology that have been published in the Proceedings. Emphasis in this paper is given to papers that are concerned with the Missouri River and the Homestake gold mine.

Keywords
Geology, hydrology, Missouri River, Homestake mine

INTRODUCTION

During the past 100 years there have been 180 full papers published in the Proceedings of the South Dakota Academy of Science that are primarily concerned with geology, paleontology, or hydrology. In addition, there are numerous abstracts published in the Proceedings that touch on these subjects.

The purpose of this paper is to briefly review several of these papers and show how they have contributed to their respective disciplines. Since there have been so many papers published in the Proceedings that have been written about diverse subjects within the general areas of geology and hydrology, it is not feasible to discuss all these references. Therefore, only a few citations are given in this paper, and two general themes are chosen that represent important works from both “East River” and “West River” within the State of South Dakota. In this endeavor, the two chosen themes are: the Missouri River and the Homestake Mine.

Missouri River—The Missouri River (Figure 1) is the most important hydrologic feature in South Dakota. It separates the glaciated East River, with its rich farmland, from the unglaciated ranch lands of West River.

Historically, the U.S. government acquired the Missouri River basin as part of the Louisiana Purchase, and in 1804 the Lewis and Clark expedition traveled...
up the Missouri River, encountering numerous Indian tribes as the expedition explored for a water passage to the Pacific Ocean (DeVoto 1953; Ambrose 1996). Meriwether Lewis and William Clark described the geography of the Missouri River and the flora and fauna as they explored for the Northwest Passage. Later in the 19th Century, the Missouri River served as the main route of transportation throughout the region, and South Dakota towns such as Yankton, Vermillion, Springfield and Pierre served as ports for steamboats.

The Proceedings of the South Dakota Academy of Science contain a number of articles that deal with the Missouri River. An early paper by Kirby and Abbott (1930) deals with the 1881 Missouri River flood in the Vermillion area. Figure 2 shows maps with the location of the river prior to 1881, and the new channel after the 1881 flood (as it appeared in 1930). The paper by Kirby and Abbott illustrates that rivers can dramatically change position by sudden flood events. These dramatic shifts supplement the gradual changes in river position by continual meander migration from erosion on the outside of a meander (“undercut bank”) and deposition on the inside of a meander (“slip-off slope”). Dramatic shifts profoundly impact citizens of a river port town because they suddenly find they are no longer near the river.

Examples of fluvial processes are illustrated by other papers in the Proceedings. For example, Rahn (1976, 2004) described changes in the Missouri River erosional and depositional pattern following dam construction upstream of Yankton. It was found that erosion no longer proceeded only on the outside of a meander, but proceeded along both sides of the river. Changes brought about by
channelization of the Missouri River between Yankton and Saint Louis includes dikes and revetments in an attempt to keep the channel in the same place, and deep enough for barge transport.

**Homestake Mine**—There are numerous articles published in the Proceedings that deal with geology and hydrology in the Black Hills and adjacent areas, such as the Badlands. One important subject is the Homestake Mine in Lead. This mine has supplied 40 million troy ounces of gold since it began operation in 1878 until it closed in 2001 (Mitchell 2009). [Interestingly, using the density of gold, this weight is equivalent to a volume of a cube 13 ft (4 m) on a side.] Thus, the Homestake Mine has been an important domestic source of gold, and was an impetus for the establishment of the South Dakota School of Mines.

The Homestake Mine is the second deepest mine in the world, extending to a depth of 8,150 ft (2,438 m) below the land surface. The mine contains over 300 miles (480 km) of drifts, shafts, and underground workings. Figure 3 is a cross section of the Homestake Mine. The mine was abandoned in 2001, and in 2003 the pumps were shut off, allowing groundwater to flood the workings, reaching 20 ft (6 m) above the 4,550 ft (1,387 m) level (Mitchell 2009). Rahn and Roggenthen (2002) published a paper in the Proceedings that showed a model that predicted the rate of rise of water. In 2008, pumps were activated, and the mine dewatered to 4,850 ft (1,478 m) level, ensuring that this level could be used for a neutrino laboratory. Stetler et al. (2010) published a paper in the
Proceedings that shows the water level and instrumentation used to study the groundwater level (Figure 4). Hydrologic data collected at this unique location has contributed to the understanding of hydrogeology of metamorphic rocks at great depths.

Rothrock (1941) published a paper in the Proceedings that describes the general Precambrian geology of South Dakota. In the Black Hills the Precambrian rocks are largely metamorphic rocks such as schist and quartzite. Hart et al. (2014) described the geology at the Homestake Mine; Figure 5 shows Precambrian schist and metagabbro intruded by Tertiary rhyolite. The disposition and density of various rocks types surrounding the Davis Campus Laboratory for the Sanford Underground Research Facility (SURF) is important for physics research because at the 4850 level shielding from cosmic rays is critical in order to detect neutrinos.

**SUMMARY**

Geology and hydrology articles published in the Proceedings of the South Dakota of Science have contributed to our scientific knowledge in these areas. In this paper examples of research are given for papers concerned with the Missouri River and the Homestake Mine. A complete discussion of all the geology and hydrology articles published in the Proceeding in the last 100 years is beyond the scope of this paper. Nevertheless acknowledgment is due to the many authors of all the published papers.

From a personal perspective, the author found that, in addition to the published works, a highlight of his association with the South Dakota Academy of Science has been the personal contacts and comradery that is present at the annual meetings of the Academy.
Initial deployment
6 winze hoist room, 1387 m

Current deployment, 1478 m
Datalogger, barometric pressure

Water ~1540 m

Pressure 1582 m

Total depth = 2484 m

Figure 4. 2008 water level in the No. 6 winze and instrumentation in the Homestake Mine (From Stetler et al. 2010). The elevations shown are the distance (meters) below the land surface.

Figure 5. Three-dimensional geologic model of the Homestake Mine (From Hart et al. 2014).
LITERATURE CITED


SIGNIFICANT CONTRIBUTIONS TO PALEONTOLOGY IN 100 YEARS OF THE SOUTH DAKOTA ACADEMY OF SCIENCE

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ABSTRACT

This report serves to recount major contributions in the field of paleontology, throughout the lifetime of the South Dakota Academy of Science. The Proceedings of the South Dakota Academy of Science has provided an invaluable venue for the descriptions and establishments of type specimens, poorly known bio-chronologic faunas, and research that covers many other aspects of paleontology. In several cases, the Proceedings provides the only recorded or citable information on a fossil site, taxonomic component, stratigraphic occurrence, or other information not provided elsewhere. We chronicle some of the most notable paleontological contributions through the South Dakota Academy of Science, and the major contributors who fully utilized this venue to make a wide variety of information available.

There is great value in providing a venue for peer-reviewed research in a more academically relaxed atmosphere, which can be better utilized for citation. Some research may not be deemed significant enough for journals with more perceived prestige, and this hinders the release of potentially valuable information. Quality of research appears to be erroneously gauged by a journal’s impact factor or notoriety rather than the content provided by the contributor. These accounts should not only serve to chronicle contributions, but encourage researchers to service this venue for continued academic productivity and further enrich the academic value of the organization.

INTRODUCTION

The South Dakota Academy of Science (SDAS) has recently celebrated its centennial. Countless discoveries and contributions within varied scientific disciplines (mathematics, chemistry, biology, etc.) have been accomplished in the 100 years of the SDAS. Though the mission of the SDAS is to improve the quality of life of South Dakotans, it has also accomplished the goal of providing a productive atmosphere for academics and students to share their work. All scientific conclusions can be shared regardless of perceived importance. This attitude has
often resulted in having important information and records been made available, whereas they might have been rejected elsewhere.

The main goal of this study is to review what could be considered the most significant paleontology contributions made through the SDAS. We have chosen to focus on papers dealing specifically with fossil remains, excluding papers dwelling entirely on stratigraphy or other geologic emphases on fossil-bearing units. Though there are countless abstracts included in the Proceedings, peer-reviewed papers are the only publications we have considered. We have systematically searched through the Proceedings which have recently been made available through online open access. This search has narrowed down the field to 72 published contributions, beginning with a singular publication in 1918, a hiatus from 1918 to 1952, with a somewhat steady manuscript submission following.

Contributions to paleontology through the SDAS have been somewhat sporadic with pulses of productivity, which is dependent on contributors who recognized the value of the venue. We have chosen to acknowledge tiers of contributions based on information uniquely provided through the SDAS, e.g. the recognition of new species with the designation of holotypes. There are also several instances of exclusive faunal descriptions within a particular geologic unit or geographical area. Various other unique records are included based on new biogeographic, geochronologic, or taxonomic information. Updated taxonomic statuses and information based on the best current knowledge are also included. Finally, we have compiled data on the number of manuscripts published during each of several time intervals. Authors who have made multiple contributions throughout the SDAS timeline are also recognized. Space does not allow us to acknowledge all published works of paleontological contributions, however, we have included citation information for all SDAS contributions in an appendix.

**Abbreviations**—BADL, Badlands National Park, Interior, South Dakota; BCGM, Bob Campbell Geology Museum, Clemson University, Clemson, South Carolina; FHKM, Fort Hays Kansas State College Natural History Museum, Hays, Kansas; FHSM, Sternberg Museum of Natural History, Hays, Kansas; SDGS, South Dakota Geological Survey, Department of Environment and Natural Resources, Vermillion, South Dakota; SDSM, South Dakota School of Mines & Technology, Museum of Geology, Rapid City, South Dakota; USD, The University of South Dakota, Vermillion, South Dakota.

**Holotypes**—There are only two holotype specimens named through the SDAS. Only one of these taxa is currently recognized as valid.

Green (1957) described *Syllaemus hanifii* (SDSM 56139) (Figure 1) from the Turner Sandy Member of the Carlile Shale (Upper-Middle Turonian) at Hanify Ranch, Butte Co., SD. The specimen was located above an invertebrate horizon containing *Prionocyclus* sp., *Scaphites warreni*, and *Inoceramus dimidius*. This would place the specimen within the *Inoceramus dimidius* Inoceramid Interval Zone, since it is difficult to distinguish its position within the *Scaphites warreni* Ammonite Taxon Range Zone or the overlying *Scaphites ferronensis* Zone of Cobban et al. (2006). This taxon has since been invalidated and synonymized with *Apsopelix anglicus* (Teller-Marshall and Bardack 1978).

Harksen (1966) described the holotype of *Pteranodon sternbergi* (FHKM 5426; now FHSM VP-339) (Figure 2), which is one of the 4 iconic pterosaur species
Figure 1. Left Lateral view of FHKM 5426 (now FHSM VP-339) Pteranodon sternbergi (Holotype). Scale bar is 50 cm. Original image provided by Mike Everhart, Oceans of Kansas Paleontology.

Figure 2. Dorsal and left lateral views of SDSM 56139, Syllaemus hanifii (Holotype). Scale bar is 5 cm.
of the Western Interior Seaway. The specimen was collected from the Smoky Hill Chalk Member of the Niobrara Formation (Upper Coniacian) along the Solomon River in Graham County, Kansas by George F. Sternberg in 1952. There was minor taxonomic reassignment and splitting with two subgenera and species P. (Sternbergia) sternbergi and P. (Occidentalia) eatoni (Miller, 1971). Kellner (2010) reassigned the taxon to a new genus and species, Geosternbergia sternbergi. The current status of these taxonomic additions have been recently synonymized within the revalidated Pteranodon sternbergi (Vila Nova et al. 2014). Based on Harksen’s (1966) comparison to P. longiceps, P. sternbergi represents a markedly larger pterosaur with an estimated 30 foot wingspan. This was the largest known flying vertebrate until the discovery of Quetzalcoatlus northropi (Lawson 1975).

**Faunas**—The only vertebrate fauna for the Minnelusa Limestone was described by Elder (1993), then appended by Cicimurri and Fahrenbach (2002). Elder (1993) discussed the difficulty of correlating the Minnelusa Formation in Elk Creek Canyon, near Piedmont, South Dakota, but did distinguish two shark-bearing marker layers as the “Petrodus I” and “Petrodus II” beds. Her fauna included the elasmobranchs Petrodus occidentalis (=P. patelliformis) (SDSM 26051, SDSM 26052, and SDSM 26053) and Listracanthus histrix (SDSM 26057 and 26058), the holocephalian? Cranodus (SDSM 26056), and the chimaeriform Cladodus sp. (SDSM 26054 and SDSM 26055) (Elder 1993). Elder (1993) also identified conodont elements from the Petrodus II bed attributed to Idiognathodus magnificus and I. claviformis, representing a middle Pennsylvanian (Desmoinesian) age.

Cicimurri and Fahrenbach (2002) continued research in the Minnelusa and identified the elasmobranchs Petrodus patelliformis (BCGM 2932, BCGM 2933, BCGM 2950, and BCGM4425) and “Listracanthus histrix” (=L. histrix) (BCGM 2934 and BCGM 2935) as well as the chimaeriform cf. “Cladodus” sp. Elder’s (1993) specimens of P. occidentalis were reclassified as P. patelliformis in Cicimurri’s and Farenbach’s (2002) description. These authors had also appended Holmesella quadrata (BCGM 2931, BCGM 4747 and BCGM 4748), Caseodus aff. C. eatoni (BCGM 2942, BCGM 2943, BCGM 2944, BCGM 2945, BCGM 2946, BCGM 2947, BCGM 2948, and BCGM 2949), Edestus sp. (BCGM 2938), cf. “Cladodus” sp. (BCGM 2936 and BCGM 2937), and Janassa sp. (BCGM 2939, BCGM 2940, and BCGM 2941) to the fauna (Cicimurri and Fahrenbach 2002). The presence of Idioprioniodus conjunctus, Neognathodus roundyi-dilatus plexus, and Idiognathodus “delicatus” in the Petrodus II bed reiterated the designation of a Middle Pennsylvanian (middle to late Desmoinesian) age based on Rowe and Fox (1997).

The only fossils formally described from the Minnekahta Limestone (Permian) through SDAS are stromatolites (Dopheide and Winger 2010). The stromatolite structures described appear consistent with modern stromatolite colonies that are currently observed in intertidal to subtidal environments. One particular specimen of stromatolite (SDSM 13987) produced what appears to be preserved bacteria representing two genera, Bacillus and Cocillus (Dopheide and Winger 2010). Fish, mainly palaeoniscid, are also known from this formation, but these are only briefly mentioned (Parris et al. 2005). Several fossils of these fish are...
housed at SDSM. The only other described specimen from the Minnekahta has been identified as Platysomus (Hussakof 1916).

Johnson (1966) provided the only thoroughly collected microfaunal assemblages from the Badlands, which includes several first occurrences from “middle Oligocene”. Johnson’s (1966) systematically collected microfaunal material from harvester ant mounds from Cedar Pass to Sage Creek Basin. At the time this paper was released, it included the first middle Oligocene occurrences of Geolaabis (Geolabidae), Proscalops (Talpidae), Sinclairella (Pantolestida), and Agnotocastor (Castoridae); the first White River Group occurrence of Archaeolaginae (Leporidae); the first occurrence of Pelycomys (Aplotontidae), and Scottimus (Cricetidae) from the Big Badlands of SD. This work has been frequently overlooked, with minimal citations in subsequent research. Nonetheless, this work has provided an abundance of material worth revisiting for further faunal analyses of new fauna and occurrences (e.g. Starck and Welsh 2013).

Unique records—Though the fossil record of Bison is abundant and well known, the only occurrence Bison occidentalis (=Bison antiquus) in South Dakota was provided by Galbreath and Stein (1962). It was discovered during the construction of Sheridan Dam, northeast of Hill City, South Dakota, and referred to as Bison occidentalis, which is currently synonymized with B. antiquus (McDonald 1981). Also, B. antiquus had been previously synonymized with B. occidentalis by Schutz and Cheatum (1970), and B. antiquus had been synonymized with B. Bison by Kurten and Anderson (1980). Bison taxonomy has been notably turbulent in recent history, and all aforementioned synonyms were subjective.

The Herrick Formation (Pleistocene) found within the Cahill Gravel Pit, west of Burke, Gregory County, South Dakota, produced the only known occurrence of the Rangifer sp. (Cervidae) in the state (SDSM 6421) (Green and Lillegraven 1965). Teeth referred to Plesippus and a dentary of Stegomastodon mirificus were also recovered, inferring a post-Kansan extension of Stegomastodon, a pre-Wisconsin extension of Rangifer, or a previously unrecognized biochronologic zone (Green and Lillegraven 1965).

Parris and Grandstaff (2000) reported on a right angular of cf. Baptanodon (SDSM 62277) from the Stockade Beaver Shale Member of the Sundance Formation (Jurassic; Bathonian and Callovian) in Rapid City, South Dakota, this, being the first and only ichthyosaur known from the state. The specimen was an amateur discovery by Mrs. Elsie Biegler, and was generously donated to SDSM (Parris and Grandstaff 2000). It should also be noted that this is the only known vertebrate specimen from the Stockade Beaver Shale Member, with only three known sites producing a limited amount of invertebrate material (Herrick and Schram 1978; Wright 1974).

Parris and Grandstaff (2003) also documented a unique occurrence of the oreodont Merychus cf. arenarum (Merycoidodontidae) (SDSM 62282) from the Arikaree (?) Formation at Slim Buttes, Harding County, South Dakota. SDSM 62282 has been attributed to the Hemingfordian North American Land Mammal Age and represents the only known record of the species in northern South Dakota, and the second specimen from South Dakota overall (Harksen and Macdonald, 1967; Parris and Grandstaff 2003).
Welsh (2014) documented the first occurrence of the rare canid *Osbornodon renjiei* (BADL 63382) from the fourth subdivision of the Orellan North American Land Mammal Age (Or4; *Merycoidodon bullatus* zone) at Badlands National Park, South Dakota. This was one of two specimens known from South Dakota, one of eight specimens overall, and the most complete dentition of any other referable specimen (Welsh 2014).

Welsh et al. (2015; this volume) have most recently provided the first detailed description of an infant nimravid, *Nimravus brachyops*, along with insights on the ontogeny and phylogeny of the taxon. This work also compiled the first comprehensive assessment of the associated Little Muddy Creek local fauna. Collective information based on previously recorded ungulates, rodents, and carnivores attribute the local fauna to the Early Arikareean (Ar1 and Ar2), and possible latest Whitneyan (Wh2), North American Land Mammal Ages (Welsh et al. 2015; this volume).

**Contributions**—There was a severe paucity of published paleontological works through the SDAS in the early years (1917-1952), with only one publication marking the earliest known human remains from Iowa (Webster 1918). This is likely due to the somewhat exclusive concentration of colleges and universities east of the Missouri River within the SDAS and to West River institutions, such as SDSM, publishing most paleontological research in-house and elsewhere while not having yet joined the SDAS.

![Top Contributors](image1)

*Figure 3. Authors that have contributed more than one paleontological publication to the Proceedings.*
Numerous authors have contributed manuscripts throughout the 100 years of the South Dakota Academy of Science. A vast majority of these manuscripts are by single authors, with a dozen authors contributing to more than one manuscript (Figure 3). There are a few major pulses of contributions through the decades (Figure 4). The first pulse occurred in the 1950’s followed by a large one in the 1960’s. This occurred when paleontologists such as J. R. Macdonald, J. C. Harksen, and Morton Green were the most active researchers in South Dakota. SDAS produced 29 papers on paleontology in the first two productive decades, with the majority of those publications coming from SDSM, USD, and the SDGS. USD was the dominant contributor in the 1950’s, and SDSM in the 1960’s. Only two publications were produced in the 1970’s. The 1970’s lull could have been due to a decrease in funding because of the Vietnam war, the lull that followed the space program’s efforts to reach the moon, or a general mistrust of science altogether (Mullin 2015). There was another increase in publications in the 1980’s with a noticeable, yet not significant, decline in the 1990’s, then another resurgence in the 2000’s. Much of this was due to contributions of James E. Martin, Dave Parris, and Barbara Smith Grandstaff. Martin has numerous published contributions due mainly to student submissions under his supervision as advising faculty at SDSM. Martin’s contributions were concentrated in the 1980’s and early 1990’s, while Parris, Martin, and others were the primary contributors through the first decade of the 2000’s. The contributions of the current decade represent the history currently being written. We are anxious to see what future submissions to the SDAS will advance our knowledge of paleontology in the Great Plains.

**Contributions through Time**

<table>
<thead>
<tr>
<th>Years</th>
<th>Number of Publications</th>
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<tr>
<td>2010-2015</td>
<td>9</td>
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<tr>
<td>2000-2009</td>
<td>14</td>
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<td>1960-1969</td>
<td>17</td>
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<tr>
<td>1917-1959</td>
<td>12</td>
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*Figure 4. Collective years of South Dakota Academy of Sciences publications in paleontology. Note that there are no publications focusing on paleontology prior to 1952, with the exception of Webster (1918).*
CONCLUSIONS

Our knowledge of paleontological resources in the Midwest has been enhanced through venues such as the SDAS. This is made evident through the numerous unique records that provide information that unlikely would be found elsewhere. Contemporary attitudes towards sharing scientific work appears to lean towards more “prestigious” scientific journals, such as Nature and others, leaving institutions such as state academies of science(s) on the wayside. This is compounded by the academic culture of “publish or perish”, which can pressure researchers to publish quickly and often recklessly. Such dubious motivation and the consequential results have been demonstrated by studies on research journals (e.g. Fanelli 2010; Fox 1994). These pressures could also result in the a priori rejection of potentially unique and important records of previously unknown information. Venues such as the SDAS provide opportunities for students and professionals alike to make this information available and to amend knowledge of local Earth history without the potential rejection due to subjective attitudes towards what information is worth publishing. The quality of the Proceedings relies entirely on the active participation of the state’s scientists rather than on academic discretion.

ACKNOWLEDGEMENTS

First, special thanks to Robert Tatina and the SDAS for the invitation to include this history of contributions to the Proceedings, as well as making the Proceedings open access to make this study easier. We also thank the complete list of contributors who published through the Proceedings and subsequently increased its academic value.

LITERATURE CITED


Webster, C.L. 1918. Low Types of Primitive Man in the Middle West. Proceedings of the South Dakota Academy of Science 3:5-14.
APPENDIX: PALEONTOLOGY CONTRIBUTIONS THROUGH THE SDAS NOT CITED IN THIS PAPER


ONE HUNDRED YEARS OF VALUABLE SCIENTIFIC RECORDS: WHAT CRITICALLY IMPORTANT INFORMATION CAN WE “EXTRACT” FROM OUR SDAS PROCEEDINGS THAT INFORMS OUR COLLECTIVE FUTURE IN SOUTH DAKOTA AND THE WORLD?

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INTRODUCTION

Like you, I have had an exciting and rewarding life. Professionally speaking, I’ve been able to conduct molecular genetics research on the genes controlling melanogenesis in coat color mutants of mice – the agouti locus and the lethal yellow mouse as our primary research foci. And I’ve been able to work with and know many fine researchers and scholars in South Dakota. I’ve also had the opportunity to teach many exciting courses, from bioethics to evolution, global studies to international literature (The 100 – Year - Old Man Who Climbed Out the Window and Disappeared by Jonas Johansson), “Two Cultures” (considerations of sciences and humanities) to considerations of “Five Wishes” (making health care decisions at the end of life), and many more like embryology and comparative anatomy (do you remember the mudpuppy (Necturus) and the dogfish (Squalus)?)

The last six years of my career at SDSU were devoted to coordinating our new Global Studies Program at SDSU. My two major themes for Global Studies were: 1) the concept that other cultures and other traditions, no matter how different, have tremendous value and are worthy of our deepest respect; in short, we need to learn to love “the other”; and 2) how do we become authentic global citizens – how can we Americans gain the perspective to behave in ways that improve the world and make it a better place. The recent (March 2015) Obama Administration efforts and, in particular, the work of Michelle Obama to promote education for young women internationally are two cases in point. When young women are kept in school, effectively delaying their marriage for a few years, they get married later, have fewer children, are better wage earners, show improvements in family health and nutrition, have children able to attend school, and enjoy a fuller and more satisfactory life.

How does a person like me go from thirty-five years of rather intensive research and teaching in biology to Global Studies? What possible credentials would I have for this job? My credentials came in the form of an intense interest in global resources and all things ecological. I was also privileged to teach Bioethics for
close to thirty years. This course treated medical ethics and the critically important environmental ethics; we read and exhaustively analyzed Aldo Leopold’s *A Sand County Almanac*. To be honest with you, I can’t think of a better experience for our college and university students than bioethics – a unique mix of moral philosophy and science. In addition, for many years, I was privileged to teach an honors course entitled “The Two Cultures: Bridging the Gap between the Sciences and the Humanities”. It is critically important for scientists to consider and embrace concepts of philosophy, art, music, literature, and others. Reciprocally, those practicing humanities are more effective and move convincing in their poetry, prose, art, and music if, in fact, they have an appreciation of science, e.g., the second law of thermodynamics. As I stated repeatedly in class, we have a staggering number of problems in our world. Given these profound problems, it takes the minds of our best scientists, poets, novelists, musicians, artists and others to address and hopefully resolve them. The late physician – scientist Dr. Lewis Thomas had a splendid “two-cultures” arts/sciences approach; his essays offer great possibilities for our future. For example consider analyzing Dr. Thomas’ extraordinarily compelling essays in his 1997 collection of essays, *The Medusa and the Snail: More Notes of a Biology Watcher*.

Enough! How does all of this introduce today’s topic of one hundred years of SDAS records? And to what extent are these *Proceedings* valuable? Of course, these one hundred years of *Proceedings* are valuable as a historic record. But, are they valuable in other ways as well? I believe they are precious! They are very informative, and a careful analysis of them will serve us well in the future. In the remainder of this paper, I hope to be able to convince you that our *Proceedings* are priceless in terms of what they can tell us about the past as well as how they can instruct our future.

**Overall Value of the last one hundred years of the Proceedings:**

The last one hundred years of *Proceedings* are invaluable for the following reasons:

1. Extensive record of biological, chemical, agricultural (including range science), microbiological or pathogen-related research, including veterinary science, geological, mathematical, perhaps meteorological, and others like sociological, anthropological, economics and other social sciences (even political science), and others;

2. History of agricultural practices in South Dakota – not only in terms of particular crops, crop genetics, and cropping practices, but also in terms of trends like drip irrigation, precision pesticide application, minimum soil disturbance practices (i.e., minimum tillage), an expression for the overall value, integrity, organic-richness, and autonomy of the soil, precision agriculture methods, and others;

3. In all the disciplines, one hundred years of baseline records. Just within the field of biology, the *Proceedings* represent an incredibly valuable reservoir of baseline data with respect to individual species, ecosystems and biomes, and others;

4. Evidence of biotic change. For example, what evidence can we extract from the *Proceedings* that support the notion of shifting ecosystems,
changing ecological community memberships, altered meteorological patterns, and other phenomena due to global climate change?. With respect to biotic change, how should we use these data to design future optimal agronomic systems for South Dakota?

5. With respect to biological research (and one could do this with other disciplines), what evidence do we have in the Proceedings for changing emphases in biological research (a kind of evolution or change in direction of biological research) over the last one hundred years? In general, have we gone from natural history (classical field studies) to cellular/molecular biology and molecular genetics and now, in a sense, are returning in part to natural history/ ecology once again? Are there authentic trends that we can recognize? And what can these trends tell us?

6. Do the subjects of the Proceedings over the last one hundred years reflect evolving political and/or social changes or patterns in South Dakota?

7. What do the Proceedings tell us, if anything, about the major interests of institutions of higher education in South Dakota like major programmatic foci, specialties, areas of unique concentration, as well as evidence for changing emphases over time? Examples include Missouri River studies at USD, agriculture at SDSU, geological, mineral and archeological emphases at SDSMT. What can we learn about the unique scientific goals of Augustana College, BHSU, Dakota Wesleyan University, Mount Marty College, NSU, Presentation College and others? To what extent have we encouraged the tribal colleges like Oglala Lakota College, Sinte Gleska University, and Sisseton Wahpeton College to participate in SDAS activities?

8. Who are the most interesting, singular, dynamic, and significant scientists and spokespersons for the SDAS over the last one hundred years and how are their unique activities reflected in the Proceedings? In my own personal experience, I would definitely suggest Dr. Swen Froiland of Augustana College as well as three gentlemen from SDSU - Charlie Taylor, Dr. David Holden and Dr. Gary Larson and others that would readily present themselves upon delving deeply and comprehensively into the last 100 years of the Proceedings.

Let me now relate some relevant information from Volume one of the SDAS (1916) and from Volume 45 fifty years later (1966) to give you an idea of the wealth of information, richness of ideas, and veritable treasure trove of valuable information embedded in our last 100 years of SDAS Proceedings.

SPECIFICS OF VOLUME I (1916) AND VOLUME 45 (1966) – FIFTY YEARS LATER:


First, a brief biography of Dr. Jones and his impressive credentials as our first SDAS President. He was born in 1882 near Mankato, MN. According to his own estimate, “His ancestry is American since the days of the Mayflower”. Dr.
Jones spent his early life in Winnebago, MN, and graduated from Parker College in Winnebago (1903) with an AB degree, majoring in ancient languages with a minor in science. That very promising humanities and science background served Dr. Jones well as a scientist, a leader, as well as a model citizen. He graduated from Drake University in 1904 with an AM (presumably chemistry) and taught science at East High School in Des Moines. Then, Dr. Jones pressed on to Harvard University (1906-08), where he worked with Dr. H. A. Torrey on the synthesis of adrenalin. He married Ms. Blanche Pinkerton of Des Moines and moved to University of Chicago as a Fellow in chemistry (1908-09). Then, they moved to Muskogee, OK, to be head of the science department at Central High School (a Junior College). While in Muskogee, Dr. Jones was a chemist for Muskogee, an assistant geologist for the Geologic Survey, and an assayer for the Arbuckle Mining Exchange. He helped organize the Oklahoma Academy of Science. In the fall of 1912, Dr. Jones came to Dakota Wesleyan University as the Head of the Chemistry Department. In 1915-16 he enrolled at USD, working on mono-nitro-phenyl ethers with Dr. Alfred N. Cook – that work resulted in his Ph.D. By 1916, Dr. Jones had authored many scientific papers, had become a Fellow of the Oklahoma Academy of Science, a Fellow of the AAAS, and a Fellow of the Chemical Society of London. Wow!

During the first year of the SDAS, Dr. Jones, fortuitously for us, presented not one but two major, presidential addresses. Themes and facts from the first address include:

1. Our academy must be active participants in the process of science in South Dakota;
2. There is an absolute need for our scientists to meet, discuss, encourage/support each other and act on important issues of science in our State;
3. The first function of the South Dakota Academy of Science is to provide the comradery and support to conduct independent research. “No man can remain a live, virile teacher of science for long who does not do some original research work along the line of his interest”;
4. Use our research to develop and utilize our vast resources of: i) Echinacea (coneflowers), ii) Lignite, iii) Sioux Falls quartzite as well as the vast and precious minerals of the Black Hills, and iv) Develop our material, physical, and agricultural resources;
5. Warning: “…..we must not be content to talk (and) attempt to graft the laissez-faire culture of the outgrown, overdone, effete East upon the forward-looking life of the young West”; and
6. Our charge: we in the SDAS “should be serving in the army of the common good—trying to make two ears of corn grow where one grew before”.

Themes and quotes from Dr. Hilton Ira Jones’ second SDAS Presidential Address of November 16, 1916 included (just a few of many important quotes):

1. “South Dakota’s present wealth is practically confined to two fields, geological and agricultural;
2. “I feel that as an organization we should undertake a campaign of education, and marshal all of our political forces in the legislature, as well as personally enlist in the geologic work of the state. All that I have said on
behalf of the geological needs should be more than doubled in the matter of agriculture”;

3. “….need to work on the buffalo grass problem for its feeding value as well as medicinal herbs of great importance, i.e., *Echinacea angustifolia*”; 

4. Dr. Jones’ final exhortation in his November 16, 1916 address is the following: “….We should not only be the scientific advisors of the governor and the legislature, holding a function within the State precisely similar to that which the National Academy of Sciences holds to the national government, but we should also energetically cooperate with all the other organizations in aiding in every good work in the upbuilding and industrialization of South Dakota. This intense cooperation of every member in a program of this sort means life and growth and power to our Academy. Anything short of this will be less than our duty and our best”.


The purpose of this listing is to give you an idea of the range of activities and some of the flavor of the 1966 Proceedings –

Minutes of the 51st Annual Meeting of the SDAS (apparently 1965).


Committee Reports: Many of these. I picked out two to highlight: 1) Conservation Committee. The Altamont Prairie was dedicated last September (1965). Conservation Committee serves as a liaison with the Nature Conservancy which along with the Wildlife Society has established South Dakota Chapters. This Committee reports on changing practices of the U.S. Fish and Wildlife Service. Quote – “any prairie dog control by Federal agents must be preceded by a survey for the presence of Black-footed Ferrets, which if present requires modification of control practices”. Committee members include: Paul Springer, Willard Rosine, and Byron Harrel (Chair).

National Science Foundation Reports: 1) visiting Science Program; 2) Junior Academy; and 3) Collegiate Program.

Treasurer’s Report.

Minutes of the Collegiate Section.

Minutes of the Junior Academy of Sciences.

Membership List. A very large number of members from all existing SD Institutions plus Dordt College, Huron College, Westmar College, Yankton College, High School Teachers, and General Junior Academy.

**B. Presidential Address of Dr. Marvin H. Hanson, Department of Physics, Huron College, 1966:**

Dr. Hanson’s remarks provide us with a truly provocative and thoughtful discussion. Let me give you a flavor of Dr. Hanson’s thoughts by listing some of the questions and considerations he raises. I think you will realize, as I do, that his questions go well beyond sciences and into the realm of the humanities, public
policy, government, and more. For example, Dr. Hanson begins with the following general questions and then proceeds with specific concerns:

1. “What will be the most urgent world-wide problems to be solved within the next 10, 20, or 50 years?
2. How are we to provide food, water, power, recreation, and space for the population growth due to increasing numbers being born and added average life span?
3. Who is to govern and control the outer spaces and the space below the level of the seas?
4. Is population growth to be controlled, and if so, where does the responsibility lie?
5. If alteration of the cells in human reproduction or life in the test tube becomes a reality, what group, government, organization, or individual is to be responsible for its control and use?
6. What are the limitations to the number and use of artificial or transplanted organs?
7. Are the research funds for space exploration being wisely spent or should they be used in areas that might be more valuable to life and to our long range economy?
8. If weather is to be modified and the moisture milked from the clouds, who determines whether one community or farm family is to receive the all-important rain and the equally deserving farmer in the next county or state is to be deprived of the same?
9. How are we to school the masses in the future? What should they be taught?”

To me, this is an incredibly creative and prescient list of questions. What truly critical considerations did Dr. Hanson omit from his list of questions? Not a whole lot! He presents themes of sustainability, governmental responsibility, and in some ways with his emphases on global population and global resources, one could make the case that he even anticipates sweeping global dilemmas like widespread poverty, global climate change, and maybe even a complex world of great hostility and conflict. I wanted to provide the essence of Dr. Hanson’s considerations to you as an example of the value--, the incredibly rich scientific, social, and historical value--of the entire body of information within one hundred years of our SDAS Proceedings.

SUMMARY

Critical future considerations:

1. Where does the SDAS go from here in our next 100 years?
2. How can SDAS become more politically relevant in South Dakota?
3. How can we capitalize on the things we have done especially well in the last 100 years?
4. Looking critically at our overall structure over the last 100 years including our various activities and components like the Junior Academy, Collegiate
Program, Visiting Science Program, and many others, which of our structural configurations provides us with the most political influence in South Dakota? What new organizational structures could enable us to enhance our political clout in South Dakota?

5. As we review our history, what have we done really well? What are our strongest features? And reciprocally, what are our greatest liabilities?

6. How can we maintain and/or revise our existing structures and functions to continue making major accomplishments for the State of South Dakota? And finally,

7. Should we engage and encourage our leadership to grapple with the kinds of broad questions raised by Dr. Marvin H. Hanson in his Presidential address of 1966? One particularly significant question raised by Dr. Hanson strikes at the hearts of all educators, i.e., “How are we to school the masses in the future? What should they be taught? For specific answers to this last two questions, I suggest an analysis of some of the themes and ideas of Granholm (2013) in his report, “Global Imperatives of the 21st Century: The Academy’s Response”.

I hope I’ve been able to convey to you some of the more critical historical, social, as well as scientific value of our one hundred years of SDAS Proceedings. Let’s do what we can to be aware, to study, and to analyze our last hundred years of progress so that we can maximize our next one hundred years of teaching, research, and service to the maximum extent possible for not only the State of South Dakota but for the greater good!

All best wishes to you and the South Dakota Academy of Science in the next 100 years!

ACKNOWLEDGEMENTS

I am very much appreciative of the many opportunities provided to all of us by the South Dakota Academy of Science. My interactions with the Academy proper as well as with my scientific colleagues have been incredibly important to my life, my professional colleagues, and to the lives of former SDSU students, many of whom are now practicing physicians in South Dakota. For my activities today, I am indebted to Dr. Gary Larson of SDSU, Dr. Donna Hazelwood of Dakota State University, and Dr. Bob Tatina of Dakota Wesleyan University.

LITERATURE CITED

Go to www.sdaos.org/proceedings/ for a complete set of the Proceedings of the South Dakota Academy of Science over the last 100 years. In addition to the annual proceedings, this site also provides extensive information on the many general aspects and features of the South Dakota Academy of Science such as Annual Conference, Officers, Mission and Activities, About Us, Contact Us, and Others.
Briggs Library at South Dakota State University. For purposes of this discussion, I made use of material from Vol. 1 (1916) and Vol. 45 (1966) of the Proceedings of the South Dakota Academy of Science.

In his essay “Science in the Service of the State,” Michael J. Mullin sets the history of the South Dakota Academy of Science in the context of the history of the state and the nation. His main focus was to examine how the scientists of the Academy responded to the events happening around them and how those events shaped the research Academy scientists reported in the volumes of the Proceedings. Because of this emphasis, much of the nuts and bolts of the Academy's history was omitted. Hence, the focus of the set of papers that resulted in the symposium, “A Century of South Dakota Scientists and Their Science,” at the 100th annual meeting of the Academy. Those papers trace the science and scientists in several disciplines. My focus is to look at some of the details of the Academy itself. Who were its founders, what did they found and when? How has the Academy changed over its 100 years? And can we learn anything from our past that might guide our future?

The Academy was the brain child of Hilton Ira Jones (DWU), its first and second president. In his Presidential Address, “South Dakota Academy of Sciences,” Jones describes the impetus for founding the academy (Jones, H. I. 1916. South Dakota Academy of Sciences. Proc. S.D. Acad. Sci. I: 20-25.) He writes that when he attended the South Dakota State Teachers’ Association meeting in 1912, he noted that the science teachers were not organized, which was contrary to his experience in Oklahoma, where he had helped organize their Academy of Science. Early in the fall of 1913, Jones sent a letter to South Dakota scientists suggesting that they meet with the teachers association in Sioux Falls “to effect some sort of organization, either in connection with the State Teachers’ Association or a distinct Academy.” When the Teachers’ Association met that fall, nearly all the scientists were in favor of a separate Academy. During the next year Jones and A. B. Poore (Northern Normal and Industrial School) met to organize the Academy’s first meeting to be held in Deadwood in 1914, but it was cancelled “at the eleventh hour” for reasons not mentioned. Instead the first meeting was held in Aberdeen on Monday and Tuesday, November 22 & 23, 1915 (Proceedings of the First Annual Session. 1916. Proc S. D. Acad. Sci. I: 10). Although the minutes do not indicate the location of the meeting, I assume it would have been held on Northern’s campus since this was the home institution of A.B. Poore. The banquet, according to the minutes, was held in Guild Hall at St. Mark’s Episcopal Church with twenty members attending. Eight papers were presented, the constitution and bylaws adopted, and officers elected for 1915-16 as follows: H. I. Jones (President), E. A. Fath (First Vice President, Redfield College), O.
R. Overman (Second Vice President, Huron College), R.J. Gilmore (Secretary, Huron College) and M. A. Mahre (Treasurer, Sioux Falls High School) (Proceedings of the First Annual Session. 1916. Proc S. D. Acad. Sci. I: 10).

At its origin, the Academy had 103 charter members and by the first meeting had added four more (Charter Members. 1916. Proc. S.D. Acad. Sci. I: 3-8). The list of charter members shows that most East River South Dakota schools were represented, including some schools that no longer exist—Redfield College, Huron College, and Southern State Normal School. Notably absent were Augustana College, Yankton College, and Mt. Marty College. Charter members came from the usual disciplines of biology, chemistry, agriculture, geology, etc., but also represented were English, philosophy and history. The Academy seemed to have a catholic appeal more so at its origin than today. The list also contains the names of four college presidents—from Redfield College, Huron College, South Dakota State College, and the University of South Dakota. Their presence among the charter members signified, I believe, their belief that the Academy would be a benefit to their faculty.

Over the years, the membership in the Academy has fluctuated widely (Figure 1). It started with about 100 charter members, but was not recorded regularly in the minutes of the Proceedings until the mid 1950s. When the number of members from the 1950s to the present are examined, three trends are evident. (I have excluded the numbers of high school teachers even though they were considered members since 1943 when the Junior Academy started because the Academy no longer attracts this group. During those years they averaged 29.8 ± 3.5 (sd) members.) Between 1956 and 1977 membership peaked, averaging 322 ± 56 (sd). From 1978 to 1989 its average numbers had dropped to 187 ± 23 (sd). From 1998 to 2014 it reached its nadir, averaging 133 ± 49 (sd) members. It should be noted that in the years between 1956 and 1977 there was a very active, separate collegiate section in which college students presented their research to each other. During those years the collegiate numbers averaged 50 ± 23 (sd) students; however, separate collegiate membership numbers were not included between 1981 and 1985, and in 1987, but were included between 1988 and 1995 during which period their numbers averaged 28 ±15 (sd), a clear drop from earlier years. In 2003, the Academy instituted the first poster session, which probably attracted college students, but even that has not stemmed the decline in membership seen since then.

Figure 1. SDAS membership 1950s to 2014. Included are collegiate and associate members; excluded are high school teachers. R² for the regression line is 39.5%.
bers. It should be noted that in the years between 1956 and 1977 there was a very active, separate collegiate section in which college students presented their research to each other. During those years the collegiate numbers averaged 50 ± 23 (sd) students; however, separate collegiate membership numbers were not included between 1981 and 1985, and in 1987, but were included between 1988 and 1995 during which period their numbers averaged 28 ±15 (sd), a clear drop from earlier years. In 2003, the Academy instituted the first poster session, which probably attracted college students, but even that has not stemmed the decline in membership seen since then.

Regardless of the causes for the decline, one pattern stands out: membership fluctuates widely from year to year and is probably tied to attendance at annual meetings. Some South Dakota scientists attend when they or their students have papers to publish in the *Proceedings*. I tested this hypothesis by comparing the authorship (According to academy policy one author must be a member of the Academy) of papers and abstracts in one year to the membership list in the following year. From 2008 through 2014, 479 full papers and abstracts were published in the *Proceedings*. Of these, only 207 had authors who were members in the year after their paper or abstract was published. Thus, for most members, membership either is associated with attendance at the annual meeting or having something published in the *Proceedings*. Should this be changed so that membership is solicited separately from the Call for Papers, perhaps at the beginning of the academic year for the next year? Doing so may produce a roster of regular members.

Earlier I mentioned that the constitution and bylaws were adopted at the first annual meeting. The first article of the constitution contains the following wording. “Article I. This society shall be called the South Dakota Academy of Sciences.” (Constitution and By Laws. 1916. Proc. S.D. Acad. Sci. I:13). That name with “Sciences” plural lasted until 1918 when, without ceremony or mention in the minutes, the terminal “s” was dropped and the Academy from then on was always referred to as the South Dakota Academy of Science. The name South Dakota Academy of Science became the official name in 1959 when a revised constitution and by laws were enacted (Constitution and By Laws of the South Dakota Academy of Science. 1959. Proc. S.D. Acad. Sci. XXXVIII:18). Then in 1960, the Academy became registered as a corporation in South Dakota. The First Article of Incorporation contains the following wording: “The name of this corporation shall be THE SOUTH DAKOTA ACADEMY OF SCIENCE.” (Figure 2). The incorporation of the Academy came with unforeseen consequences.

The early members of the Academy must have felt that their proceedings were important enough to form a Committee on Publication, responsible for assembling the program, the minutes and the papers presented at the annual meeting into a permanent record called the *Proceedings of the South Dakota Academy of Sciences*. The Committee arranged with the University of South Dakota (USD) to publish its journal—Volume I appearing as Series XVII University of South Dakota Bulletin—No. 7. It contained the 1915 and 1916 meetings. Volume II was also called the *Proceedings of the South Dakota Academy of Sciences*. This was the last time Sciences was plural. Beginning in 1918, the Academy and its
The early members of the Academy must have felt that their proceedings were important enough to form a Committee on Publication, responsible for assembling the program, the minutes and the papers presented at the annual meeting into a permanent record called the Proceedings of the South Dakota Academy of Sciences. The Committee arranged with the University of South Dakota (USD) to publish its journal—Volume I appearing as Series XVII University of South Dakota Bulletin—No. 7. It contained the 1915 and 1916 meetings. Volume II was also called the Proceedings of the South Dakota Academy of Sciences. This was the last time Sciences was plural. Beginning in 1918, the Academy and its journal were about science and called the Proceedings of the South Dakota Academy of Science.

Figure 2. Document affirming the incorporation of the South Dakota Academy of Science.
journal were about science and called the *Proceedings of the South Dakota Academy of Science*. The early publication of the journal was considered important by USD presidents, because, when in the 1920s, the state legislature cut funding to USD (Note of Explanation. 1920. Proc. S.D. Acad Sci. V: 4), the president of USD at the time rearranged his budget to include some money for the Academy (Forward. 1928-34. Proc. S.D. Acad. Sci. XIV: 4.) The shortage of funds reduced the page numbers, and in some years (1930s) caused several volumes to be combined.

Publication by USD continued until 1969 at which time the University ceased doing so. Recall that in 1960, the Academy became a private corporation. By law, state funds could not be used to support private enterprises. So the Academy became the publisher of the *Proceedings* and turned to Argus Printers in Stickney to print it. It also instituted page charges—$10.00. Over time, the editorship changed from a committee responsibility to one placed on the shoulders on one person and has remained such to the present.

No organization exists without the dedication of its membership. Over the years, the Academy has included many such individuals (See Table 1 for a list of Academy officers.). At this point I will mention only a few. One must start with the organizer and first and second president—Hilton Ira Jones. His biography (and picture) appear on pages 17-19 of Volume I and has been treated elsewhere. While he was a superb organizer and early leader, his tenure was brief.

When Jones left DWU and the state for private industry, the Academy was in good hands, a pair of which belonged to Albert L. Haines. Haines, a chemist at USD, is listed among the charter members of the Academy. He held continuous membership for 60 years. According to his obituary (Dr. Haines Memorial Statement. 1976. Proc. S. D. Acad. Sci. 55:7-8), Haines was a member of the Academy until the year of his death—a dedication probably not shared by many others, if any. During that time he was secretary-treasurer from 1916 to 1947 and then from 1949 until 1959 as well as serving on the Editorial Committee. One would think that his hiatus in 1948 would have been a vacation, but it was not, for he was elected President (1947-48). A. L. Haines served the Academy in every capacity—a rare individual indeed. He was so highly regarded that when Academy President John Willard appointed a Policy Committee in 1957, he suggested that the members “consider the possibility of an A. L. Haines annual award…” to be given “…for outstanding contribution to scientific education.” (Minutes. 1957. Proc. S. D. Acad. Sci. XXXVI:10).

Other notables include Edwin H Shaw, Jr. and Willard O. Read, both professors at USD. Shaw was a biochemist who served the Academy as president (1942-43) and as editor (1946-53) of the *Proceedings*. The 1976 *Proceedings* was dedicated to him. Read, an animal physiologist, was editor of the *Proceedings* from 1960-1972. Volume 61 of the *Proceedings* was dedicated to him.

The last person I wish to highlight was a member of the Academy in name only; however he had strong ties to South Dakota and South Dakota State University. In 1991, the members of the Academy voted to extend an honorary life membership to Edward W. Schultz, an economist at the University of Chicago (Minutes of the Seventy-sixth Annual Meeting of the South Dakota Academy of Science. 1991. Proc. S. D. Acad. Sci. 70:7.) . In 1979 Schultz had accepted the
Nobel Prize in Economic Science. Carroll Hanten, then Editor of the Proceedings, sent him a letter announcing the honor of life membership, to which he replied “I am responding to your very precious letter dated December 6. It is indeed a privilege for me to accept with pleasure the honorary life membership which you have voted to bestow upon me. I shall value it highly.”

Some Milestones:
1914—Academy organized
1915—First meeting held in Aberdeen
1916—SDAS meets jointly with SD American Chemical Society
1920—Secretary to mail membership certificates
1923—First field trips; Homestake & Sheep Mtn.
1930—Resolve that the state “should promptly make definite and adequate provision for the furtherance of scientific research.”
1937—Accepts student members
1943—Junior Academy organized
1947—SDAS affiliates with AAAS
1959-1963—SDAS receives NSF several grants to support science teacher improvement
1964—SDAS donates $33.95 (~1 acre) toward purchase of Altamont Prairie
1968—SDAS votes to support development of a field camp in the Black Hills
1971—First symposium—mercury pollution
1985—SDAS awards to outstanding H.S. physics and biology teachers
1998—First Fellow elected to the Academy
2003—First poster session (SDSMT)
2004—First meeting at Cedar Shore
2000—Website developed
2002—Proceedings uploaded to website
2012—http://www.sdaos hosted by Miner Solutions; 1916- present Proceedings uploaded to website
2015—100th Anniversary meeting held at Cedar Shore

ACKNOWLEDGEMENTS

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Complete Senior Research Papers presented at the 100th Annual Meeting of the South Dakota Academy of Science
NOTEWORTHY HEALED FRACTURES IN SOME NORTH AMERICAN ARTIODACTYLA

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ABSTRACT

The authors examined four medium-sized wild North American artiodactyl skeletons, all of which show limb bone pathologies that presumably affected the animal’s locomotor ability. One of these animals (a white-tailed deer) lived in an urban park, and might have survived a serious limb fracture due to absence of predators. The other three (a second white-tailed deer, a mule deer, and a pronghorn) were collected in rural environments. Both white-tailed deer were collected in eastern states from which most native predators have been extirpated, but where unconfined domestic dogs might sometimes act as predators on small artiodactyls. The mule deer and pronghorn were collected on range lands in northern plains states. The two white-tailed deer display fractures of major weight-bearing limb bones in which the bone pieces had completely fused prior to the animal’s death. The mule deer shows extensive osteomyelitis in the hock region. The pronghorn suffered an injury to the epiphyseal plate which resulted in a left metatarsal that is shorter than the right metatarsal. Considered as a group, these specimens demonstrate the resiliency of injured artiodactyls in wild populations with few large predators. Each of these four individuals was able to survive its injury for long enough to allow significant healing of the fractured leg bones essential to locomotion in a cursorial prey species.

INTRODUCTION

Wild artiodactyls have a remarkable ability to survive seemingly crippling injuries, despite the apparent rarity of survivable long bone fractures in wild primates (Bulstrode 1990; Bulstrode et al. 1986) and also in wolves and coyotes (Wobeser 1992). It is not uncommon to find healed fractures in cervids killed by car impacts or some other cause. In this paper we describe limb injuries in four artiodactyls which probably seriously reduced the mobility of these animals. The animals studied lived in both open western plains habitats and heavily urbanized eastern habitats. These specimens demonstrate that deer and pronghorn can survive long enough to allow their injuries to heal, and that fairly long periods
of survival are possible even in relatively undisturbed environments where one might expect predators to quickly remove injured animals.

The notable ability of cervids to survive injuries has been documented in various reports (summarized by Rothschild and Martin 2006), although there have been few published illustrations of skeletal pathologies in wild cervids (see Bartosiewicz and Gál 2013, chapter 8; Chaplin 1971, Figure 15; Grimm 2008, Figures 5, 7; Moodie 1918, Figure 7). It might be presumed that few individuals with severe skeletal injuries would escape predation, and that animals living in parklands and reservations, most of which are predator-free, are the most likely to survive (Chapman and Chapman 1969). Here we describe skeletal materials from three cervids that record very debilitating injuries which did not result in immediate death. Indeed, these animals seem to have lived for a considerable time, since their injuries had healed (at least in so far as the broken bones having fused) prior to death. We also describe herein an injury in another artiodactyl genus (an antilocaprid) from North America.

METHODS

This study was prompted by the discovery of a single skeletal specimen (NJSM-B-466) found by one of us (E.D.) while walking dogs in an urban park. Our study eventually grew to include three other pathological artiodactyls, all of which reside in the collections of the New Jersey State Museum, and all of which exhibit injuries to major weight-bearing limb bones. The three cervid specimens that we describe here were all initially surface-collected as skeletal remains. The striking deformity of the broken and healed tibia in the Clifford Park deer prompted a search for more of the same skeleton, and additional bones were recovered by digging and screening in the area where the surface finds had been made. The bones, already free of soft tissue, were cleaned by simple washing. Broken bones were reassembled with acetone-based glue. Unlike the three cervids described herein, the antilocaprid was found freshly dead in a Kansas pasture over a kilometer from the nearest road. The cadaver exhibited no wounds or obvious injuries. It was recovered by two of us (B.S.G and D.C.P), gutted, and skeletonized by burial in a large lidded garbage can filled with soil. The metatarsal pathology was discovered only after the animal had been skeletonized.

Most measurements included in this study were made using a 300mm Mitutoyo Absolute digimatic bar caliper accurate to 0.1mm. The sole exception is length of the normal tibia from the Clifford Park deer, which exceeds the length of the bar caliper. All skeletal elements were compared to a mounted white-tailed deer skeleton in the collection of the School of Veterinary Medicine to confirm side of body and to evaluate how much morphological change had occurred to each. All photographs in this study were taken in the anatomy laboratories of the School of Veterinary Medicine at the University of Pennsylvania with a Panasonic DCM-TZ4 Lumix digital camera.
RESULTS

Pennsylvania white-tailed deer (*Odocoileus virginianus*)—This profoundly affected specimen is a partial skeleton of a fully mature white-tailed deer (*Odocoileus virginianus*, NJSM-B-466), consisting of a complete scapula, one complete right and one partial left humerus, a complete left ulna, a complete left and a partial right radius, a left metacarpal cannon bone (fused metacarpals III and IV), a rib, a lumbar vertebra (possibly the second), the sacrum, the right femur (pathological), the left tibia (complete with fused proximal fibula), and the right tibia (pathological). All epiphyses of the bones are fully fused, as would be the case in an adult of more than 42 months age (Reitz and Wing 1999). The bones were discovered in Clifford Park, a unit of the Fairmount Park System, near the Tulehocken Train Station in Philadelphia County, Pennsylvania, late in the year 2009. The animal is presumed to have died earlier that same year. The bones are no longer greasy, but are unweathered (Behrensmeyer 1978) and have not been gnawed by rodents.

The most striking pathology in this skeleton involves the right tibia (Figure 1a), which was fractured and healed with the proximal and distal ends at a right angle to each other. The fusion was accompanied by substantial proliferation of periosteal bone, and the tibia was barely recognizable as a tibia when found. The associated osteomyelitis is strikingly evident as exostosis which covered much of the fractured area, and was variously expressed as encrustations, stabilizing secondary development, and offshoot strands of bone. A large part of the diaphysis appears to have been lost, possibly by remodeling, so that the pathologic right tibia is much shorter than the normal left tibia (Figure 1b, c; Table 1). The tibial plateau retains recognizable articular surfaces, but their surfaces are not as smooth as those on the normal left tibia. The fibula appears to have been rotated caudally at its distal end (Figure 1c), possibly by traction from soft tissues connecting it to the tibial diaphysis.

The right femur was not fractured, but shows considerable pathology related to the tibial articulation. The surfaces of both the articular condyles and patellar groove of the right femur are irregular rather than smooth, suggesting that mobility of the stifle joint was probably limited. The distal end shows significant exostosis in the area where the joint capsule attached. This exostosis conceals the extensor fossa in cranial view. A deep pit, 28.5 mm wide and 37.3 mm long, on the cranial surface of the distal femoral shaft (Figure 1d) may have been occupied during life by the right patella, which was not found with the specimen. This pit has a rugose elevated rim, and lies proximal to and essentially in line with the patellar groove.

It may be presumed that the right hind limb of this animal was essentially non-functional, being significantly shorter than its counterpart. However the healing, unguided as it was, seems to have been complete or nearly so. This urban animal presumably suffered a broken leg as a result of being struck by a motor vehicle. It clearly survived for some time after the leg was broken. Its survival probably was facilitated by the fact that this animal lived in an urban park setting. Philadelphia does have a feral dog population, and feral dogs could have harassed the animal even in this urban setting. To date, no coyotes have been reported in Fairmount Park.
Figure 1. Clifford Park deer (NJSM-B-466). a. articulated right femur and tibia in lateral view. Long (proximal to distal) axes of the tibial shaft pieces are indicated with dashed black lines; the long axis of the fibula is indicated with a dotted black line. b. normal left tibia and pathologic right tibia in caudal view. The proximal articular surface of the right tibia is rotated so as to be visible when the shaft of the right tibia is viewed from the caudal aspect. c. normal left and pathological right tibias in lateral view. d. distal end of right femur in cranial view. Note the pit above the patellar groove on its cranial surface. Scale bar is in centimeters.
Table 1: Measurements of the Clifford Park, Philadelphia deer (NJSM-B-466) tibias, and of the Kansas pronghorn (NJSM-B-443) metatarsals. Proximal and distal widths and anterior to posterior measurements were taken at the articular ends of the bone; the metatarsal cannon was also measured at the fused physis to show how much distortion there is in this part of the pathological metatarsal. All measurements are in millimeters. Each measurement shown is an average of three to five repetitions. Abbreviations: MT = metatarsal. a-pto = anterior to posterior dimension.

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*The normal white-tailed deer tibia was longer than the 300mm capacity of the metric bar caliper, and was therefore measured using a metric ruler. This measurement is accurate to 1.0mm.
New Jersey whitetail deer (*Odocoileus virginianus*)—A second specimen is the fused tarsus and metatarsus of a white-tailed deer (NJSM-B-459). This 227mm long specimen was found at the Merrill Creek Reservoir in Harmony Township, Warren County, New Jersey. The principal portion of the specimen is the right metatarsal cannon bone (normally the fusion of Metatarsals III and IV). The proximal end of the metatarsal cannon was displaced medially relative to the talus (astragalus), and its cranial surface was rotated laterally 59 degrees (Figure 2a) prior to fusion with the distal end of the tarsus (figure 2b-d). While the animal’s foot would have pointed somewhat laterally, the distal end of the metatarsal cannon bone lies nearly under the proximal trochlea of the talus (and

![Figure 2. Merrill Creek deer foot (NJSM-B-459). a. Proximal view. The medial-to-lateral orientations of the talus (astragalus) and distal end of the metatarsal cannon bone are indicated by the markers (see labels). The medial edge of the proximal trochlea of the talus is indicated by a dotted black line. The medial edge of the central tarsal bone is indicated by a dashed black line. The medial edge of the metatarsus is overlain by the marker for the medial to lateral axis of the talus, but is otherwise visible against the background. Note that the distal end of the metatarsus is rotated with respect to the orientation of the proximal trochlea of the talus; the white arrow indicates the direction in which the metatarsus has been rotated. Most of this rotation appears to have occurred at the level of the fracture in the proximal metatarsus. Anterior is to the left, medial is toward the top. b. Merrill Creek specimen in cranial view. Note that the distal end of the metatarsus lies almost on the proximal-to-distal axis of the talus (white dashed line) even though the proximal end of the metatarsus is offset medially relative to the tarsus. Only a small lateral fragment of the metatarsus remains associated with the tarsus. The fracture of the metatarsus is indicated by the dashed black line. c. Merrill Creek deer foot in caudal view. d. Merrill Creek specimen in lateral view. The level of the tarso-metatarsal joint is indicated by the white dotted line in both b and c. In b-d proximal is to the left, and distal is to the right. All scale bars are in centimeters. Abbreviations: c/d t = central and distal tarsal bones; DLG = dorsal longitudinal groove marking the contact between the third and fourth metatarsal bones; MT = metatarsus.)
hence the talocrural joint) when the specimen is balanced on its distal end. This suggests that the foot could have been weight-bearing, and that the animal may have been able to use its right hind limb after the fracture had healed.

The exact position of displacements in the middle and distal rows of the tarsus and of breaks in the proximal metatarsus are no longer clear due to complete fusion of the tarsals and base of the metatarsus. It is not possible to distinguish the individual tarsal bones, apart from the proximal talus and parts of the calcaneus. The only mobile joints that will have remained in this deer foot are at the proximal trochlea of the talus (the talocrural joint), the metatarsophalangeal joints, and presumably the interphalangeal joints. Mobility of the hock would have been restricted because no motion was possible on the distal trochlea of the talus. It may also have been limited by the bony callus on the hock and metatarsus. The injury could have resulted from a predator attack directed at the deer’s hind leg, or from a miss-step on a rocky hillside that trapped its foot and resulted in a metatarsal fracture.

This animal survived despite living in a rural area where free-ranging, unrestrained domestic dogs might have chased it. Coyotes are known to live in this part of New Jersey, and can also be expected to prey on injured deer. It is of interest that the metatarsal epiphyses had not even begun to fuse to the diaphysis in this animal, suggesting the animal was injured as a fawn and died before reaching maturity. Fusion of the metatarsal epiphyses begins at an age of 17 months in male and 20 months in female white-tailed deer (Purdue 1983), indicating that the Merrill Creek deer was less than two years old when it died. Nonetheless, it had lived long enough for the tarsus and metatarsus to fuse completely before its death.

**South Dakota mule deer (Odocoileus hemionus)—** The dessicated, nearly complete skeleton of a mule deer doe (Odocoileus hemionus) was found by one of us (D.C.P.) in Oacoma, Lyman County, South Dakota, in 2005. This specimen (NJSM-B-444) shows evidence of an injury to a distal portion of the right hind leg, which affected the distal right tibia, tarsus, and proximal metatarsus (Figure 3a) and resulted in osteomyelitis at the junction of the distal tibia and tarsal bones (the talocrural joint). Substantial exostosis resulted, with considerable development on the tibia, resorption of much of the calcaneum, and fusion of the central and distal tarsal bones. The astragalus (talus) was not found. The individual seems to have lived for some time after the injury, presumably lamed by its injury, but was at least moderately functional.

An additional observation in this skeleton is a thoracic vertebra in which an injury had fractured the spinous process (Figure 3b) While the complete vertebral column is not preserved, morphology of the transverse processes indicates that the fracture involved the 6th thoracic vertebra. The healing process did not restore the spinous process with a firm connection, but instead resulted in a pseudo-articulation (pseudarthrosis), essentially a hinge-like false joint that had some kinesis, primarily in the anterior to posterior direction. Pseudarthroses (false joints) develop when stresses on the broken bone result in significant motion across the break during the early soft (noncalcified) callus stage. Excessive motion will prevent calcification of the callus, and thereby prevent the bony union of the fracture. Instead, the central part of the soft tissue callus will develop into
Figure 3a. South Dakota mule deer tarsus (NJSM-B-444) in lateral view. Proximal is to the top, caudal to the left. White arrows indicate remnants of soft tissue still adhering to the bones. Note extensive development of periosteal proliferative bone on the distal tibia, tarsus, and proximal metatarsal cannon bone. The remaining tarsals are largely fused to the proximal end of the metatarsus, except for the calcanean tuber, which was present as a free element separate from the articular end of the calcaneum. No other tarsal bone is distinguishable in the fused mass that includes the proximal metatarsus. Scale is in centimeters.
a joint capsule in a manner that is analogous to joint formation in the embryo (Carter and Beaupré 2001). The epaxial muscles which insert on vertebral neural spines are active during locomotion (Ritter et al. 2001; Schilling and Carrier 2010), and these spines are therefore an excellent candidate for the development of false joints.

**Kansas pronghorn** (*Antilocapra americana*)—An adult male pronghorn (*Antilocapra americana*) was recovered by two of us (D.C.P. and B.S.G.) in Logan County, Kansas, shortly after its death, which we speculate may have been the result of internal injuries sustained when the animal was struck by a vehicle on a nearby road. When skeletonized, this individual (NJSM-B-443) was found to have suffered an injury to the left metatarsal cannon bone that had healed with considerable exostosis on the medial side just proximal to the distal articular condyles, but no fusion with other elements (Figure 4). No other bones of this animal show any signs of healed fractures.

The left metatarsal bone (Figure 4b, d) of this pronghorn is 6.5mm shorter than its normal right counterpart (Table 1; Figure 4a, c). The matter of greatest interest for this specimen is that the injured metatarsal bone was weight-compensated during healing. The weight (70.6 g) of the injured and healed left metatarsus is precisely matched by the weight of the corresponding right meta-

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*Figure 3b. South Dakota mule deer vertebral column. The black arrows point to a pseudarthrosis (false joint) in the neural spine near the center of the picture. Note the small pits flanking the black arrowhead on the distal fragment of the neural spine, just above the false joint. Cranial is to the left, dorsal to the top. Scale bar is in centimeters.*
tarsus. This would have preserved considerable cursorial ability in the individual; the species is noted for sustained running capabilities.

The pathology in this left metatarsus affects the distal end of the third metatarsal bone, close to the location of the epiphyseal plate. However, fusion of the diaphysis and epiphysis is so complete that no vestige of the growth plates can be seen on the normal right metatarsus. It is notable that the nutrient artery enters the caudal surface of the diaphysis just proximal to the metaphyseal region on the right metatarsal. The nutrient foramen is not visible in caudal view in the pathological left metatarsal because it lies deep to a thin shelf of bone. It can be seen when the left metatarsal is examined in oblique caudo-proximal view. It is possible that, before epiphyseal fusion, the animal suffered damage to the physis of its left metatarsal that resulted in shortening of the metatarsal length in the adult. Orientation of the metatarsophalangeal joint surface was not significantly disrupted by the pathology, and the proximal phalanges do not show any indication that they were affected. One way in which a young pronghorn might injure just one side of its metatarsus would be for its foot to be snagged while the animal was going under or through a barbed-wire fence. Pronghorns are known to suffer injuries from barbed-wire (Jones 2014; Jones et al 2015).

Figure 4. Normal right (a, c) and pathological left (b, d) metatarsals of the Kansas pronghorn (NJDM-B-443) in cranial view (a, b); and medial view (c, d). Note that the pathological left metatarsal is shorter than the normal right metatarsal. The overgrowth of bone on the medial side of the physeal region of the pathological left metatarsal cannon bone is indicated by the white arrows. Proximal is to the top for all images. The medial sides of the metatarsal bones face each other in the cranial view (a, b); caudal surfaces of the metatarsal bones face each other in the medial view (c, d). Scale bar is in centimeters.
Fracture healing has been extensively studied in humans and domestic animals. The biologic mechanisms of fracture healing are fairly well understood, as is the course of healing in humans or animals receiving medical care. Healing proceeds from an early inflammatory phase, through a phase of fracture repair (characterized by development of a connective tissue callus and its subsequent replacement by a bony callus), and finally to remodeling of the new bone to fine-tune the repair to the biomechanical needs of the patient (Marsh and Li 1999; Kierdorf et al. 2012). Development of a hematoma at the fracture site occurs within hours (McCall et al. 2003). In domestic cats, granulation tissue replaces the hematoma within one week, and calcification (formation of the bony callus) begins within 14 to 17 days. Domestic cats achieve clinical union (bridging of the fracture by bone) in three to four weeks, and the bone callus is completely formed within six to twelve weeks (McCall et al. 2003). Tibial fractures in some cattle, particularly in young animals, can sometimes be successfully treated by confining the animal to a stall (Martens et al. 1998), confirming that even relatively large animals can recover without surgical intervention as long as they have adequate access to food and water.

Animals can survive with little or no food for longer than it would take a broken long bone to begin bearing some weight. Domestic cats can survive between six and 23 weeks of near starvation before they are unable to maintain body temperature under cold stress. Humans have survived hunger strikes for periods as long as 79 days (McCall et al. 2003). Surviving a broken leg bone probably depends most on access to water, and on luck in avoiding predators.

Further case descriptions of healed fractures in modern wild animals are of obvious interest in the fields of medicine (human or veterinary) and wildlife management. They will also be of interest in the fields of archaeology and vertebrate paleontology, since pseudarthroses (Osborn and Wortman 1895) and healed fractures (McCall et al. 2003; Kierdorf et al. 2012) are preserved in some fossil vertebrates. The biomechanical effects of fractures have been studied in domestic artiodactyls (Seebeck et al. 2005) and healing has been monitored in captive wild cervids (Bailey et al. 1983). Experiments using sheep show that fractures which are less stabilized take longer to heal (Epari et al. 2006). It has also been shown experimentally that unstable fractures are more likely to become infected (Friedrich and Klaue 1977; Lindsey et al. 2010). However, little is known about how skeletal injuries affect the ability of wild artiodactyls to function in their natural habitats (Gilbert and Hill 1956). We advocate additional detailed analyses and descriptions of such specimens. An additional potential analysis method, described by Anne (2010), represents a contribution from excavation sciences with potential usefulness to medicine.

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LITERATURE CITED


STRATIGRAPHIC AND TAXONOMIC REVISION OF A NORTH AMERICAN FALSE SABER-TOOTHED CAT CUB

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ABSTRACT

Specimen F:AM 99259, a well-preserved skull with articulated dentaries representing the earliest ontogenetic stage of development yet observed for a North American nimravid, is occasionally mentioned in the scientific literature. Conflicting reports refer that specimen to either *Eusmilus* or *Nimravus*, with no evidence provided to support those referrals. Examination of specimen F:AM 99259 supports its referral to *Nimravus brachyops* based on the absence of a metaconid on the unerupted m1. The stratigraphic position of specimen F:AM 99259 was reported as the Chadron Formation of Niobrara County, Wyoming, which would represent the earliest North American occurrence of *Nimravus*. However, the geographic position is reported as the first draw east of Robertson Draw, which corresponds with the location of the Little Muddy Creek fossil locality. At least 182 specimens within the collections of the American Museum of Natural History were recovered from that locality, including specimens of *Palaeocastor*, *Diceratherium*, *Mesoreodon*, *Sespia*, and *Pseudolabis*. Additionally, matrix affixed to F:AM 99259 does not match the typically volcanic-rich, uranium-bearing sediments of the Chadron Formation; rather, those sediments are more consistent with the sandstones of the stratigraphically higher Gering Formation, which is reported at Little Muddy Creek. These two lines of evidence support an early to middle Arikareean “age” for F:AM 99259, well within the previously reported range of that taxon. Given the basal position of *N. brachyops* within Nimravidae, this specimen provides important insights into the early evolution of saber-toothed features within this clade.

Keywords

Arikareean, Chadron, Gering, *Eusmilus*, Monroe Creek, Nimravidae, *Nimravus*
INTRODUCTION

The Nimravidae comprise a well-studied family of feliform carnivores that existed from the late Eocene through the Oligocene, spanning a wide biogeographical range throughout Eurasia and North America. Despite the numerous specimens curated in museum collections, there is a distinct paucity of known material from specimens representing the earliest ontogenetic stages. Only a handful of very young individuals are described (Bryant 1988; Peigné and de Bonis 2003), making the discovery of new, immature specimens significant.

One of the youngest nimravid specimens yet discovered from North America is F:AM 99259. Previous studies referred that specimen to either *Eusmilus* (Holliday and Steppan 2004; Holliday 2010) or *Nimravus* (Peigné and de Bonis 2003), though no study provides character evidence for these referrals. All of those studies reported the provenance of F:AM 99259 as the Chadron Formation, but the significance of that proposed stratigraphic position was never discussed (Holiday 2010; Holiday and Steppan 2004; Peigné and de Bonis 2003). *Nimravus* is represented in the late Eocene of Eurasia with *Nimravus intermedius*, but the taxon does not appear in North America until the early Oligocene; *Nimravus brachyops* has its first appearance sometime during the Whitneyan North American Land Mammal Age (NALMA) (Prothero and Whittlesey 1998). Thus, the discovery of a specimen of *Nimravus* from the late Eocene of North America would be significant, making the North American and Eurasian first appearances of this taxon synchronous.

This study has two primary goals. The first is to clarify the taxonomic affinities of F:AM 99259. The second is to resolve the stratigraphic position and approximate age of F:AM 99259. The former goal was addressed via extensive examination of the specimen to identify diagnostic characters and comparison to the results of a recent taxonomic revision of the clade (i.e., Barrett 2015). The latter goal was approached in two ways. The lithology of the matrix preserved on the specimen was examined and compared to samples and published descriptions of sediments from the White River Group and the younger Arikaree Group. A biochronologic study was also conducted by compiling a list of taxa reported from the same geographic area as F:AM 99259 and comparing their known stratigraphic ranges to determine a set of NALMAs to which this specimen could possibly be referred. Answering these questions is key to clarifying the scientific importance of this specimen and its role in understanding nimravid ontogeny and the timing and pattern of biogeographic dispersal within the clade.

**Abbreviations**—BADL, Badlands National Park, South Dakota, U.S.A.; F:AM, Frick collection, Department of Vertebrate Paleontology, American Museum of Natural History, New York, U.S.A.; FSP, collections of palaeontology, Faculté des Sciences Fondamentales et Appliquées, Université de Poitiers, Poitiers, France; SDSM, South Dakota School of Mines and Technology Museum of Geology, South Dakota, U.S.A.

**Stratigraphic position of F:AM 99259**—The exact geographic location where F:AM 99259 was collected is unclear, but data recorded with the specimen indicate that it was collected in the general vicinity of the previously well-known and heavily collected Little Muddy Creek area in Niobrara County, Wyoming (Figure
Previous publications report that F:AM 99259 was collected from the Chadron Formation (Holiday 2010; Holiday and Steppan 2004; Peigné and de Bonis 2003). The matrix encasing F:AM 99259 consists of a brown, medium-grained sandstone, which is not consistent with the typical clays and sand channels of the Chadron Formation in the Great Plains region. White River Group sandstones are typically greenish in color. The lowest sandstones in the White River Badlands, situated above the Interior Paleosol, are the greenish-white sediments of the “blazing white” sandstone of the Ahearn Member of the Chadron Formation (Clark et al. 1967; Terry 1998). The remaining sandstones of the Chadron Formation are greenish-gray and are found in the type area of the “Titanotherium Sandstone” (Osborn 1929; Harksen and Macdonald 1969). However, the brown or brownish-gray sandstone preserved on F:AM 99259 is more consistent with the Gering, Monroe Creek, and Harrison formations (Schultz and Stout 1955; Swinehart et al. 1985). Schultz and Falkenbach (1968) provided a generalized overview of the stratigraphy at Little Muddy Creek, identifying the presence of the upper portion of the Gering Formation and the lower portion of the Monroe Creek Formation. The difficulty of differentiating these beds outside of a few localized sections resulted in the current designation of these formations in the northern Nebraska Panhandle and Wyoming as undifferentiated Arikaree Group.

(LaGarry 1998). Alternatively, the uppermost Brule Formation of northwestern Nebraska consists of pinkish-tan claystones and siltstones (LaGarry 1998). Given these differences, the sediment preserved on F:AM 99259 is consistent with referral to the Arikaree Group and not the White River Group.

Little Muddy Creek Local Fauna—The fauna recovered from the Little Muddy Creek area of Wyoming has been described in numerous studies, and portions of the fauna have been re-examined and synonymized over the years. For this study, a comprehensive faunal list was assembled for the Little Muddy Creek area, and the stratigraphic ranges of those taxa were compiled based on reports in the published literature in correlation with NALMA biochronologic divisions under the conventions of Woodburne (2004) and Janis et al. (2008). Those results are presented in Figures 2 and 3 and are summarized below.

The rodents of the Little Muddy Creek area are almost entirely Arikareean forms. Wahlert (1983) described the presence of the florentiamyids Sanctimus stouti, Sanctimus simonsi, Florentiamys kennethi (a synonym of S. stuartae; Korth 1992), Florentiamys kingi (a synonym of F. loomisi; Korth 1992), and Florentiamys kinseyi. Sanctimus stouti and S. simonsi are restricted to biochron Ar2, while S. stuartae and F. kinseyi are restricted to biochron Ar1 (Flynn et al. 2008). Xu (1996) also reported the presence of Capacikala parvus and Capacikala gradatus, both of which are known from the Arikareean.

The morphologic trends of oreodonts (Merycoidodontidae) have proven to be useful in understanding middle Cenozoic biochronology (Stevens and Stevens 1996, 2007). Though Schultz and Falkenbach (1954, 1968) described numerous merycoidodontids from the Little Muddy Creek area, many of those taxa were eventually restudied and reclassified (Lander 1998; Hoffman and Prothero 2004; Prothero and Sanchez 2008; Stevens and Stevens 1996, 2007). Most of the Little Muddy Creek oreodonts, which are largely represented by members of the Desmatochoerinae and Leptaucheniinae, are characteristically Arikareean taxa, including Mesoreodon minor, Desmatochoerus megalodon, Promerycochoerus superbis, Sespia nitida, and Sespia ultima. Leptauchenia decora, Leptauchenia major, and Leptauchenia lullianus are also present at Little Muddy Creek, but only L. lullianus has a strictly Arikareean record (Schultz and Falkenbach 1968; Prothero and Sanchez 2008).

The only carnivoramorphs previously described from Little Muddy Creek are canids. Wang’s (1994) study of the Hesperocyoninae included specimens of Ectopocynus antiquus, Ectopocynus intermedius, Enhydrocyon pahinsintewakpa, and Philotrox condoni from the area. Wang et al. (1999) reported the presence of the borophagines Archaeocyon leptodus, Phlaocyon minor, and Otarocyon cooki from the Little Muddy Creek area. Only E. antiquus and A. leptodus are also reported elsewhere from Whitneyan faunas, while the remaining taxa are restricted to the Arikareean (Figure 2). Specimen F:AM 99259 represents a new addition to the carnivoran component of the Little Muddy Creek local fauna.

Overall, the majority of the taxa reported from the Little Muddy Creek area are elsewhere reported only from early Arikareean faunas, although a handful of those taxa are also reported from the late Whitneyan (Figures 2 and 3). The only taxon reported from this area that has a reported distribution restricted to the Whitneyan is Merycoidodon major (Stevens and Stevens 2007). Assuming this
identification is correct, it suggests that some upper Brule Formation sediments may be exposed in the Little Muddy Creek area. Alternatively, if Chadron Formation sediments were exposed in that area, the presence of typical Chadronian-Orellan taxa would be expected from the collection area (e.g., Agnotocastor, Trigonias, Subhyracodon, Poebrotherium, Hesperocyon gregarius, Merycoidodon culbertsoni, etc.).

Given the evidence presented above, F:AM 99259 is likely part of an Arikareean age fauna. This conclusion is supported by prior reports that specimens collected in the Little Muddy Creek area were recovered from the Monroe Creek Formation (e.g., Schultz and Falkenbach 1968).

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**Figure 2. Little Muddy Creek local fauna, Part 1. Diagram displaying known biochronologic ranges of rodent and carnivore taxa previously described from the Little Muddy Creek site and the ranges of each known taxa (Bryant 1996; Flynn et al. 2008; Flynn and Jacobs 2008; Korth 1992; Martin 1998; Wahlert 1983; Wang 1994; Wang et al. 1999; Xu 1996). Gray area represents the biostratigraphic zones previously recognized in the area.**
SYSTEMATIC PALEONTOLOGY

Class MAMMALIA Linnaeus, 1785
Order CARNIVORA Bowdich, 1821
Suborder FELIFORMIA Kretzoi, 1945
Family NIMRAVIDAE Cope, 1880

*Nimravus* Cope 1879

**Type species**—*Nimravus brachyops* (Cope 1878)

**Other Included Species**—*Nimravus intermedius* (Filhol 1872)

**Diagnosis**—The following revised differential diagnosis is taken directly from Barrett (2015:116-117): “Sutural contact between the lacrimal and jugal; presence of lateral and medial fossae on the zygoma; broadly circular zygoma in dorsal view; presence of discrete petrobasilar and posterior lacerate foramina; postglenoid foramen present; nasals extend posterior to the maxillofrontal suture;
reduced mastoid with large plate-like paroccipital process; posterior lip of the
glenoid socket projects more ventrally than anterior lip; oblique angle between
the braincase and axial plane of the cranium; horizontally projecting postorbital
process of frontal; posteriorly orientated posterior border of coronoid process; no
genial flange, but the ventral rim of the chin is distinctly angulate; presence of
fossa on ventral face of chin; spatulated incisors, with accessory denticules espe-
cially on the lower incisors, I3 slightly caniniform and distinctly larger than the
other incisors; mesial-distal length of C1 less than that of P4; ratio of height of P3
to P4, 0.71 and greater; parastyle absent from P4; P4 protocone reduced, short,
crest-like; M1 transversely reduced, crest-like, with low cusps and near absent to
absent protocone; lower incisor arcade not or little curved, so as i1 is not visible
in lateral view; p3 height is as tall or slightly taller than p4; anterior cusp on p4
mesially/distally longer than the posterior cusp; p4 as tall as or taller than the
paraconid of m1; m1 metaconid absent; trigonid proportion of m1 is 77-87%;
serrations absent on adult minimally worn cheek teeth; ratio of tibia to femur
87% and higher; articulation between the calcaneum and navicular present.”

**Nimravus brachyops** (Cope 1878)

**Diagnosis**—The following differential diagnosis is taken directly from Barrett
(2015:119) “A nimravine of moderately large size with basilar length ranging
from 159 to 194 mm, mean of 177 mm. [n=9]; lambdoid crest angle ranging
from 133 to 146 degrees, mean of 138 degrees, [n=10]; serration density per
millimeter on upper canines ranging from 2.2 to 2.3, mean of 2.2, [n=4]; C1
compression ranging from 1.56 to 1.84, mean of 1.74, [n=11]; lacrimal process
absent; presence of alveolar torus variable; anterior P3 cusp absent; presence of
anterior p3 cusp variable.”

**Referred Specimen**—F:AM 99259: Complete skull and mandible (Figures 4
and 5).

**Locality and Horizon of Referred Specimen**—Recorded as: “1st DRAW E
OF ROBERTSON DRAW WYO.” The town name “LUSK” is also written on
the skull in two places, referring to the town of that name in Niobrara County,
Wyoming. Robertson Draw is located approximately 17.5 miles southwest of
Lusk, Wyoming, and 0.5 miles east of Robertson Draw is Little Muddy Creek,
which is inferred to be the collection area. The stratigraphic position and age
of the specimen is interpreted as: Undifferentiated Arikaree Group (Arikareean;
Ar1 or Ar2).

**Basis of Referral**—Examination of F:AM 99259 reveals the presence of a suite
of characters that support the referral of this specimen to *Nimravus brachyops*,
including the presence of spatulate incisors, absence of a metaconid on the exposed
adult m1, and the presence of a fossa on the ventrointernal face of the zygomatic
arch below the postorbital process.

**Comments**—Peigné and de Bonis (2003) described a juvenile skull and
jaws referred to the Hoplophoneini (FSP-ITD 342) from the Phosphorites du
Quercy, France. Specimen F:AM 99259 appears to share a similar ontogenetic
age with FSP-ITD 342, approximately 5-6 months of age (Peigné and de Bonis
2003). There are some clear contrasts between the two specimens that also distin-
guish F:AM 99259 from members of the Hoplophoneini, including a relatively uninflated infraorbital foramen, lack of a glenial phlange on the dentary, and the presence of a relatively large talonid on dp4. The relative size and morphology of the lower and upper canines are important characters for differentiating nimravids. In basal taxa, like *Nimravus*, the lower canines are substantially larger than the adjacent lower incisors. Taxa within the Hoplophonini and the infant specimen FSP-ITD 342 display lower canines that are roughly the same size and morphology as the adjacent lower incisors. Another trend in nimravid canine morphology is the increased serration density of the adult upper canines from relatively coarse serrations in shorter canines, as observed in *Nimravus*, to fine and condensed serrations in enlarged canines, as observed in the Hoplophoneini.

Figure 4. Skull of F:AM 99259 in A) dorsal, B) ventral, and C) right lateral views. Saggital crest (sc) and temporal crests (tc) are labeled. Scale bar = 5cm.

(Barrett 2015; Boyd and Welsh 2013). F:AM 99259 exhibits a coarse serration density within the parameters of *Nimravus* (average of 2.0 serrations per millimeter: Barrett 2015). Thus, the overall morphology of F:AM 99259 is consistent with a referral to *Nimravus brachyops*, and not to the hoplophonin taxon *Eusmilus* (contra Holliday and Steppan 2004; Holliday 2010).

**Preliminary Overview of Ontogenetic Changes in Nimravus brachyops**—A full description of the morphology of F:AM 99259 and a discussion of ontogenetic change within *Nimravus brachyops* will be provided elsewhere, but a few important insights can be made here. Bryant (1988) provided a detailed study of the tooth eruption sequence of *Barbourofelis* in comparison with members of the Nimravidae and Felidae. The nimravids included in that study were *Eusmilus*, *Hoplophoneus*, *Dinictis*, and a brief mention of canine replacement.

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**Figure 5. Skull of F:AM 99259 in A) left lateral view, with left dentary in B) labial, C) lingual, and D) occlusal view. Scale bar = 5cm.**

in *Nimravus* (Bryant 1988). Bryant (1998) was able to demonstrate that the adult canines were the last teeth to be replaced in *Barbouroufelis* and nimravids, as opposed to early canine replacement prior to the P3 and P4 in felids. This trend is also demonstrated by a specimen of *Eusmilus villebramarensis* (Peigné and Brunet 2001). Owing to the trend towards brachycephaly in more derived nimravids, compounded by the loss of anterior premolars in many derived taxa (e.g., *Hoplophoneus*), the timing of canine replacement in nimravids that retain the full premolar dentition was previously unclear. Most specimens of *Nimravus* possess a complete upper premolar count, but the presence of a P1 is variable within the taxon. This can also vary between the left and right sides as observed in SDSM348. F:AM 99259 and a handful of specimens from the collections at SDSM provide a thorough view into the dental ontogeny of that taxon, in order from youngest to oldest: F:AM 99259, SDSM 15012, BADL 52047 (= SDSM 12530), and SDSM 348. In those specimens, the upper premolars erupt/are replaced in sequential order from posterior to anterior, P4 to P1. P1 first erupts posterolingual to the canine, as observed in BADL 52047. During elongation of the muzzle, the P1 migrates posterolaterally, eventually being positioned posterior to the C as observed in SDSM 348. The adult upper canine is indeed the last tooth to erupt, following the full eruption of the upper premolars.

Also of note, the cranium of F:AM 99259 possesses laterally expanded or lyrate temporal crests that converge and join near the posterior end of the skull. During ontogeny, the temporal crests reduce anteromedially as the sagittal crest forms, relocating the temporal crest junction to the fronto-parietal suture, as observed in other adult nimravids.

CONCLUSIONS

Specimen F:AM 99259 represents the earliest ontogenetic stage of development yet reported for the nimravid taxon *Nimravus* based on the clear morphologic contrast of the canines and the dentary when compared to contemporaneous hoplophonins, confirming the interpretation provided by Peigné and de Bonis (2003). Matrix appended to the specimen best matches with Arikaree Group sandstones and sharply contrasts with White River Group sandstones. The faunal constituents in the Robertson Draw and Little Muddy Creek area are almost entirely representative of the Arikarean NALMA, which remains consistent with previous interpretations of the stratigraphy by Schultz and Falkenbach (1968).

The present study was focused on identifying the provenance and taxonomic affinities of F:AM 99259. Further research is underway on this and other specimens to describe in detail the series of ontogenetic changes that occur from infancy to adulthood in *Nimravus brachyops*, since no other juvenile or infant specimens are thoroughly described. Once that information is compiled, comparisons to known ontogenetic series for other nimravid taxa can be made and broad trends in the ontogenetic development of nimravids can be understood. These comparisons will also reveal any impact heterochrony had on the evolution of nimravids, particularly in the transition from the basally-placed scimitar-toothed forms to the derived dirk-toothed taxa.
LITERATURE CITED


REASONS ANGLERS DID NOT RESPOND TO AN INTERNET SURVEY AND EVALUATION OF DATA QUALITY

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ABSTRACT

Natural resource management agencies have traditionally used statewide mail surveys to gather information from anglers, but cost savings and faster returns occur using the internet. This study examined mail or internet fishery survey return rates and associated data by license type of South Dakota resident anglers. Junior anglers (ages 16-18; Junior Combination license) had the lowest internet and mail survey return rates (20% and 28%, respectively), followed by adult anglers (ages 19-64; Adult Fishing and Adult Combination licenses; 30% and 39%, respectively), and senior anglers (ages 65+; Senior Fishing and Senior Combination licenses; 42% and 66%, respectively). The three age groups were significantly different on three email use characteristics (shared email, frequency of use, and comfort level). The primary reason for not responding to the internet survey was not receiving or noticing the email request, and secondarily, being too busy to respond. Although having a relatively low response rate, data collected by the internet compared to follow-up mail surveys of internet non-respondents were similar.

Keywords

Angler surveys, human dimensions, internet surveys, nonresponse bias

INTRODUCTION

Natural resource management agencies often use surveys to collect stakeholder information. In particular, angler surveys have been used to measure participation in fishing (e.g., where, when, frequency, type), estimate catch and harvest, evaluate programs and regulations, estimate economic impact, measure satisfaction and benefits sought, generate user profiles, and collect opinions on various management issues (Brown 1991). Typically, statewide surveys have used the
mail and telephone to collect information from license holders. Using internet-based surveys results in cost savings by eliminating printing, postage, and stuffing envelopes and encoding data, in addition to faster response times, (Cook et al. 2000; Ward et al. 2012; Wright and Schwager 2008). However, concerns have been raised about natural resource management internet surveys due to poor data quality as a result of incomplete email address coverage and lower response rates (Couper et al. 1999; Duda and Nobile 2010; Fraze et al. 2003; Gigliotti and Dietsch 2014; Kaplowitz et al. 2004; Nulty 2008; Stern et al. 2014; Vaske et al. 2011).

Response rate has traditionally been one indicator of survey quality (Kaminska et al. 2010). In many cases, internet survey return rates have been substantially lower than comparable mail surveys (Couper et al. 1999; Fan and Yan 2010; Fraze et al. 2003; Resnick 2012; Shih and Fan 2009). Gigliotti (2011) reported a 44% email-invitation internet survey return rate by turkey hunters versus 75% for a mail survey. Kwak and Radler (2002) reported a lower response by university students to an internet survey (27%) than a corresponding mail survey (43%). Nulty (2008), summarizing eight studies, reported an average return rate of 33% for online surveys and 56% for paper-based surveys. Manfreda et al. (2008) summarized 45 studies and reported internet surveys yielded an 11% lower response rate than other survey methods. Low response rates raise concerns about the representativeness of results.

Response rates measure only the potential for nonresponse bias and may be a poor measure of survey data quality (Fisher 1996; Kaminska et al. 2010; Kreuter 2013; Peytchev 2013; Peytchev et al. 2009; Wagner 2012). If non-respondents respond similarly to survey respondents on the variables measured, effort taken to increase response rate uses resources that could be better used elsewhere (Becker and Illiff 1983). Agencies have the responsibility to use resources wisely and must consider both data quality and cost. If both mail and internet surveys can be shown to collect representative data, the internet may be the better choice.

The South Dakota Game, Fish and Parks (SDGFP) is considering a switch from a large-scale, statewide angler survey of licensed anglers performed every five years to conducting a shorter survey annually, if costs can be significantly reduced while still maintaining quality. The objectives of this study were to: 1) identify reasons why anglers did not respond to an email request to complete an internet survey about fishing during the previous year, and 2) evaluate the quality of data collected by an internet survey by measuring internet nonresponse bias using a mail survey. This paper focuses on the problem of low response rates to internet surveys compared to mail surveys. Additionally, the extent of incomplete email address coverage is discussed in perspective to overall survey design.

METHODS

Email coverage from 2010 through 2013 was obtained from the SDGFP for the five types of resident fishing licenses. The license types included three combination licenses that provide both fishing and small game hunting privileges [junior (ages 16-18), adult (ages 19-64) and senior (ages 65 and older)] and two
annual fishing licenses providing only fishing privileges [adult (ages 19-64) and senior (ages 65 and older)]. For this analysis, anglers with and without email were divided into groups. The internet survey represented only the anglers with email and this study evaluates only internet nonresponse bias (internet data quality in respect to incomplete email coverage is not included in this study).

Internet data were collected by sending personalized (first and last name) email invitations to all 2012 licensed resident anglers with an email address in the SDGFP database asking them to participate in an internet survey about their 2012 fishing activities in South Dakota. The email contained a link to an internet survey hosted by SurveyMonkey (www.SurveyMonkey.com). The initial email invitation was sent at the end of the 2012 fishing season (2013 January 1), with an email reminder seven days later. A final email reminder was sent after another seven days specifying the survey would close in a week (closed 2013 January 24). The email invitation stated that the survey should take only about 5 to 7 minutes if the recipient fished in South Dakota in 2012 or less than 1 minute if no fishing occurred.

Following the conclusion of the internet survey, we randomly selected 200 anglers from each of the five resident annual licenses who did not respond to the internet survey email invitation to receive a one-page mailed survey. The paper survey was mailed at the end of the third week of January, followed a week later by a postcard reminder, with a second mailing of the questionnaire occurring three weeks later.

**Mail Questionnaire**—The first question asked whether the respondent provided a home or work email address, or neither, when purchasing their 2012 fishing license. The neither option was intended to identify anglers in the email database who do not actually have an email address in the SDGFP database, which can happen if anglers have someone else buy their license online. The second question identified anglers who have a shared email address (e.g., with spouse) versus an exclusive address. This could affect internet response rates, especially when personalized email invitations are sent and opened by someone other than the intended recipient. The following two questions measured the frequency with which anglers access their email and their general comfort level with communicating via email. Next was a question asking whether they remembered receiving the email invitation to participate in the fishing survey, followed by a request to identify reasons for not responding to the internet survey from a list of possible reasons. The final four questions (days of fishing, satisfaction, importance of fishing, and sex) were included for comparing responses to the original internet survey responses.

**Analyses**—South Dakota’s five license types were grouped into three age groups for analyses: a) junior anglers (Junior Combination: ages 16–18); b) adult anglers (Adult Annual and Adult Combination: ages 19-64); and c) senior anglers (Senior Annual and Senior Combination: ages 65+). The email use variables for the three age groups were compared using a chi-square analysis and Cramer’s $V$ was used to measure effect size. To evaluate the quality of the internet data, the fishing variables (proportion not fishing, mean days of fishing, satisfaction, and
importance of fishing) collected by the mail survey of internet non-respondents were compared with those collected by the internet survey using analysis of variance (ANOVA) and 95% confidence intervals with $\eta$ for the effect size measure. A record-linking technique (Smith 2008) was used to compare the sex ratios of fishing license purchasers with sex ratios of the internet survey data for each age group using a chi-square analysis and $\phi$ for the effect size measure. Internet return rates were based on the actual number of emails sent (the number of email addresses in the database minus the number of email addresses that were previously opted-out or were invalid). Previously opted-out emails occur when someone has previously received an email invitation to participate in any survey hosted by SurveyMonkey and elected to opt-out of the survey. Invalid addresses are those not having the proper email address format. Internet and mail survey return rates were compared by age group and combined using a chi-square analysis with $\phi$ for the effect size measure.

RESULTS

Email coverage for South Dakota’s resident fishing licenses has increased 8% from 2010 through 2013 (48%, 52%, 52%, and 56%; respectively). Email coverage measured in 2013 varied among the five resident license types from 29% for the Senior Fishing license to 78% for the Adult Combination license (Table 1). Email coverage was higher for the combination licenses (fishing and hunting privileges) than the fishing-only licenses.

Internet and mail survey return rates increased with age; junior angler return rates were lowest (20% internet and 28% mail), adults were next (30% and 39%, respectively), and senior anglers were highest (42% and 66%, respectively) (Table 2). The mail survey of internet non-respondents achieved higher return rates than the internet survey for all three age groups: junior anglers 8% difference, adult anglers 9% difference, and senior anglers 24% difference.

The three age groups were statistically similar on two of the email-use characteristics: providing an email address and providing a home versus a work email address. Overall, 41% of the anglers said that they did not provide an email address when purchasing their 2012 fishing license, which can happen if someone else purchases the license online for them: 35% of junior, 36% of adult and 46% of senior anglers ($\chi^2 = 4.41, P = 0.110$, Cramer’s $V = 0.101$). Most anglers providing an email address said it was a “home” email address (96%): 100% of junior, 92% of adult and 98% of senior anglers ($\chi^2 = 5.70, P = 0.058$, Cramer’s $V = 0.150$).

Significant differences were found among age groups for percent sharing an email address, frequency of checking their email and comfort level with communicating via email. More senior anglers (68%) shared an email address than did junior (39%) and adult (37%) anglers ($\chi^2 = 23.86, P < 0.001$, Cramer’s $V = 0.302$). Junior anglers reported checking their email less than adults or senior anglers, although about 31% of the seniors and 15% of the adults infrequently (1–4 times per month) check their email (Table 3). Adult anglers were more comfortable communicating via email than junior and senior anglers (Table 4).
The Cramer’s V effect size statistic indicates a moderate association for the difference in percent sharing an email address and a weak association for the differences in frequency of checking email and comfort level with communicating via email (Rea & Parker 2005).

Overall, 59% of the anglers did not recall receiving the January 2013 email: 72% of the junior, 52% of the adult and 61% of the senior anglers ($\chi^2 = 4.90, P = 0.086, \text{Cramer’s V} = 0.137$). For the anglers who remember receiving the email request, “being too busy during the survey period” was the most often cited reason (43%) for not responding (Table 5). Junior (70%) and adult anglers (61%) were more likely to select being “too busy” as a reason for not completing the internet survey than senior anglers (14%) ($\chi^2 = 27.57, P < 0.001, \text{Cramer’s V} = 0.505$). The high value for Cramer’s V suggests a relatively strong association (Rea and Parker 2005). Seven of the eight respondents selecting the “not fishing in 2012” reason for not responding to the internet survey were senior anglers.

The internet survey and the mail survey of internet non-respondents collected similar responses for the percent of licensed anglers not fishing in 2012, mean days of fishing in 2012, satisfaction with the 2012 fishing experience, and anglers’ rating of the importance of fishing when analyzed by age group (junior, adult and senior anglers; $P > 0.05$) so the age groups were combined (Table 6). The only significant difference was internet respondents rated the importance of fishing slightly higher compared to the internet non-respondents contacted by mail, although the difference was negligible as indicted by the small eta effect size (Cohen 1988).

Females were underrepresented in the internet survey for adult anglers (14% internet vs. 19% license database) ($\chi^2 = 172.81, P < 0.001, \phi = 0.047$) and senior anglers (11% vs. 13%; respectively) ($\chi^2 = 5.91, P = 0.015, \phi = 0.026$) and over-represented in the internet survey for junior anglers (20% vs.16%; respectively) ($\chi^2 = 6.76, P = 0.009, \phi = -0.037$). The statistical significance is more attributable to the inherent sensitivity of the chi-square analysis to sample size rather than meaningful differences in sex ratios for the three age groups (as evidenced by negligible phi effect sizes).

**DISCUSSION**

**Email Coverage**—Coverage will be a potential problem with conducting email invitation internet surveys until an agency collects email addresses from all licensed anglers (Vaske 2008). However, the coverage issue may eventually become insignificant as more people provide the agency with an email address. About 80% of the adult population is estimated to use email by 2014 (96% of the adult internet users) (eMarketer 2013). Email coverage for South Dakota resident anglers has been slowly but steadily increasing over the past four years without any special effort by the SDGFP. Email coverage for senior licenses is likely to continue increasing simply due to adults with emails already in the database reaching age 65. Tsotsis (2011) reported a 28% increase in email use in 2010 among the 65 and older age group. However, we believe that an agency can take steps to augment this natural increase in coverage. Providing an email ad-
dress, which is optional, is the last piece of personal information collected when license purchasers complete their profile information. The only encouragement for providing an email address is the following statement; “To receive information from GF&P regarding your license information please provide a valid email address.”

Email Use Characteristics and Internet Response Rate—Similar to previous research (Couper et al. 1999; Fan and Yan 2010; Fraze at al. 2003; Resnick 2012; Shih and Fan 2009), our follow-up mail survey had a response rate higher than the internet survey. In this case, the mail survey sent to a sample of anglers who, for various reasons did not respond to the internet survey, had a higher response rate than the internet survey itself. The survey topics were somewhat different with the internet survey asking about their 2012 fishing and the mail survey asking why they did not respond to the internet survey and a few fishing questions. However, a related component of this project also found much higher response rates to the mail survey compared to the internet survey when an identical questionnaire was sent to a random sample of internet non-respondents (Henderson 2014).

Similar to Gigliotti and Dietsch (2014), this research found that response rate increased with age. Differences in email use characteristics may account for some of the age-related difference in internet response rate. Senior anglers had the highest internet survey response and the highest percent of shared email addresses. A shared email address may contribute to an increased response rate by increasing the probability that email invitations will be noticed, although the relationship may be spurious.

Response to a question about the frequency of email use suggests some non-response may be attributed to missing the invitation because of infrequent email use. Infrequent use may reflect individual preferences other than email for communicating. Although email is the most popular online activity (eMarketer 2013), email use by teens is declining (Palis 2012). Palis (2012) reported a 31% decline in email use by 12-17 year olds for 2011, with young people turning to texting and social networks (e.g., Facebook, LinkedIn, and Twitter) to communicate (Lee 2011; Tam 2012). Junior anglers had the lowest email use frequency which may, in part, account for the lower internet response rate observed with this age group.

Being “too busy” was most often chosen as the primary reason for nonresponse by junior and adult anglers who recalled receiving the email. Cranford et al. (2008) also found that “too busy” was the most common reason (46%) given by undergraduate college students for nonresponse to a web-based survey. Gigliotti and Dietsch (2014) suggested that higher survey response rates by seniors may be due to having more time to complete a survey. Nisbett and Wilson (1977) caution that people may be unaware of the cognitive processes leading to a decision not to participate in a survey; selecting easily accessible and simple responses to quickly complete the survey. In other words, being “too busy” may be a simple and convenient excuse masking underlying motivations for not participating in the survey. However, being “too busy,” as a reason for nonresponse, may be more common in internet surveys than mail surveys. Paper questionnaires are more flexible than internet surveys in when and where they can be completed. Nichols
reported that when offered a choice between responding to a survey by paper or via the internet, convenience was the most frequently cited reason by people selecting the paper option. Also, an email request to complete an online survey may be perceived as less important since it is less expensive than a mailed questionnaire, and subsequently, easier for people to reject under the excuse of being “too busy” (Nisbett and Wilson 1977). This difference impacts data quality from internet surveys only if anglers too busy to complete the internet survey differ on measured variables from anglers who complete a mail survey.

**Internet Data Quality**—Internet survey data that do not accurately measure the percent of active/inactive anglers can negatively impact the quality of internet survey data. Percent fishing affects the calculation of fishing effort, catch, harvest, and economic impact. The email invitation stated the survey should take about 5 to 7 minutes or only 1 minute if the person did not do any fishing in 2012. This was done to encourage licensed anglers who did not fish in 2012 to participate in the survey by reducing the perceived burden on this subset of anglers (Crawford et al. 2001). Only a small percentage of anglers listed their inactivity as a reason for not responding to the internet survey and both survey modes had statistically similar results for the percent fishing. However, “not fishing” may be an important reason why anglers do not complete angler surveys in general because they believe that their information is not needed.

Responses from the internet survey and the mail survey of internet non-respondents were also similar for mean days of fishing and satisfaction in 2012, and had only small differences in angler rating of the importance of fishing and sex bias by survey mode. Importance of fishing may be correlated with higher internet response rates. Interest in the survey topic (salience) has been shown to be strongly correlated with survey response (Groves et al. 2004; Sheehan and McMillan 1999). Although salience may be responsible for a slight increase in internet response compared to follow-up mail surveys, importance of fishing may be strongly related to survey response in general, regardless of survey mode (Heberlein and Baumgartner 1978). The sex bias in the internet data was small, but because exact sex ratios are known for license buyers, this variable can be weighted to adjust for sex related response differences (Huggins et al. 2002; Rogellberg and Stanton 2007; Vaske 2008).

Our results found slightly higher response rates by males for the adult and senior anglers compared to Smith (2008) who reported a higher response rate to an online survey by female faculty (36%) than male faculty (24%). Smith (2008) suggested gender differences in communication styles as the reason, based on the research findings of Jackson et al. (2001) showing higher email use by females was consistent with stronger interpersonal communication motives. Lower email use by males was consistent with their tendency to use the internet more for seeking information. Smith (2008) concluded that responding to an email invitation to take an internet survey was more a type of online information-exchange behavior than an information-seeking behavior, thus explaining their finding of a higher female response. However, our results suggest other factors (e.g., salience, level of interest in the survey topic) are involved in explaining sex-related differential internet survey response rates for anglers (Brown 1984; Sheehan 2001).
Although studies have found lower response rates for internet surveys than mail surveys (Hayslett and Wildemuth 2004; Knapp and Kirk 2003, Kypri et al. 2004; Yun and Trumbo 2000), Groves (2006, p. 670) states that there is “no simple relationship between nonresponse rates and nonresponse biases” and that “covariances between survey variables and response propensities are highly variable across items within a survey, survey conditions, and populations.” Identifying and correcting for nonresponse bias is a critical component of survey research (Barriball and While 1999; Fisher 1996; Vaske 2008). A number of researchers have concluded that it may be more appropriate to spend resources to identify and correct for nonresponse biases than to blindly work to increase response rates (Babbie 2004; Crompton and Tian-Cole 2001; Krosnick 1999). Even with response rates of 70% or more, nonresponse could strongly bias variable estimates (Brown and Wilkins 1978; Crompton and Tian-Cole 2001).

Cost savings is one main benefit for agencies selecting the internet versus mail to survey anglers. However, due to incomplete coverage and lower internet response rates, it has been suggested that some of the cost savings of the internet can still be obtained by utilizing the internet in a mixed-mode survey (Dillman 2007). However, our data suggest an internet/mail mixed-mode survey of anglers with email may not sufficiently address nonresponse bias, as a mail follow-up of internet non-respondents would still have an unacceptable (<80%; Office of Management and Budget 2006) response rate. We estimated an internet/mail mixed-mode survey would have received response rates of 42% for junior anglers, 57% for adult anglers and 80% for senior anglers (64% combined) for this survey. A better use of resources might be to conduct a smaller, but more intensive, representative sampling of non-respondents rather than conducting a follow-up mail survey (Crompton and Tian-Cole 2001; Groves 2006; Rogelberg and Stanton 2007).

**Increasing the Value of Internet Surveys**—Increasing email coverage offers benefits beyond having a cost effective way to conduct stakeholder surveys by providing an interactive information outlet to proactively interact with stakeholders during the management process. As more governmental agencies turn to the internet as the primary venue to disseminate information and provide transaction services, State natural resource agencies could consider requiring online license purchasers to provide a valid email address. All State natural resource agencies offer the opportunity to purchase a fishing license online, and for half of them, an email address is mandatory (Southwick Associates 2013).

Educating the public about the importance of the survey information and the potential cost savings of internet surveys may stimulate future participation in agency surveys. Tse (1998) stated that paperless surveys (internet) may be perceived as environmentally friendly, a fact that could be included in an educational message. Groves et al. (1992) reported that an appeal to the helping norm may significantly increase participation in a survey. Schaefer and Dillman (1998) reported that a prior email notification increased response rates. Fan and Yan (2010) provide advice for increasing internet response rates based on the four stages of the entire internet survey process: a) survey development, b) survey
delivery, c) survey completion, and d) survey return. We also suggest the courtesy of providing feedback from the survey results. Respondents donated their time to provide input and may appreciate receiving results in a short nontechnical format. For a mailed survey, this would be relatively expensive; however, costs are negligible for an email survey. This inexpensive type of feedback sent to both the respondents and non-respondents may increase participation in future surveys by demonstrating that the information is being used.

Conclusions—Email is one of the most prevalent communication tools used in business now and for the foreseeable future (eMarketer 2014; Fauscette 2012; Pogue 2015). Thus, email is likely to remain a valuable communication tool of government agencies and serve as an inexpensive avenue for providing and receiving information from stakeholders. Internet survey research presents some unique research opportunities, as well as some design and implementation challenges not found in mail surveys (Andrews et al. 2003; Archer 2008; Atif et al. 2012; Graefe et al. 2011; Huang 2006; Lesser et al. 2011; Manzo and Burke 2012; Rhodes et al. 2003; Sexton et al. 2011). Continued research is needed to use this tool more effectively and efficiently. For example, can offers of sending time sensitive fishing information increase email coverage, what is the most effective number of email reminders, how does survey length affect internet response rate and data quality, and do offers to provide survey results increase participation?

Note: Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

ACKNOWLEDGMENTS

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<table>
<thead>
<tr>
<th>Resident License Type</th>
<th>Number</th>
<th>Proportion of Resident Licenses</th>
<th>Number with Email</th>
<th>Percent Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult Fishing</td>
<td>65,115</td>
<td>0.47</td>
<td>29,326</td>
<td>45%</td>
</tr>
<tr>
<td>Senior Fishing</td>
<td>12,528</td>
<td>0.09</td>
<td>3,663</td>
<td>29%</td>
</tr>
<tr>
<td>Junior Combination</td>
<td>8,025</td>
<td>0.06</td>
<td>4,335</td>
<td>54%</td>
</tr>
<tr>
<td>Adult Combination</td>
<td>45,689</td>
<td>0.33</td>
<td>35,555</td>
<td>78%</td>
</tr>
<tr>
<td>Senior Combination</td>
<td>6,452</td>
<td>0.05</td>
<td>3,822</td>
<td>59%</td>
</tr>
</tbody>
</table>

**Table 1. Number and email coverage for the five types of South Dakota resident annual fishing licenses in 2013.**

Total  137,809  1.00  86,701  56%
Table 2. Return rates for the internet survey of anglers and the mail survey of non-respondents by age group.

<table>
<thead>
<tr>
<th>Angler Age-Group</th>
<th>Internet Survey</th>
<th>Mail Survey</th>
<th>( \chi^2 )</th>
<th>( p )</th>
<th>( \phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Number</td>
<td>Return Rate</td>
<td>Total Number</td>
<td>Return Rate</td>
<td></td>
</tr>
<tr>
<td>Junior</td>
<td>3,835</td>
<td>20%</td>
<td>196</td>
<td>28%</td>
<td>8.14</td>
</tr>
<tr>
<td>Adult</td>
<td>54,874</td>
<td>30%</td>
<td>375</td>
<td>39%</td>
<td>16.17</td>
</tr>
<tr>
<td>Senior</td>
<td>5,442</td>
<td>42%</td>
<td>387</td>
<td>66%</td>
<td>87.90</td>
</tr>
<tr>
<td>Combined</td>
<td>64,151</td>
<td>30%</td>
<td>958</td>
<td>48%</td>
<td>141.28</td>
</tr>
</tbody>
</table>

Table 3. Anglers’ monthly frequency of accessing their email in 2012 by age group: How many times per month do you access this email account?

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Sample Size</th>
<th>1 - 4</th>
<th>5 - 9</th>
<th>10 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior (16-18)</td>
<td>36</td>
<td>36%</td>
<td>14%</td>
<td>50%</td>
</tr>
<tr>
<td>Adult (19-64)</td>
<td>93</td>
<td>15%</td>
<td>13%</td>
<td>72%</td>
</tr>
<tr>
<td>Senior (65+)</td>
<td>118</td>
<td>31%</td>
<td>5%</td>
<td>64%</td>
</tr>
<tr>
<td>Combined</td>
<td>247</td>
<td>26%</td>
<td>9%</td>
<td>65%</td>
</tr>
</tbody>
</table>

\( \chi^2 = 13.39, \ p = 0.010, \) Cramer’s \( V = 0.165 \)

Table 4. Anglers’ reported comfort level with communicating via email in 2012 by age group: How comfortable are you communicating via email?

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Sample Size</th>
<th>Not Comfortable</th>
<th>Somewhat Comfortable</th>
<th>Very Comfortable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior (16-18)</td>
<td>35</td>
<td>17%</td>
<td>49%</td>
<td>34%</td>
</tr>
<tr>
<td>Adult (19-64)</td>
<td>97</td>
<td>17%</td>
<td>22%</td>
<td>62%</td>
</tr>
<tr>
<td>Senior (65+)</td>
<td>139</td>
<td>31%</td>
<td>30%</td>
<td>40%</td>
</tr>
<tr>
<td>Combined</td>
<td>271</td>
<td>24%</td>
<td>29%</td>
<td>47%</td>
</tr>
</tbody>
</table>

\( \chi^2 = 19.57, \ p < 0.001, \) Cramer’s \( V = 0.190 \)
Table 5. Reasons why anglers who recall getting an email request to participate in an internet survey did not complete the internet survey (multiple responses possible).

<table>
<thead>
<tr>
<th>Reasons for not responding to the internet survey…</th>
<th>Number</th>
<th>Percent of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was too busy during the survey period</td>
<td>42</td>
<td>43%</td>
</tr>
<tr>
<td>I chose to not complete this survey</td>
<td>16</td>
<td>17%</td>
</tr>
<tr>
<td>I deleted it thinking it was SPAM / did not trust the link</td>
<td>14</td>
<td>14%</td>
</tr>
<tr>
<td>I think I completed the on-line survey</td>
<td>11</td>
<td>11%</td>
</tr>
<tr>
<td>I do not complete internet surveys</td>
<td>10</td>
<td>10%</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
<td>9%</td>
</tr>
<tr>
<td>I did not fish in 2012</td>
<td>8</td>
<td>8%</td>
</tr>
<tr>
<td>The link did not work</td>
<td>6</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Total (Cases = 97)</strong></td>
<td><strong>116</strong></td>
<td><strong>120%</strong></td>
</tr>
</tbody>
</table>

Table 6. Proportion not fishing, means days of fishing, satisfaction with fishing experience in 2012, and anglers’ rating of the importance of fishing comparing anglers who responded to an internet survey with a sample of internet non-respondents contacted by mail.

<table>
<thead>
<tr>
<th>Parameter / Survey</th>
<th>Mean</th>
<th>95% C.I.</th>
<th>N</th>
<th>F</th>
<th>p</th>
<th>η</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion Not Fishing</td>
<td>0.42</td>
<td>0.517</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Respondents</td>
<td>0.10</td>
<td>±0.5</td>
<td>19,322</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Non-respondents</td>
<td>0.10</td>
<td>±2.9</td>
<td>444</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days Fished in 2012</td>
<td>1.40</td>
<td>0.237</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Respondents</td>
<td>18.5</td>
<td>±0.3</td>
<td>17,496</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Non-respondents</td>
<td>19.9</td>
<td>±2.9</td>
<td>398</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfaction</td>
<td>2.45</td>
<td>0.117</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Respondents</td>
<td>1.37</td>
<td>±0.02</td>
<td>16,148</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Non-respondents</td>
<td>1.25</td>
<td>±0.15</td>
<td>394</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Importance of Fishing</td>
<td>5.01</td>
<td>0.025</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Respondents</td>
<td>2.32</td>
<td>±0.02</td>
<td>17,311</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Non-respondents</td>
<td>2.19</td>
<td>±0.11</td>
<td>425</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Excludes anglers who did not fish in 2012
2 Satisfaction scale: -3 = Very Dissatisfied, -2 = Moderately Dissatisfied, -1 = Slightly Dissatisfied, 0 = Neither or No Opinion, 1 = Slightly Satisfied, 2 Moderately Satisfied, and 3 = Very Satisfied.
3 Importance scale: 0 = Not Important, 1 = Slightly Important, 2 = Moderately Important, 3 = Very Important, and 4 = Most Important Recreational Activity
ANGLER SATISFACTION IN SOUTH DAKOTA

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ABSTRACT

Many industries use satisfaction measures to evaluate performance. The South Dakota Department of Game, Fish and Parks identified satisfaction as one of their performance measures for evaluating fishing in South Dakota. In fisheries management, the perspectives’ of license buyers are valuable to determine if management activities are providing the benefits anticipated by biologists. Surveys of South Dakota anglers are conducted to better understand licensees in order to promote satisfying angling experiences. Internet surveys were distributed to all license buyers providing email addresses in 2011 and 2012. Angler satisfaction was analyzed by angler type (demographics and fishing characteristics) to further clarify performance measures. Most anglers (> 70%) were satisfied with their angling experiences. Nonresidents expressed higher levels of satisfaction with fishing in South Dakota in 2011 and 2012 than residents. Anglers’ rating of fishing quality was more strongly correlated with satisfaction than their reported number of fish harvested, which suggests that strategies to influence angler perceptions and expectations can also be employed to influence satisfaction (in addition to techniques influencing fish populations). This research further integrates sociological data into South Dakota fisheries management processes.

Keywords

Angler satisfaction, surveys, angler segmentation, fisheries management

INTRODUCTION

Satisfaction is considered indiscernible from customer service quality (Burns et al. 2003; Oliver 2010). Accordingly, entities in many industries use satisfaction measures to evaluate performance (Burns et al. 2003; Oliver 2010). Although successful fisheries management encompasses multiple objectives (habitat conservation, species preservation, etc.), state agencies are ultimately beholden to the licensees who finance their programs. In this manner, evaluating performance from the consumer perspective (i.e., angler) is essential (Gigliotti et al. 2008).
Their viewpoints are particularly critical considering fisheries managers may have misconceptions about angler preferences (Connelly et al. 2000). Satisfaction and other sociological measures provide means to determine if management activities are giving licensees the benefits anticipated by fisheries professionals (SDGFP 2014).

Satisfaction is considered the principle product of recreational angling (Graefe and Fedler 1986; Holland and Ditton 1992). Satisfaction (or dissatisfaction) is the difference between the outcomes an angler wants or thinks should be received (i.e., motivations) and the perceived fulfillment of those outcomes (Holland and Ditton 1992; Arlinghaus 2006). The subjective nature of attitude assessment presents challenges to satisfaction measurement and its potential utilization in fisheries management (Graefe and Fedler 1986; Arlinghaus 2006). Authors generally categorize the experiences sought by anglers into activity-specific and activity-general elements (Fisher 1997; Arlinghaus 2006). Activity-specific elements are characteristics unique to fishing, and include the species pursued, fish size, number of fish and opportunity for harvest (Fedler and Ditton 1994; Arlinghaus 2006). Activity-general elements are characteristics common to general outdoor recreation and include relaxation, escape and experiencing nature (Fedler and Ditton 1994; Arlinghaus 2006). The relative importance of these satisfaction determinants varies by angler population, individual angler and even between separate fishing trips (Graefe and Fedler 1986; Arlinghaus 2006). Research suggests most anglers rate activity-general motivations more important than activity-specific motivations (Fedler and Ditton 1994; Fisher 1997; Hutt and Jackson 2008). However, activity-specific motivations may become more important over longer periods; anglers not catching fish on a particular trip may be satisfied but would likely grow frustrated with successive trips of this nature (Hutt and Jackson 2008).

Past research has addressed the diverse nature of anglers and illustrated the misnomer of the average angler (Ditton et al. 1992; Holland and Ditton 1992; Gigliotti 1996). Segmenting licensees has value (Holland and Ditton 1992; Fisher 1997; Fedler and Ditton 2001) for determining changes in group satisfaction in response to management actions (sensu Martin and Pope 2011). There are many ways to group licensees; primary among these are attitudes toward regulations, catch preferences (size, number of fish and harvest choices) and participation choices (Fedler and Ditton 2001; Martin and Pope 2011). Considering South Dakota Game, Fish and Parks’ (SDGFP) angler survey, anglers can be segmented based on license type, residence, type of fishing (shore vs. boat), management region fished, importance of fishing, age and gender. Examining the determinants of satisfaction by the various possible angler segments can provide additional information for understanding and potentially influencing future angler satisfaction.

Research has enhanced our understanding of the complexity of angler satisfaction. Satisfaction-related surveys entail several considerations. One is temporal scale; several authors suggest annual measurement is the broadest yet still meaningful timeframe (Pollock et al. 1994, Arlinghaus 2006). Trip-specific measures are likely more variable than annual counterparts (Arlinghaus 2006). Pollock et al. (1994) summarized popular approaches to measuring satisfaction in recre-
ational fishing. Typically, the sums of scores to individual component questions are assumed to be related to the angler’s overall satisfaction (Graefe and Fedler 1986; Arlinghaus 2006). Unfortunately, no measurement standard has been established related to recreational fishing (Burns et al. 2003; Arlinghaus 2006).

Given that angler satisfaction is an important component of recreational fishing, providing satisfying angling opportunities is a primary objective of state agencies (Graefe and Fedler 1986; Holland and Ditton 1992; Radomski et al. 2001; SDGFP 2014). Some research has shown poor fishing quality is strongly related to dissatisfaction and a primary reason for why people stop angling (Sutton et al. 2009). As such, SDGFP has established angler satisfaction as a measure of agency performance (SDGFP 2014). The agency has conducted seven angler surveys since 1995 to collect critical information for managing fisheries (SDGFP 2014). However, infrequent surveys can only provide a snapshot of the constraints faced by anglers; the value of measuring satisfaction can be enhanced when it is consistently measured over time to analyze trends, which was SDGPF’s intention by selecting satisfaction as a performance measure.

The objective of this study was to further understanding of South Dakota angler satisfaction by evaluating its relationship to other survey measures, specifically: (1) correlations with fishing quality, harvest, effort, fishing methods (shore vs. boat), age and fishing importance; and (2) by angler groups determined by responses to questions addressing management regions fished, fishing methods used, gender and nonresidents’ future intention to fish South Dakota.

METHODS

Sampling and Questionnaire—All anglers providing email addresses were sent invitations to participate in the survey via an embedded link (to SurveyMonkey.com). Invitations were sent January 1 and 2 and those not responding to the email received two reminders encouraging participation, emailed approximately January 12 and 18, with the internet survey ultimately closing January 24 in both study years (2011 and 2012).

Surveys began with an introductory paragraph explaining the nature of the survey to encourage response. Questions were developed by SDGFP staff, and included standard questions from previous angler surveys to measure trends in attitudes, harvest and effort (Pollock et al. 1994; SDGFP 2014). Three separate attitudes were measured: (1) “How dissatisfied or satisfied were you with your total South Dakota fishing experience last year?” (2) “How would you rate the fishing in South Dakota last year in terms of numbers and size of fish caught?” and (3) “How important is fishing to you in relation to all your other types of recreation?”. These attitudes were scaled (Likert 1932) as follows: angler satisfaction (scale: -3 = very dissatisfied, -2 = moderately dissatisfied, -1 = slightly dissatisfied, 0 = neutral or no opinion, 1 = slightly satisfied, 2 = moderately satisfied and 3 = very satisfied), rating of fishing quality (scale: -2 = very poor, -1 = poor, 0 = fair, 1 = good, 2 = excellent and no opinion was coded as missing), and importance of recreational fishing (scale: 0 = not important, 1 = slightly important, 2 = moderately important, 3 = very important, 4 = most important and no opinion was coded as
missing). Anglers were asked to estimate their annual harvest of walleye and/or sauger, bass (largemouth and/or smallmouth), northern pike, trout (rainbow, brown, brook, lake, splake, tiger), yellow perch, catfish and/or bullhead, sunfish (bluegill, green, rock bass) and crappie (common carp and/or silver carp was added to the list in 2012). Total number of fish caught for each fish group was added to the 2012 survey. Annual catch and harvest data were used to produce daily catch and harvest rates for the fish listed. Resource use questions measured total days fishing (statewide and four management regions), specific types of fishing (i.e., boat, shore, ice and spear/bow) and nonresidents’ future intention to fish in South Dakota. Demographic variables (gender and age) were also measured.

**Analysis**—Licenses were grouped into resident annual licenses (Annual, Combination, Senior Combination, Junior Combination and Senior Annual), nonresident annual licenses (Annual and Family) and nonresident temporary licenses (3-Day and 1-Day) for evaluating relationships between ratings of angler satisfaction and other survey measures. Satisfaction analysis was performed using Pearson correlation (r) with rating of fishing quality, importance of recreational fishing, percent of time spent shore fishing and boat fishing, annual fish harvested for the listed fish, daily catch rate, daily harvest rate, annual days fished, and age by license group (each year and combined). The same set of variables was also used in a stepwise linear regression with satisfaction as the dependent variable. Pearson correlations were denoted as follows: weak ≥ 0.1, moderate ≥ 0.3 and strong ≥ 0.5 (Vaske 2008). One-way ANOVA was used to compare mean satisfaction for anglers fishing exclusively in a particular management region (Figure 1; Black Hills, West River, Missouri River and East River), and percent of time shore and boat fishing for the three license groups. One-way ANOVA was also used to compare mean satisfaction by nonresidents’ intention to fish in

![Figure 1. South Dakota fisheries management regions: A, Black Hills; B, West River; C, Missouri River; and D, East River](image-url)
South Dakota next year (no, unsure or yes) and mean satisfaction by gender. A chi-square test was used to compare importance of fishing by license type. Analysis was performed in SPSS 21 (IBM 2012). Eta (η) and Cramer’s V were used to measure effect size (Vaske 2008). Differences were assessed at $\alpha \leq 0.05$.

RESULTS

The three license groups varied in email coverage and response rates. Email coverage was about 52% for resident annual licenses (both years), 40% for nonresident annual licenses (both years), and 24% and 22% for nonresident temporary licenses (2011 and 2012, respectively). Internet response rates in successive years were 33% and 30% for resident annual licenses, 44% and 41% for nonresident annual licenses, and 37% and 36% for nonresident temporary licenses. Potential coverage and nonresponse biases were determined to be minimal (e.g., small differences in gender and age that did not significantly affect estimates of other variables measured by the internet survey) (Henderson 2014). The Internet surveys resulted in data from 17,262 and 19,322 resident annual anglers, 3,420 and 4,063 nonresident annual anglers, and 2,343 and 2,858 nonresident temporary anglers in 2011 and 2012, respectively.

Pearson correlations between satisfaction and other variables measured by the statewide angler survey were similar for the three license types across years so we combined the data to measure these relationships (Table 1). Specifically, satisfaction was significantly correlated with rating of fishing quality, importance of recreational fishing, percent of time either boat or shore fishing, fish harvested (and harvest rate), catch rate, days fished and age. Only anglers’ rating of the fishing quality was strongly correlated with satisfaction ($r = 0.67$) (Figure 2); all other significant variables were weakly correlated with angler satisfaction ($r \leq 0.20$).

![Figure 2](image-url)

Figure 2. Mean satisfaction of anglers fishing in South Dakota in 2011 and 2012 (resident and nonresident anglers combined) analyzed by anglers’ rating of fishing quality ($r = 0.67$). Note: 95% confidence intervals are mostly obscured by the squares marking the means for each rating response (ANOVA $F_{(4,3451)} = 7116.38, P < 0.001, \eta = 0.675$).
Table 1. Pearson correlation with angler satisfaction\(^1\) summarized for all 2011 and 2012 licenses.

<table>
<thead>
<tr>
<th>Rating of fishing(^2)</th>
<th>Importance of fishing(^3)</th>
<th>Shore fishing</th>
<th>Fish harvested</th>
<th>Boat fishing</th>
<th>Catch rate/day(^4)</th>
<th>Days of fishing(^3)</th>
<th>Harvest rate/day</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.67**</td>
<td>0.22**</td>
<td>-0.17**</td>
<td>0.16**</td>
<td>0.16**</td>
<td>0.15**</td>
<td>0.14**</td>
<td>0.12**</td>
<td>-0.02**</td>
</tr>
<tr>
<td>Rating of fishing(^2)</td>
<td>Importance of fishing(^3)</td>
<td>Shore fishing</td>
<td>Fish harvested</td>
<td>Boat fishing</td>
<td>Catch rate/day(^4)</td>
<td>Days of fishing(^3)</td>
<td>Harvest rate/day</td>
<td>Age</td>
</tr>
<tr>
<td>-0.20**</td>
<td>-0.19**</td>
<td>-0.88**</td>
<td>-0.18**</td>
<td>-0.18**</td>
<td>-0.04**</td>
<td>-0.20**</td>
<td>-0.11**</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Importance of fishing(^3)</td>
<td>Shore fishing</td>
<td>Fish harvested</td>
<td>Boat fishing</td>
<td>Catch rate/day</td>
<td>Days of fishing(^3)</td>
<td>Harvest rate/day</td>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>-0.14**</td>
<td>0.05**</td>
<td>0.36**</td>
<td>0.54**</td>
<td>0.45**</td>
<td>0.06**</td>
<td>0.06**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish harvested</td>
<td>0.15**</td>
<td>-0.01</td>
<td>0.13**</td>
<td>0.17**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boat fishing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catch rate/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days of fishing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvest rate/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{**}\)Correlation is significant at the 0.001 level (2-tailed).

\(^{1}\)Mean Satisfaction (7-point scale): -3 = Very Dissatisfied, -2 = Moderately Dissatisfied, -1 = Slightly Dissatisfied, 0 = Neutral or No Opinion, 1 = Slightly Satisfied, 2 = Moderately Satisfied, 3 = Very Satisfied.

\(^{2}\)Mean Rating of fishing quality (5-point scale): -2 = Very Poor, -1 = Poor, 0 = Fair, 1 = Good, 2 = Excellent, No Opinion = missing.

\(^{3}\)Mean Importance of recreational fishing (5-point scale): 0 = Not Important, 1 = Slightly Important, 2 = Moderately Important, 3 = Very Important, 4 = Most Important, No Opinion = missing.

\(^{4}\)Catch rate (fish caught per day) was only measured in the 2012 surveys.

\(^{5}\)Days fished not included in the analyses for the nonresident temporary license.
Although anglers’ “rating of fishing quality in terms of numbers and size of fish caught” explained about 44% ($r^2 = 0.44$) of the variance in angler satisfaction with their fishing experience, fishing variables like total recalled annual harvest, harvest per day or catch per day did not add any predictive value to a linear regression model for predicting angler satisfaction (Table 2). In addition, anglers rating of fishing quality had very low predictive ability in explaining total recalled annual harvest ($r^2 = 0.03$), harvest per day ($r^2 = 0.02$) and catch per day ($r^2 = 0.02$).

### Resident / Nonresident Comparisons related to Satisfaction—
Mean satisfaction was similar between 2011 and 2012 for the three angler groups (Table 3). Nonresident annual and nonresident temporary anglers expressed higher levels of satisfaction with fishing in 2011 and 2012 than resident counterparts (Table 3). Percent of resident anglers satisfied (slightly, moderately and very combined) in 2011 and 2012 was 70% and 72%, respectively compared to 83% and 81% for nonresident annual anglers and 73% and 83% for nonresident temporary anglers (Figure 3). Although significant, the difference in percent satisfied between resident and nonresident anglers was small as measured by Cramer’s $V$ in 2011 ($V = 0.052$) and 2012 ($V = 0.089$) (Figure 3). Additionally, both nonresident angler groups rated fishing quality in 2011 and 2012 higher than resident anglers (Table 4).

Nonresident annual anglers had a significantly higher percent of anglers rating fishing as their most important recreational activity (35%) compared to 15% of resident anglers ($P < 0.001$, $V = 0.247$) and 19% of nonresident temporary anglers ($P < 0.001$, $V = 0.073$) (Figure 4). Overall, importance of fishing had a weak correlation ($r = 0.195$) with satisfaction (Table 2).

Nonresidents spent a significantly higher percent of their time boat fishing in South Dakota in 2011 and 2012 (75% for nonresident annual anglers and 69% for nonresident temporary anglers) compared to resident annual anglers (52%).

### Table 2. Stepwise linear regression with satisfaction as the dependent variable using all nine variables from Table 1 as independent variables.

<table>
<thead>
<tr>
<th>Variables Added</th>
<th>$r$</th>
<th>$r^2$</th>
<th>$r^2$ Change</th>
<th>$F$ Change</th>
<th>Sig. $F$ Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating of fishing quality</td>
<td>0.666</td>
<td>0.444</td>
<td>0.444</td>
<td>17367.72</td>
<td>0.000</td>
</tr>
<tr>
<td>Importance of fishing</td>
<td>0.668</td>
<td>0.446</td>
<td>0.003</td>
<td>99.84</td>
<td>0.000</td>
</tr>
<tr>
<td>Shore fishing (% time)</td>
<td>0.669</td>
<td>0.448</td>
<td>0.001</td>
<td>54.78</td>
<td>0.000</td>
</tr>
<tr>
<td>Age</td>
<td>0.670</td>
<td>0.449</td>
<td>0.001</td>
<td>37.45</td>
<td>0.000</td>
</tr>
<tr>
<td>Catch rate (per day)</td>
<td>0.670</td>
<td>0.449</td>
<td>0.000</td>
<td>11.80</td>
<td>0.001</td>
</tr>
<tr>
<td>Day of fishing (per year)</td>
<td>0.670</td>
<td>0.449</td>
<td>0.000</td>
<td>5.46</td>
<td>0.019</td>
</tr>
</tbody>
</table>

1IBM SPSS Statistics, Version 22. Model: Stepwise Linear Regression (Probability of $F$ entry = 0.05 and removal = 0.10 with option: exclude cases pairwise).

2Variables excluded: fish harvested (total), boat fishing (% time), and harvest rate (per day).
Other noteworthy differences observed between the three license groups included: nonresident anglers (50% annual and 52% temporary) spending more time fishing in the Missouri River System compared to resident anglers (34%) (Table 4). Nonresidents reported overall higher satisfaction with their fishing compared to resident anglers and this was observed mainly in the Black Hills and East River management regions (Figure 5). Also, resident annual and nonresident annual male anglers were slightly more satisfied with their fishing in South Dakota compared to female counterparts; the eta values for these measurements indicates that the differences were very small ($\eta = 0.034$ and 0.036, respectively) (Table 5).

Table 3. Satisfaction statistics comparing resident annual, nonresident annual and nonresident temporary anglers fishing in South Dakota (2011 and 2012).

<table>
<thead>
<tr>
<th>Angler Type</th>
<th>Year</th>
<th>$\bar{x}$ Satisfaction</th>
<th>$s$</th>
<th>$n$</th>
<th>95% C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident Annual</td>
<td>2011</td>
<td>1.36</td>
<td>1.520</td>
<td>10,505</td>
<td>1.33 – 1.39</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>1.37</td>
<td>1.506</td>
<td>16,150</td>
<td>1.35 – 1.40</td>
</tr>
<tr>
<td>Nonresident Annual</td>
<td>2011</td>
<td>1.68</td>
<td>1.554</td>
<td>1,441</td>
<td>1.59 – 1.76</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>1.76</td>
<td>1.525</td>
<td>3,747</td>
<td>1.71 – 1.81</td>
</tr>
<tr>
<td>Nonresident Temporary</td>
<td>2011</td>
<td>1.60</td>
<td>1.558</td>
<td>849</td>
<td>1.50 – 1.71</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>1.69</td>
<td>1.591</td>
<td>2,553</td>
<td>1.63 – 1.75</td>
</tr>
</tbody>
</table>

$^1$Mean Satisfaction (7-point scale): -3 = Very Dissatisfied, -2 = Moderately Dissatisfied, -1 = Slightly Dissatisfied, 0 = Neutral or No Opinion, 1 = Slightly Satisfied, 2 = Moderately Satisfied, 3 = Very Satisfied.

Figure 3. Angler satisfaction (percent) comparing resident annual anglers with nonresident annual anglers in 2011 ($\chi^2 (2, 11946) = 56.57, P < 0.001, V = 0.069$) and 2012 ($\chi^2 (2, 19897) = 275.17, P < 0.001, V = 0.118$) and comparing resident annual anglers with nonresident temporary anglers in 2011 ($\chi^2 (2, 14686) = 92.12, P < 0.001, V = 0.079$) and 2012 ($\chi^2 (2, 20331) = 149.20, P < 0.001, V = 0.086$).
Future Fishing and Satisfaction—More nonresident annual anglers (90%) than nonresident temporary anglers (66%) reported that they planned to fish in South Dakota next year, with 8% and 27% unsure (respectively) and 2% and 7% (respectively) not planning to fish South Dakota next year ($\chi^2 (2, 9188) = 754.62, P < 0.001, V = 0.287$). However, the correlation of future fishing with satisfaction was similar for the two types of nonresident licenses (annual license: $r = 0.20, P < 0.001$; temporary license: $r = 0.18, P < 0.001$). Nonresident anglers (annual and temporary combined) planning to fish South Dakota next year were significantly more satisfied ($P < 0.001$) than anglers not planning on returning to fish in South Dakota next year (Figure 6).

![Figure 4](image-url)

Figure 4. Importance of fishing comparing resident annual anglers with nonresident annual anglers ($\chi^2 (4, 40053) = 2437.95, P < 0.001, V = 0.247$) and resident annual anglers with nonresident temporary anglers ($\chi^2 (4, 38566) = 206.27, P < 0.001, V = 0.073$).

Table 4. Anglers' mean rating of fishing quality comparing resident annual, nonresident annual and nonresident temporary anglers fishing in South Dakota (2011 and 2012).

<table>
<thead>
<tr>
<th>Angler Type</th>
<th>Year</th>
<th>$\bar{x}$ Rating$^1$</th>
<th>s</th>
<th>n</th>
<th>95% C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident Annual</td>
<td>2011</td>
<td>0.77</td>
<td>0.948</td>
<td>14,268</td>
<td>0.76 – 0.79</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.75</td>
<td>0.884</td>
<td>15,575</td>
<td>0.74 – 0.76</td>
</tr>
<tr>
<td>Nonresident Annual</td>
<td>2011</td>
<td>0.95</td>
<td>0.916</td>
<td>3,163</td>
<td>0.92 – 0.98</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.93</td>
<td>0.872</td>
<td>3,715</td>
<td>0.90 – 0.96</td>
</tr>
<tr>
<td>Nonresident Temporary</td>
<td>2011</td>
<td>0.85</td>
<td>1.027</td>
<td>2,088</td>
<td>0.81 – 0.90</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.83</td>
<td>0.971</td>
<td>2,487</td>
<td>0.79 – 0.87</td>
</tr>
</tbody>
</table>

$^1$Mean Rating of fishing quality (5-point scale): -2 = Very Poor, -1 = Poor, 0 = Fair, 1 = Good, 2 = Excellent, No Opinion = missing.
Figure 5. Mean satisfaction of resident and nonresident anglers fishing exclusively in the Black Hills (ANOVA $F_{(1,3578)} = 105.72, P < 0.001, \eta = 0.169$), West River region (ANOVA $F_{(1,1320)} = 2.19, P = 0.139, \eta = 0.041$), Missouri River system (ANOVA $F_{(1,8792)} = 26.25, P < 0.001, \eta = 0.055$) and East River region (ANOVA $F_{(1,12054)} = 184.43, P < 0.001, \eta = 0.123$) in 2011 and 2012.

Figure 6. Mean satisfaction of nonresident anglers (ANOVA $F_{(2,6534)} = 111.01, P < 0.001, \eta = 0.181$) in South Dakota in 2011 and 2012 analyzed by their response to the question asking if they planned to fish South Dakota next year with 95% confidence intervals (the 95% confidence intervals are smaller than the triangles marking the means for the “unsure” and “yes” responses).
Table 5. Percent of fishing time spent in each of the major fish management regions of South Dakota in 2011 and 2012 comparing resident annual anglers, nonresident annual anglers and nonresident temporary anglers.

<table>
<thead>
<tr>
<th>Regions</th>
<th>Resident Annual Anglers</th>
<th>Nonresident Annual Anglers</th>
<th>Nonresident Temporary Anglers</th>
<th>ANOVA F</th>
<th>P</th>
<th>Eta (η)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Hills</td>
<td>13%</td>
<td>9%</td>
<td>15%</td>
<td>69.89</td>
<td>&lt; 0.001</td>
<td>0.056</td>
</tr>
<tr>
<td>West River</td>
<td>8%</td>
<td>4%</td>
<td>3%</td>
<td>158.02</td>
<td>&lt; 0.001</td>
<td>0.084</td>
</tr>
<tr>
<td>Missouri River System</td>
<td>34%</td>
<td>50%</td>
<td>52%</td>
<td>706.28</td>
<td>&lt; 0.001</td>
<td>0.176</td>
</tr>
<tr>
<td>East River</td>
<td>45%</td>
<td>37%</td>
<td>30%</td>
<td>298.49</td>
<td>&lt; 0.001</td>
<td>0.115</td>
</tr>
<tr>
<td>Number</td>
<td>32,433</td>
<td>7,201</td>
<td>4,786</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Mean satisfaction of anglers fishing in South Dakota (2011 and 2012) analyzed by gender and by angler license type.

<table>
<thead>
<tr>
<th>Angler license type</th>
<th>x Satisfaction1 (95% C.I.)</th>
<th>Number</th>
<th>ANOVA F</th>
<th>P</th>
<th>Eta (η)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>Resident Annual</td>
<td>1.39</td>
<td>1.24</td>
<td>22,978</td>
<td>3,352</td>
<td>29.80</td>
</tr>
<tr>
<td></td>
<td>(1.37 – 1.41)</td>
<td>(1.18 – 1.29)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonresident Annual</td>
<td>1.75</td>
<td>1.53</td>
<td>4,797</td>
<td>333</td>
<td>6.81</td>
</tr>
<tr>
<td></td>
<td>(1.71 – 1.80)</td>
<td>(1.36 – 1.70)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonresident Temporary</td>
<td>1.67</td>
<td>1.62</td>
<td>3,086</td>
<td>269</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>(1.62 – 1.73)</td>
<td>(1.41 – 1.82)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Mean Satisfaction (7-point scale): -3 = Very Dissatisfied, -2 = Moderately Dissatisfied, -1 = Slightly Dissatisfied, 0 = Neutral or No Opinion, 1 = Slightly Satisfied, 2 = Moderately Satisfied, 3 = Very Satisfied.
DISCUSSION

Angler satisfaction is a critical performance measure for effective fisheries management (Driver 1985; McCormick and Porter 2014). While there is no measurement standard for angler satisfaction in recreational fishing (Burns et al. 2003; Arlinghaus 2006), SDGFP has used a standardized measure of satisfaction since the 1990s. South Dakota Game, Fish and Parks established satisfaction as one of their performance measures as listed in their Statewide Strategic Plan (SDGFP 2014, pp. 59):

*Over a 5-year period, have an average of 70% of anglers surveyed during the annual statewide angler survey indicate satisfaction with their fishing during the past year.*

The performance measure of 70% satisfied is based on a summary statistic for both resident and nonresident anglers, while this research measured satisfaction based on three angler groups (resident annual, nonresident annual and nonresident temporary). Angler satisfaction for all three groups met or exceeded agency objectives in 2011 and 2012.

South Dakota Game, Fish and Parks’ statewide angler survey provides estimates of participation (total days fished and days fished by region and license type), type of fishing (shore, boat, ice and fly), harvest of nine types of fish, rating of fishing quality, importance of fishing, angler demographics (gender and age) and satisfaction. This monitoring is an excellent tool for identifying potential challenges to providing recreational fishing services (as determined by the measurement of participants’ overall satisfaction). A drop in satisfaction would indicate that something is negatively impacting anglers’ enjoyment of the fishing experience, which may warrant further inspection. Unfortunately, the variables collected by the monitoring survey do not provide an understanding of angler satisfaction applicable to some type of management action. The only measured variable predictive of satisfaction was anglers’ evaluation of the quality of fishing, but no variable effectively measured anglers’ evaluation of fishing quality and thus no clear management action. A drop in angler satisfaction can initiate a more detailed study of the reasons for low angler satisfaction. Also, some of the variables measured by the statewide angler survey may help focus the study to a particular component of fishing. For example, was the drop in satisfaction due mainly to a particular type of fishing, location, or experienced by a specific license type?

The high satisfaction correlations observed with anglers’ rating of fishing quality suggests that catching numbers of appropriate-sized fish is an important component of angler satisfaction. In this study fishing quality was the best predictor of satisfaction (Table 2) and it could very well be the most important factor affecting satisfaction, although the number of evaluation variables in the agency’s monitoring survey is not exhaustive. Success-related factors have been reported as antecedents to angler satisfaction in several studies (Hicks et al. 1983; Graefe and Fedler 1986; McMichael and Kaya 1991; Spencer 1993; Hunt et al. 2012; McCormick and Porter 2014), while others have reported non-success factors were stronger predictors of satisfaction (Hampton and Lackey 1976; Spencer and Spangler 1992; Arlinghaus 2006; Vaske and Roemer 2013). Satisfaction is too complex of a construct to be reduced to an either-or conclusion of which is
more important: success-related factors or non-success factors. The correlation between satisfaction and anglers’ rating of the fishing quality in South Dakota can explain about 44% of the variance in satisfaction, which leaves the probability that much of the unexplained variance in satisfaction is from unmeasured, non-success factors (Arlinghaus 2006).

While the high correlation between satisfaction and rating of fishing quality indicates that success-related factors are important, this information does not lead to a management solution. Other success-related, antecedent variables (e.g., total annual harvest, harvest rate per day, or catch rate per day) were not correlated with rating of fishing quality. In other words, the survey does not identify what variables affect anglers’ rating of the fishing quality. Thus, the angler survey is useful for identifying when and where there may be a need for a management action to improve angler satisfaction, but further study will be necessary to identify any appropriate actions that may be needed.

Because satisfaction is one of the agency’s performance measures, it is critical to understand the theoretical underpinnings of satisfaction and the factors associated with providing satisfying angling experiences (McCormick and Porter 2014). Holland and Ditton (1992) reported that motivations and satisfactions are interrelated and that both vary between angler groups. Anglers have both catch and non-catch motivations and related satisfactions (Holland and Ditton 1992). Satisfaction measurements summarize both catch related (i.e., species pursued, fish size, number of fish and harvest opportunities) and non-catch related components of the fishing experience (i.e., relaxation, reflection, sport, thrill, socializing, exploration and enjoying nature; Holland and Ditton (1992).

Expectancy theory may provide a useful model for guiding further inquiry into angler satisfaction (Manning 1999). The satisfaction construct is hypothesized to be determined by differences between expectations and actual outcomes achieved (Schreyer and Roggenbuck 1978). For example, what information or factors do anglers use to form an opinion about fishing quality and how does that relate to their expectations for future experiences? Such an approach will require incorporating a segmentation model recognizing the diversity of anglers (Gigliotti 1996). Different types of anglers will have different expectations. Arlinghaus (2006) segmented anglers by their catch orientation into three groups (low, medium and high catch orientation) and reported high catch-oriented anglers being significantly less satisfied with the previous angling season than were anglers with a low catch-orientation. Similar to our study, Arlinghaus (2006) reported that satisfaction was not related to catch or harvest rates and that all three catch orientation groups had similar catch and harvest rates, suggesting that “catch expectation was the primary driver of satisfaction.” The fact that perceptions of fishing quality are more relevant to satisfaction than the recalled numbers of fish caught is valuable because it suggests that strategies designed to influence angler perceptions (i.e., expectations) can also be employed to improve satisfaction rather than simply focusing on managing fish populations to influence satisfaction (Petering et al. 1995; Hutt and Jackson 2008).

South Dakota Game, Fish and Parks is entrusted with enhancing recreational opportunities and protecting South Dakota’s natural resources (SDGFP 2014). Success in this endeavor would be impossible without the funding provided by
anglers, and satisfaction is a critical performance measure for monitoring to ensure the agency is providing enjoyable recreational opportunities (Driver 1985; Radomski 2001; McCormick and Porter 2014). This research provides valuable information about satisfaction as it relates to other survey measures, including angler demographics, types of angling, and regions fished in SDGFP’s angler survey program. Additionally, this study contributes to other research suggesting that efforts to influence angler expectations may improve angler satisfaction (Spencer and Spangler 1992, Arlinghaus 2006; Hutt and Jackson 2008). The SDGFP statewide angler survey’s utility may be improved by including a catch-orientation or similar segmentation model coupled with a more detailed study of angler expectations.

**Note**—The use of trade names or products does not constitute endorsement by the U.S. Government.

**ACKNOWLEDGEMENTS**

We thank the Chipps lab, B. D. S. Graeb, K. N. Bertrand and M. A. Kaemingk for thoughtful comments on the article. Funding for this research was provided by Federal Aid in Sport Fish Restoration funds (Project F-15-R, Study 1523) administered by South Dakota Department of Game, Fish and Parks, and South Dakota State University, and by the U.S. Geological Survey, S.D. Cooperative Fish and Wildlife Research Unit.

**LITERATURE CITED**


ABSTRACT

This study assessed the differences in the behavioral reactions of rainbow trout (Oncorhynchus mykiss) reared in tanks with or without overhead cover. Fish were reared for eight weeks in tanks either completely uncovered, or with either 33% or 66% overhead cover, prior to behavioral observation. In the initial experiment, a hand-waving stimulus applied over the tank for approximately five seconds resulted in a significantly different behavioral response between the fish in the uncovered and partially-covered tanks. The fish in the uncovered tanks randomly scattered, while the fish in the tanks with 66% overhead cover displayed retreating behavior from open to covered areas of the tanks. Fish in tanks with 33% cover responded by a mix of random scattering and retreating behavior. In a subsequent experiment, three fish per tank from the first experiment were removed from their original tanks and placed into tanks with a different cover treatment. After two hours, a hand-waving stimulus was applied. In this experiment, fish reared without cover maintained the same random scattering behavioral response to a hand-waving stimulus exhibited in the first experiment, even if overhead cover was available as a retreating location. Fish reared using either of the overhead cover treatments in the first experiment continued to respond to the stimulus by retreating, even if the amount of overhead cover was changed from 33% to 66% or vice-versa. This study may have implications regarding the use of tank covers during hatchery rearing to improve post-stocking survival.

Keywords

rainbow trout, Oncorhynchus mykiss, overhead cover, hatchery rearing, behavior

INTRODUCTION

Fish are typically placed in uncovered tanks during hatchery rearing to allow easy access for observation and periodic cleaning (Reisenbichler and Rubin 1999). Overhead cover is essential for juvenile salmonids in natural habitats (Swales et al. 1986; Smith and Griffith 1994; Keith et al. 1998). In a hatchery setting, the growth and feeding efficiency of rainbow trout (Oncorhynchus mykiss) and brown trout (Salmo trutta) was increased by partially covering circular rear-
ing tanks (Barnes and Durben 2003; Barnes et al. 2005). Devore and White (1978), and Hartzler (1983) suggested that partial cover accommodates the innate behavioral adaptations developed by trout in natural situations to respond to startled or antipredator stimuli. In the wild, trout spend a considerable amount of time under cover (Hartman 1963; O’Hara 1986) and are especially prone to use covered areas as refuge sites when disturbed (Bachman 1984). Because refuge sites are not usually available during hatchery rearing, trout would not be able to learn this behavioral response, which could potentially affect post-stocking survival.

The behavior of rainbow trout in response to a stimulus during hatchery rearing has not been reported, nor has rainbow trout behavior under different amounts of overhead cover (tank coverage). Behavioral responses to novel amounts of cover have also not been reported. Thus, the objectives of this study were to examine the behavior of rainbow trout during hatchery rearing in tanks with varying degrees of overhead cover, and to determine the response of trout reared under a set cover regime to a novel cover treatment.

METHODS

All experimentation occurred at McNenny State Fish Hatchery, Spearfish, South Dakota, USA, using well water at 11 °C (total hardness at CaCO₃, 360 mg/L; alkalinity as CaCO₃, 210 mg/L; pH 7.6; total dissolved solids, 390 mg/L). At initial feeding, twelve 100-L tanks each received 375 rainbow trout fry. Four tanks were uncovered, four tanks had overhead coverage of approximately 33% of the tank surface, and the remaining four tanks had overhead coverage of approximately 66%. The covers were constructed from 6.35 mm corrugated black plastic sheeting and sat on the lip of each tank, approximately 15 cm from the water surface. The fish were fed a commercial trout diet (Skretting, Tooele, Utah, USA) at a hatchery constant of 5.60 (Buterbaugh and Willoughby 1967), with feed weighed daily to the nearest 0.1 g and dispensed via automatic feeders (Sweeney Enterprises, Inc., Boerne, Texas, USA) hourly from 08:00 to 16:00. Tanks were cleaned twice a week, but otherwise left undisturbed except for daily feeding. The fish were reared in these tanks for a total of eight weeks, reaching a mean (± S.D.) length of 40.4 ± 2.4 mm and mean weight of 0.72 ± 0.13 g, before behavioral data were collected in two experiments.

**Experiment 1.** An individual stood above one of the tanks for 30 seconds to allow the fish to acclimate to their presence. After 30 seconds, a digital image of the tank was recorded to capture the location of the fish before a stimulus was applied. After taking the digital image, the individual applied a stimulus (vigorous hand-waving across the top of the tank for five seconds), and recorded another digital image immediately after the stimulus ceased. One set of images was taken for each tank, with replication provided by the four tanks per treatment. The digital images were then transferred onto a computer where a numbered grid was superimposed over the tank surface, and fish location was quantified by grid location (Figures 1a, 1b, 1c). Grid location data were analyzed using one way analysis of variance and Tukey’s mean comparison procedure with significance set
at $\alpha = 0.05$. In addition to the grid data, observational data were also recorded using the ethogram in Table 1.

**Experiment 2.** After experiment 1 was completed, three fish per tank from the first experiment were removed from their original tanks and placed into tanks with all three of the different cover treatments (uncovered, 33% cover, 66% cover). After two hours, a hand-waving stimulus was applied. Only visual observations of behavior were recorded; digital images were not taken. The visual observations were categorized by using the same ethogram as the first experiment. One observation was recorded for each tank, with replication provided by the four tanks per treatment.

![Uncovered tank](image1_a.png)

![33% covered](image1_b.png)

![66% covered](image1_c.png)

**Figure 1.** View of uncovered, 33% covered, and 66% covered tanks with the numeric grid superimposed.

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Reaction</td>
<td>No influence or difference in the behavior</td>
</tr>
<tr>
<td>Random Scatter</td>
<td>Swimming to no particular area</td>
</tr>
<tr>
<td>Retreat</td>
<td>Swimming to a particular area</td>
</tr>
</tbody>
</table>

**Table 1.** Ethogram used to describe the behavioral reaction to a stimulus of rainbow trout reared in tanks with varying amounts of overhead cover.
RESULTS

**Experiment 1.** Observationally, the fish from the tanks with overhead cover reacted very differently to the handwaving stimulus in comparison to fish in the uncovered tanks. While all of the fish were randomly scattered before the stimulus, the fish in the partially-covered tanks exhibited clear retreat behavior after the stimulus was applied (Table 2). Significant differences in the number of fish per tank grid after the stimulus were detected among the overhead cover treatments (Table 3). Significantly fewer fish were observed in the uncovered parts of the tank in those tanks with 66% cover compared to both the uncovered and 33% covered tanks. A mean of only 33 fish, out of the 375 fish in each tank, were observed in the open areas of the 66% covered tanks, while in the same

<table>
<thead>
<tr>
<th>Overhead cover</th>
<th>Pre-stimulus Behavior</th>
<th>Post-stimulus Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (uncovered)</td>
<td>Random Scatter</td>
<td>Random Scatter</td>
</tr>
<tr>
<td>33%</td>
<td>Random Scatter</td>
<td>Retreat</td>
</tr>
<tr>
<td>66%</td>
<td>Random Scatter</td>
<td>Retreat</td>
</tr>
</tbody>
</table>

**Table 2. Behavioral responses to a hand-waving stimulus of rainbow trout reared in tanks with varying amounts of overhead cover.**

**Table 3. Mean (+ SE) number of rainbow trout observed in defined tank grid locations. Means across a row with different letters are significantly different (P < 0.05). Grid sections where fish could not be counted because the grid was covered are indicated in the table by covered.**

<table>
<thead>
<tr>
<th>Grid</th>
<th>Time</th>
<th>None</th>
<th>33%</th>
<th>66%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pre-stimulus</td>
<td>0.00 + 0.00 z</td>
<td>0.00 + 0.00 z</td>
<td>0.00 + 0.00 z</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>3.75 + 1.25 z</td>
<td>0.00 + 0.00 y</td>
<td>0.00 + 0.00 y</td>
</tr>
<tr>
<td>2</td>
<td>Pre-stimulus</td>
<td>0.00 + 0.00 z</td>
<td>5.00 + 0.00 z</td>
<td>0.00 + 0.00 z</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>3.75 + 1.25 z</td>
<td>2.50 + 1.44 z</td>
<td>0.00 + 0.00 y</td>
</tr>
<tr>
<td>3</td>
<td>Pre-stimulus</td>
<td>0.00 + 0.00 z</td>
<td>covered</td>
<td>covered</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>5.00 + 0.00</td>
<td>covered</td>
<td>covered</td>
</tr>
<tr>
<td>4</td>
<td>Pre-stimulus</td>
<td>15.00 + 5.00 z</td>
<td>3.75 + 2.39 z</td>
<td>7.00 + 1.77 z</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>55.00 + 15.00 z</td>
<td>3.75 + 2.39 y</td>
<td>4.25 + 0.75 y</td>
</tr>
<tr>
<td>5</td>
<td>Pre-stimulus</td>
<td>137.50 + 12.50 z</td>
<td>100.00 + 28.86 z</td>
<td>17.50 + 2.50 z</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>100.00 + 0.00 z</td>
<td>75.00 + 14.43 z</td>
<td>4.00 + 1.00 y</td>
</tr>
<tr>
<td>6</td>
<td>Pre-stimulus</td>
<td>50.00 + 33.41 z</td>
<td>covered</td>
<td>covered</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>42.50 + 19.73</td>
<td>covered</td>
<td>covered</td>
</tr>
<tr>
<td>7</td>
<td>Pre-stimulus</td>
<td>28.75 + 9.21 z</td>
<td>12.50 + 4.78 z</td>
<td>covered</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>27.50 + 10.30 z</td>
<td>12.50 + 4.79 z</td>
<td>covered</td>
</tr>
<tr>
<td>8</td>
<td>Pre-stimulus</td>
<td>25.00 + 5.00 z</td>
<td>60.00 + 23.45 z</td>
<td>covered</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>10.00 + 0.00 z</td>
<td>58.75 + 24.35 z</td>
<td>covered</td>
</tr>
<tr>
<td>9</td>
<td>Pre-stimulus</td>
<td>12.50 + 2.50 z</td>
<td>covered</td>
<td>covered</td>
</tr>
<tr>
<td></td>
<td>Post-stimulus</td>
<td>12.50 + 2.50</td>
<td>covered</td>
<td>covered</td>
</tr>
</tbody>
</table>
grid locations, 82 fish were observed in the 33% covered tanks and 163 in the uncovered tanks.

**Experiment 2.** The behavioral response to a stimulus was influenced by the amount of overhead cover experienced during prior rearing (Table 4). When fish previously reared under either of the overhead cover regimes were placed in open (uncovered) tanks and a stimulus was applied, random scatter behavior was observed, similar to the response of fish reared previously in open tanks. When fish previously reared under either of the covered treatments were placed again in tanks with either 33% or 66% overhead cover and received a hand-waving stimulus, retreating behavior to under the covered areas of the tanks was observed. However, when fish reared in uncovered tanks were placed in tanks with either 33% or 66% overhead cover, they reacted to the stimulus by randomly scattering; their behavior was the same as if there was no overhead cover available.

**Table 4. Behavioral response to a hand-waving stimulus of three rainbow trout originally reared in tanks that were uncovered, or had either 33% or 66% overhead cover and subsequently placed in different tanks that were either uncovered, or had either 33% or 66% overhead cover.**

<table>
<thead>
<tr>
<th>Original Rearing</th>
<th>Overhead Cover</th>
<th>None</th>
<th>33%</th>
<th>66%</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Random Scatter</td>
<td>Random Scatter</td>
<td>Random Scatter</td>
<td>Random Scatter</td>
</tr>
<tr>
<td>33%</td>
<td>Random Scatter</td>
<td>Retreat</td>
<td>Retreat</td>
<td>Retreat</td>
</tr>
<tr>
<td>66%</td>
<td>Random Scatter</td>
<td>Retreat</td>
<td>Retreat</td>
<td>Retreat</td>
</tr>
</tbody>
</table>

**DISCUSSION**

These results indicate that rainbow trout reared in tanks with overhead covers behave differently than those reared in uncovered tanks. These results are similar to the observations made by Devore and White (1978) and Hartzler (1983) who indicated that partial cover accommodates the innate behavioral adaptations developed in natural situations to respond to startle or antipredator stimuli. Our results support the conclusions of Bachman (1984), Hartman (1963), and O’Hara (1986) that trout spend a considerable amount of time under cover and seek refuge under overhead cover when they are disturbed. Similarly, Barnes et al. (2005) noted that when partial tank covers were available during hatchery rearing, brown trout concentrated under the cover and remained relatively motionless. It is possible that the use of tank covers could be simulating a nocturnal strategy described by Meyer and Gregory (2000) with larger salmonids in streams. However, nocturnalism is typically associated with colder water temperatures during the winter (Griffith and Smith 1993; Contor and Griffith 1995; Meyer and Gregory 2000) while the trout in this study were maintained at a constant 11 °C.

There are implications to hatchery rearing practices and post-stocking survival of hatchery-reared fish from this study. The benefits of overhead cover on the
hatchery rearing performance of juvenile salmonids have been described previously (Barnes and Durben 2003; Barnes et al. 2005), although results may be specific to unique strains or species (Pickering et al. 1987). More importantly, the lack of response to overhead cover of the trout reared in uncovered hatchery tanks may indicate an inability to adjust quickly to novel habitats after stocking. This in turn may make the stocked fish more vulnerable to both conspecific aggression and predation (Hossain et al. 1998). The inability of hatchery-reared fish to learn other adaptive behaviors for survival in the wild after stocking is well-documented (Shumway 1999; Huntingford 2004). In addition, using overhead cover during hatchery rearing has been shown to increase the likelihood of the use of overhead cover after stocking in salmonids (Roberts et al. 2011; Näslund et al. 2013), which may increase post-stocking survival (Johnsson et al. 2014). It would be beneficial for future studies to examine if the use of overhead cover during hatchery rearing has any impacts on the growth or survival of rainbow trout after stocking.

Based on the results of this study, the use of overhead cover during the hatchery rearing of rainbow trout is recommended, particularly if the trout are to be released into the wild for recreational use or for conservation.

LITERATURE CITED


RE-ESTABLISHMENT OF FINESCALE DACE
(PHOXINUS NEOGAEUS) IN MUD LAKE,
LAWRENCE COUNTY, SOUTH DAKOTA

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ABSTRACT

Finescale dace (Phoxinus neogaeus) were historically numerous in the Black Hills of South Dakota, but the population has decreased substantially over the past 125 years. By 2003, the only finescale dace populations in South Dakota occurred in Cox Lake and Crow Creek. In 2004, 30 adult dace were moved from Cox Lake to Mud Lake in Lawrence County in an attempt to establish another self-sustaining population. Mark-recapture population estimates in 2014 indicated 7,022 adult finescale dace in Mud Lake, with 95% confidence limits of 5,152 and 9,407 fish. The successful establishment of the Mud Lake population indicates the feasibility of transplantation to conserve this state-endangered species. New sites for additional populations should be considered due to the successful re-introduction of the finescale dace in Mud Lake.

Keywords
finescale dace, Black Hills, endangered, rotenone

INTRODUCTION

Finescale dace (Phoxinus neogaeus) are small (< 127 mm) members of the Cyprinidae family, widely distributed in Canada and the northern United States (Isaak et al. 2003). The population in South Dakota is isolated, likely as a result of historical glaciation (Bailey and Allum 1962). Finescale dace prefer cool water, occupy habitats associated with spring seeps and headwater areas (Stasiak 1973), and eat a variety of zooplankton, aquatic insects, and detritus (Litvak and Hansell 1990). They typically are found with other Cyprinid species (Bailey and Allum 1962; Scott and Crossman 1973; Baxter and Stone 1995).

Finescale dace in South Dakota were first noted by Evermann and Cox (1896) with the populations restricted to the northern Black Hills (Evermann and Cox 1896; Bailey and Allum 1962). By 1998, finescale dace were only found in two locations in South Dakota, both in Lawrence County, Cox Lake and a small
sinkhole pond adjacent to Crow Creek (Olson 1998). Based on these data, the State of South Dakota classified this species as state endangered (SDGFP 2015). It is also considered a sensitive species by the United States Forest Service within the Black Hills National Forest (USFS 2015).

The reason for the decline of finescale dace in South Dakota is unknown. However, Stasiak and Cunningham (2006) suggest that human demand on water resources, the loss or decline in suitable habitat, and the introduction of non-native species as possible causes. In particular, the presence of non-native fish species, such as predacious brown trout (*Salmo trutta*), may be impacting finescale dace either through competition or predation (Isaak et al. 2003).

We investigated sites for potential introduction to protect and possibly increase the population of finescale dace in South Dakota. Mud Lake was chosen based on several factors including suitable habitat, safe and feasible removal of existing fish populations, low probability of illegal introductions of other fish species, and complete ownership by the State of South Dakota. Mud Lake is a small, shallow lake that receives groundwater inflows from the Madison Aquifer. Bailey and Allum (1962) had previously documented finescale dace in Mud Lake, but the original population was likely extirpated by the introduction of green sunfish (*Lepomis cyanellus*) (Isaak et al. 2003). In 2004, resident green sunfish were eradicated from Mud Lake and 30 finescale dace were relocated from Cox Lake.

Since the re-introduction of finescale dace into Mud Lake, little has been done to see if the relocation effort was successful in re-establishing a viable dace population. Casual sampling efforts in 2010 and in 2013 yielded only a few individuals, so the extent of the reestablishment was unknown (South Dakota Department of Game, Fish and Parks unpublished data). The current study had two primary objectives: 1) to determine if Mud Lake contained a viable, reproducing population of finescale dace, and 2) to estimate the size of the Mud Lake finescale dace population.

**METHODS**

**Study Area**—Mud Lake, located on the McNenny State Game Production Area in Lawrence County, is a shallow (< 0.61 m deep) 1.6 ha pond with a marl bottom and an abundance of *Chara* sp. It is among the very few natural lakes found in western South Dakota (Shearer and Erickson 2005). Mud Lake has no watershed, but contains clear, cool water from an underground aquifer (Carter et al. 2002). The underlying gypsum lenses of the Spearfish Formation in the northern Black Hills are easily dissolved by ground water, resulting in sinkhole-formed lakes such as Cox and Mud (Naus et al. 2001). In 2004, thirty finescale dace were captured in minnow traps from Cox Lake and transported and stocked into Mud Lake.

**Capture and Marking**—Mud Lake was sampled in the summer of 2014 to determine the status of the finescale dace population. On July 16, 2014, four vinyl-dipped mesh minnow traps, 42 cm long with a 2.54 cm opening, were baited with wheat bread and placed into the lake. The traps were set for two
hours. Any adult dace in the trap were counted and then sedated in a bath containing 2% tricaine methanesulfonate (MS-222) and marked by removal of the left pectoral fin. After recovery in fresh water, the recently fin-clipped fish were released back into the lake.

A second sampling event occurred one week later on July 23, 2014. The traps were set in the same locations. The number of unmarked and marked fish (absent left pectoral fin) was recorded. On each sampling day, young-of-the-year dace were observed, but were too small for capture by the minnow traps. Only a single marking event for population estimation was used because of the exclusive range and relatively small numbers of finescale dace in South Dakota.

A population size estimate was obtained from the Lincoln-Peterson mark and recapture method (Petersen 1896; Lincoln 1930) using the following formula:

\[
\frac{M \times C}{R} = N
\]

Confidence limits (95%) were determined using the Poisson frequency distribution (for \( R \)) and the formula from Seber (1982):

\[
\frac{(M + 1)(C + 1)}{(R + 1)} - 1 = N
\]

Mortality was assumed to be the same between the marked fish and the unmarked fish. Immigration and emigration was assumed to be negligible because Mud Lake has only one small outlet and no inlet except through the underground aquifer.

RESULTS

On the first sampling date, 525 finescale dace were captured. During the second sampling event, 535 individuals were captured, of which 40 were previously marked, resulting in a Mud Lake finescale dace population estimate of 7,022. Confidence limits were 5,151 and 9,408.

DISCUSSION

Minnow traps were very successful at collecting finescale dace at Mud Lake and have also been used in other locations to sample populations of finescale dace (Stasiak 1973; He and Lodge 1990) and other fish species (Tonn and Magnuson 1982; Bryant 2000). The dace in Mud Lake were relatively easy to capture when traps were baited with wheat bread and only required two hours of fishing to be effective. We used minnow traps similar to previous sampling efforts in 2010 and 2013; however, in our efforts we checked the traps after a two-hour period. Other fish species have been observed to leave minnow traps within 1 h (Johnson et al. 2005). We believed that the finescale dace would not be able to
leave the traps after this short time period. In the earlier efforts, traps were left overnight before checking. It is highly probable that after the bread is eaten or dissolved, the dace are able to escape the trap. Anecdotal information from 2010 and 2013 sampling showed the presence of only a few individuals.

The successful establishment of the Mud Lake finescale dace population shows the feasibility of transplantation to conserve this state-endangered species. With another self-sustaining population, the chance of an isolated event leading to the extirpation of finescale dace within South Dakota is greatly reduced. However, the relatively close proximity of both Mud and Cox Lakes, which are in the same Game Production Area necessitates the establishment of additional dace populations either proximate to this Game Production Area or in other distant waters. Future sites to consider might be ponds created by beaver dams (Bailey and Allum 1962; Stasiak 1978; Baxter and Stone 1995) and other small waters either devoid of any predatory fish species or with characteristics that make removal of resident species relatively easy and inexpensive. Of primary concern would be the possible introductions of predatory fish, particularly those of the Centrarchidae family, which have been shown to have severe impacts on finescale dace populations (Litvak and Hansell 1990; Stasiak and Cunningham 2006). It may also be important to consider the proximity of woody vegetation and other bird perch sites during pond selection for possible dace transplantation. Belted kingfisher (Megaceryle alcyon) have been observed to eat as many as six dace in a 10-minute period (Stasiak 1973).

The success of this project may be a model for subsequent conservation efforts of other fish species. For relict species, whose survival is dependent on refugia (Sedell et al. 1990; Dugan and Davis 1993; Reeves et al. 1998), transplantation into novel waters may be a viable conservation option. Lake chub (Couesius plumbeus) are native to the Black Hills, but may be experiencing population declines (Isaak et al. 2003). If suitable areas can be identified and renovated, new lake chub populations might be established via transplantation. This would provide protection against further decreases in the number of fish or the number of self-sustaining populations of the lake chub.

LITERATURE CITED


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CLASSIFICATION AND MONITORING PLAINS COTTONWOOD ECOLOGICAL TYPE IN THE NORTHERN GREAT PLAINS

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ABSTRACT

A multivariate statistical model was developed for the plains cottonwood (Populus deltoides) ecological type to classify seral stages and to monitor succession based on three key variables. Four ecological seral stages representing early to late succession were identified quantitatively with a classification accuracy of 95%. All seral stages were significantly different (P < 0.001). Information required to predict seral stages within 0.2 acre or 0.08 ha macroplots by the model includes DBH of plains cottonwood trees >1 inch, stem number <1 inch and tree number. These are the only measurements required for seral stage classification and monitoring. Resource managers will be able to use this model to evaluate management actions by monitoring changes within and among seral stages. This model is simple to use, reliable, repeatable, accurate, and cost effective to meet resource management objectives and monitoring plans.

Keywords

Woodlands, succession, seral stages, ecological type, riparian, monitoring

INTRODUCTION

Increasing demands for intensive management and mitigation of public lands require improved and efficient methodologies to counter the effects of disruptions by the natural environment on our renewable biological resources. Baseline studies of grassland and wooded vegetation types, and associated wildlife habitats are important in that they provide the basis for needed mitigation actions, restoration, and management. Long-term studies on the Missouri River riparian system have shown considerable changes since 1892 to recent times (Rumble et al. 1998; Johnson et al. 2012; Dixon et al. 2012). Recent years have seen declines in age and structural diversity of cottonwood stands to old decadent stands from limited regeneration along the river system. This is the result, in part, of large dams in place on the Missouri River (Johnson et al. 2012; Dixon et al. 2012). Declines of cottonwoods are related to limited water flows and minimum or restricted scouring needed to create new sandbars for regeneration of trees. However, for the plains cottonwood (Populus deltoides) ecological type (Girard et al.
along the Missouri River and associated tributaries, there is a lack of quantitative tools to classify and document seral stages based on succession and to monitor the changes. The plains cottonwood is the dominant tree with understory species of narrowleaf willow (*Salix exigua*), western snow-berry (*Symphoricarpos occidentalis*), and peachleaf willow (*Salix amygdaloides*). Additional information for vegetative characteristics on the plains cottonwood ecological type are presented by Girard et al. (1989), Thilenius et al (1995) and Rumble and Gobeille (2004).

The plains cottonwood ecological type and associated seral stages are highly important to wildlife. The importance of the cottonwood type is disproportionate to the total land area occupied. Loss of seral stages (and associated age and structural diversity) needed to maintain the diversity of wildlife and plants within the cottonwood type is a key concern because some wildlife species require specific seral stages for maintaining their populations (Steenhof et al. 1980; Rumble and Gobeille 2001; Rumble and Gobeille 2004). Seral stage classification of plains cottonwood woodlands, especially in key areas, can provide an accurate assessment of tree and habitat conditions within a limited period as related to wildlife species (Uresk, 1990; Uresk et al. 2010). Once procedures for seral classification and monitoring are developed, resource managers can apply the results in the decision-making processes to enhance management and restoration of the plains cottonwood type.

The ecological status of the plains cottonwood type has undergone many changes over time following human induced and natural disturbances (Carter, et al. 2012; Dixon et al. 2012). However, little work has been done to describe relationships between disturbance processes and associated seral stages or to identify and quantify key disturbance transition indicators between seral stages or successional communities. Qualitative state and transition models have received much attention in recent years (Briske et al. 2005) and generally provide a framework to understand natural and human induced disturbances. Nevertheless, these models are conceptual and qualitative, based on expert opinion and personal judgments (Twidwell et al. 2013). State and transitional models attempt to describe community phases and are equivalent to seral or successional stages (USDA-NRCS 2013). State and transitional models (conceptual) can be quantified using multivariate statistical models we have developed based on field data and plant succession as an approach for predicting an ecological process of vegetation change with discrete categories (Uresk 1990; Uresk et al. 2012; Uresk et al. 2013; Uresk and Mergen 2014). This multivariate model approach can be applied and incorporated into the ecological site descriptions for state and transition models (Bestelmeyer et al. 2010; USDA-NRCS 2013). The method and approach described in this paper and previous publications provide a tool for using empirical data to identify vegetation indicators for seral stages and community phase descriptions and transitions.

The objectives of this study were to develop a quantitative multivariate model and tool for identification and classification of seral stages for the plains cottonwood type and to provide a sampling and monitoring protocol for the plains cottonwood type.
STUDY AREA

This study was conducted along Lake Sharpe and Oahe Reservoir, including the river tributaries located in the approximate geographic center of the Dakotas. The project extended from Big Bend Dam at Fort Thompson, South Dakota, to Bismarck, North Dakota. The shoreline is bordered by rugged bluffs, which smooth out into gentle and rolling hills upstream. Tree growth is sparse and tends to occur mostly on tributary ravines except where bottomland riparian forests occur in North Dakota and major stream drainages (Cheyenne, Moreau, Grand, Cannonball Rivers). Major stream drainages may be dominated by shrubs or, in more mesic situations, trees. Common shrubs include silver buffalogrberry (*Shepherdia argentea*), western snowberry chokecherry (*Prunus virginiana*), Saskatoon serviceberry (*Amelanchier alnifolia*) and skunkbush sumac (*Rhus trilobata*). Trees include plains cottonwood, and willows (*Salix* spp.). Willow trees are common codominants on floodplains of lower order drainages. Other trees include green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), boxelder (*Acer negundo*), hackberry (*Celtis occidentalis*), and bur oak (*Quercus macrocarpa*). Rocky Mountain juniper (*Juniperus scopulorum*) is found on shallow soils on steep north facing slopes along drainages leading to the major rivers (Severson 1981; Barker and Whitman 1988). Plant nomenclature followed USDA-NRCS (2015).

The climate of the northern Great Plains is semi-arid continental and characterized by wide daily and seasonal fluctuations in temperature and by erratic precipitation within the study area. May and June are the wettest months and 75% of the annual precipitation falls from April through September. Locally severe thunderstorms are common in summer. Mean annual precipitation at Bismarck, ND, is 16.4 in (417 mm) with an average maximum temperature of 52.7 F (11.5 C) and minimum temperature of 29.8 F (-1.2 C). Mean annual precipitation at Pierre, SD, is 17.7 in (450 mm); annual maximum and minimum temperatures are 59.2 F (15.1 C) and 35.2 F (1.8 C), respectively. At Chamberlain, SD, mean annual precipitation is 23.6 in (599 mm) with average maximum and minimum temperatures of 59.5 F (15.3 C) and 34.8 (1.6 C), correspondingly (HPRCC, 2015).

METHODS

The data collection and analyses followed procedures described by Uresk (1990) with additions to the experimental design to account for tree measurements in this section. A preliminary survey of the study area was undertaken to assess the range of variability within the plains cottonwood ecological type. Study sites were selected so the full range of variability based on plant succession (early to late) was sampled within this type.

Data were collected on 71 macroplots (sites). Each macroplot was randomly selected within one of three perceived seral stages, early, mid, and late (Cochran 1977; Thompson et al. 1998; Levy and Lemeshow 1999). First, an area was located within the perceived seral stage for site location. Once the area was
located, a random direction and a random number of paces were established, prior to macroplot location for transects. Within each perceived seral stage, macroplots 65.6 ft X 131.2 ft (20 m X 40 m) were established. Two adjacent plots were established for cottonwood stands in narrow riparian systems to stay within the riparian zone, each 32.8 ft X 131.2 ft (10 m X 40 m). The two plots were combined and analyzed as one site. Diameter at breast height (DBH) was measured in inches on all trees that had a DBH greater than 1 in (2.54 cm) within the macroplot. These data were converted to total basal area (ft²/acre; 1 ft²/acre = 0.23 m²/ha) as a new variable for analyses. Plains cottonwood stems <1 in (2.54 cm) were counted within the macroplot. However, plots established in early succession with many stems < 1-inch, required sub-sampling to count the number of stems. All stems were counted along two parallel, 32.8 yds (30 meter) belt transects, 1.1 yds (1 meter) wide. Subsample measurements collected within the 71.8 yd² (60 m²) subplot were corrected to the 65.6 ft. x 132.2 ft. (20 x 40 meter) plot 956.8 yd² (800 m²) for analyses.

Two parallel 32.8 yards (30m) transects were established 22 yards (20 m) apart within the macroplot. Canopy cover (six classes) of plant species was estimated within 7.9 in X 19.7 in (20 cm X 50 cm) frames (Daubenmire 1959). These quadrats were located at 3.3 foot (1m) intervals along each of the two transect for 60 microplots. All microplot data were averaged by transect. The two transect means were then averaged for each macrosite to generate a grand mean for data analyses. Additional details for macroplot establishment and transects may be obtained from USDA Forest Service website (Uresk et al. 2010): http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml

Preliminary examination of all data reduced the number of variables to seven variables (n =71 sites) for further analyses. Most understory plant species were highly variable among all macroplots and present in minimal amounts (<3% canopy cover). Thus, these plant species were not considered for further analyses in model development. The seven variables including plant species with a high consistency within the plains cottonwood ecological type: plains cottonwood tree diameter at breast height (DBH), tree number for cottonwood trees >1 in DBH, stems <1 in DBH , basal area (ft²/acre ;1 ft²/acre = 0.23 m²/ha), percent canopy cover for narrowleaf willow, western snowberry, and peachleaf willow. Stepwise discriminant analyses were used for initial data reduction of the seven variables on the three perceived seral stages (early, mid, late) from field observations (Uresk 1990). This initial data reduction resulted in three variables for model development: cottonwood tree diameter (DBH), tree number, and number of stems <1 in within a macroplot (0.2 acres or 0.08ha). These three variables were analyzed with a non-hierarchical clustering procedure, ISODATA (Ball and Hall 1967, del Moral 1975), which grouped the 71 macroplots (sites) into four distinct clusters (seral stages). Stepwise discriminant analysis applied to the four clusters (seral stages) estimated the compactness of the clusters and provided Fisher classification coefficients for seral stage classification and monitoring within the cottonwood ecological type (Uresk 1990; SPSS 2003 ). Misclassification error rates were estimated with SAS (1988, 2012) and SPSS (2003) using a cross validation procedure or “leave one site out”. The cross validation procedure was repeated for each of the sites for a true error rate. By collecting data from additional sites
(approximately, 20-30 sites), including sites outside the original study area in western North Dakota and South Dakota, I subjected the developed model to field-testing.

RESULTS

Cluster analysis (ISODATA), a non-hierarchical analysis, grouped the 71 sites into 4 distinct seral stages ($P < 0.001$) based on three variables (Table 1). Basal area (69 ft²/a (16 m²/ha)) and canopy cover of understory plants for narrowleaf willow (4%), western snowberry (3%) and peachleaf willow (3%) did not enter into the final analyses. Stepwise discriminate analysis for model development was built on cottonwood tree diameter at breast height and tree number >1 in, and stem number <1 in, as predictive variables for seral stage classification and monitoring transitions within the plains cottonwood ecological type. The distributions of the three variables throughout the seral stages show the dynamics occurring within the plains cottonwood ecological type (Figure 1). Tree diameter dominated the late seral stage with a mean of 25 in (63.5 cm). Tree number, with an average of 240 trees, was low in the late seral stage but was greater in the early intermediate seral stage. Stem number, at a mean of 1938 stems, clearly dominated the early seral stage.

Tree and non-tree plant species by life form varied among seral stages (Figure 2). Forbs dominated the late intermediate and early seral stages with 43 and 38 species, respectively. Graminoids remained relatively constant among the seral stages ranging from 14 to 19 species. Shrubs varied from 3 to 10 species throughout the 4 seral stages, while trees ranged from 3 to 7 species.

Key plant variables by seral stage

![Figure 1. Key variables with tree diameter, stem number and tree number throughout four seral stages in the Plains Cottonwood ecological type. Graph provides an approximate mixture of variables at each seral stage.](image)
Fisher’s discriminant function coefficients (SPSS 2003) for ecological seral stage classification and monitoring with 3 key variables for plains cottonwood are presented in Table 2. Variables with the greatest coefficients by seral stage express the importance of the key variable within a stage for this ecological type. These key variables with corresponding coefficients interrelate together within the model to classify seral stages and do not function as independent variables. An example of calculating seral stage assignment by Fisher coefficients from key variables is presented in Table 3. In this example seral stage assignments are calculated using the following data for key variables: mean tree diameter (DBH) = 8 in (20.3 cm), stems = 74 and cottonwood tree number = 63. These key variables are multiplied by the coefficients for each seral stage (row) and the products, including the constant, are summed (+ and -) for a score. The greatest positive score or least negative score, when all scores are negative, is the assigned seral stage. In this example, the assigned seral stage is late intermediate with a score of 5.4. Overall accuracy of the model based on cross validation was 95% (SAS 1988). Additional information on plot establishment, data collection, seral stage classification, monitoring and trend monitoring, including programs for personal data assistants (PDAs) and personal computers, can be obtained at USDA Forest Service website (Uresk 2010): http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.
Table 1. Key variables used in model development for Plains Cottonwood ecological type by seral stages with standard errors (in parentheses).

<table>
<thead>
<tr>
<th>Seral stage</th>
<th>n</th>
<th>Diameter</th>
<th>Stem number</th>
<th>Tree number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>9</td>
<td>25 (2)</td>
<td>24 (22)</td>
<td>9 (1)</td>
</tr>
<tr>
<td>Late intermediate</td>
<td>30</td>
<td>7 (1)</td>
<td>38 (19)</td>
<td>76 (7)</td>
</tr>
<tr>
<td>Early intermediate</td>
<td>14</td>
<td>4 (1)</td>
<td>104 (45)</td>
<td>240 (19)</td>
</tr>
<tr>
<td>Early</td>
<td>18</td>
<td>1 (1)</td>
<td>1938 (293)</td>
<td>2 (1)</td>
</tr>
</tbody>
</table>

n= number of sites, 0.08ha (0.2 acres) each.
1 Diameter = inches. Convert inches to centimeters by multiplying by 2.54.
2 Stems <1-inch
3 Trees >1-inch

Table 2. Fisher’s discriminant function coefficients (SPSS 2003) for ecological classification model based on tree diameter, stem number, and tree number for Plains Cottonwood ecological type by seral stage.

<table>
<thead>
<tr>
<th>Species</th>
<th>Late</th>
<th>Late intermediate</th>
<th>Early intermediate</th>
<th>Early</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (inches)</td>
<td>2.496</td>
<td>0.882</td>
<td>1.107</td>
<td>0.123</td>
</tr>
<tr>
<td>Stem number &lt;1 inch</td>
<td>0.001</td>
<td>0.072</td>
<td>0.001</td>
<td>0.005</td>
</tr>
<tr>
<td>Tree number &gt;1 inch</td>
<td>0.084</td>
<td>0.001</td>
<td>0.175</td>
<td>0.003</td>
</tr>
<tr>
<td>Constant</td>
<td>-33.051</td>
<td>-7.034</td>
<td>-24.385</td>
<td>-6.135</td>
</tr>
</tbody>
</table>

1 Diameter breast height (DBH)
2 Convert inches to centimeters by multiplying inches by 2.54

Table 3. An example of assigning seral stages by using Plains Cottonwood Fisher’s discriminant coefficients with diameter (DBH) 8-inches, stem number 74, and tree number 63 from new data collected from the field.

<table>
<thead>
<tr>
<th>Seral</th>
<th>Diameter (inches)</th>
<th>Stem number&lt;1”</th>
<th>Tree number&gt;1”</th>
<th>Constant</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>(2.496 * 8)</td>
<td>+</td>
<td>+</td>
<td>-43.051</td>
<td>-7.72</td>
</tr>
<tr>
<td>Late Int.</td>
<td>(0.882 * 8)</td>
<td>+</td>
<td>+</td>
<td>-7.034</td>
<td>5.41</td>
</tr>
<tr>
<td>Early Int.</td>
<td>(1.107 * 8)</td>
<td>+</td>
<td>+</td>
<td>24.385</td>
<td>-4.43</td>
</tr>
<tr>
<td>Early</td>
<td>(0.123 * 8)</td>
<td>+</td>
<td>+</td>
<td>6.135</td>
<td>-4.59</td>
</tr>
</tbody>
</table>

1 Coeff = Fisher’s discriminant classification coefficient. Diameter = diameter at breast height (DBH)
2 Assigned seral stage
DISCUSSION

The plains cottonwood ecological type has undergone major changes, mainly by human caused disturbances along the Missouri River, most recently with the building of large dams for water storage, flood control, electrical production, and irrigation for farming. These large dams have altered natural fluvial processes and periodic flooding needed for floodplain development and the associated long-term sustainability of the cottonwood type. Substantial losses of cottonwood woodlands are found behind the dams along the Missouri River. However, regulated water flows below the dams are limited to provide adequate regeneration of cottonwoods, and long-term sustainability (Dixon et al. 2012; Carter et al. 2012).

Inventory, monitoring and assessment of the cottonwood woodlands will provide valuable information about the ecological condition and successional status of these cottonwood woodlands related to environmental or human induced stresses. The developed model is quantitative and can be used to describe the dynamics occurring among cottonwood seral stages throughout the riparian system based on three key variables for plains cottonwood (DBH, stem number <1 in DBH, tree number >1 in DBH). This model requires collecting only the three key variables on permanent sites, yearly or every few years and can determine trends within a seral stage or among seral stages, allowing resource professionals to meet objectives. Data collected for these three variables by the Forest Service Inventory and Analyses (FIA) would provide seral stage assignment and trends over time. The variables are not linear and show variations throughout the four stages (Figure 1). All developed model coefficients can be incorporated into the conceptual state and transition models used by the Natural Resource Conservation Service (NRCS), Bureau of Land Management (BLM), and USDA Forest Service that are qualitative (Bestelmyer et al. 2003; Briske et al. 2005; Twidwell et al. 2013; USDA-NRCS 2013). Once the model coefficients are incorporated into state and transition models, these models will then become a powerful tool for sustaining our natural resources.

Management for all four ecological seral stages as a mosaic within the plains cottonwood type enhances plant and animal diversity across the landscape. Plant species diversity among the seral stages was approximately the same for total numbers, but proportions of life forms varied among the stages (Figure 2). Some bird and mammal species require single seral stage and others multiple stages (Rumble and Gobeille 2004; Rumble and Gobeille 2001). Most bird species were observed to be in the late and late intermediate stages, while the early seral stages had more small mammals than the late seral stages.

Cottonwood trees in the late seral stage were not abundant and many were becoming decadent with no understory cottonwood regeneration or recruitment due to lack of flooding and scouring within the flood plain. Planting cottonwood cuttings has been proposed to increase regeneration, but with limited success. Possible reasons are related to lower water depth, competing vegetation and livestock grazing (Dreesen, et al. 2002; Hoag 2007). Heavy livestock grazing (late seral stage) with substantial hoof action during the spring for 3-4 days on a small
area resulted in regeneration of cottonwood seedlings (personal observations). I recommend further scientific research using livestock for regeneration of cottonwood in old decadent stands. In this current study, cottonwood regeneration was primarily in narrow channels for river tributaries flowing into the Missouri River. Other trees in the cottonwood ecological type were green ash, boxelder, peachleaf willow, American elm, and Russian olive. Green ash and Russian olive were abundant in many areas within cottonwood stands. Cottonwood regeneration is limited with the invasion of these trees because space and the opportunity for water to scour the soil for establishment of new seedlings.

The number of cottonwood saplings (stem number) showed a steady decrease from early to late seral stage as expected within the cottonwood type (Table 1). The late seral stage, primarily old cottonwood stands, had variable understories that were highly diverse, ranging from grass to grass/forb to grass/forbs/shrubs. Green ash was the dominant tree in some cottonwood stands, especially in areas where flooding and scouring was not evident for many years. Russian olive, a nonnative invasive species was dominant within some cottonwoods stands in areas of moist saline soils. To monitor changes or trends for the plains cottonwood ecological type with co-dominant trees, I recommend establishing permanent plots within the co-dominant woodlands and collecting data for the 3 key variables for only the plains cottonwood. Monitoring the plains cottonwood with key variables over time will provide information on seral stage status and trends within a co-dominant tree complex.

The developed ecological seral stage classification and monitoring model based on multivariate statistical methods defined three key variables related to plains cottonwood succession in riparian systems. Four seral stages representing early to late succession were identified quantitatively with a classification accuracy of 95%. Information required to define the seral stages using the model include DBH of cottonwood trees >1 inch, cottonwood stem number <1 inch and cottonwood tree number. These are the only measurements required for seral stage classification and monitoring. Data collection may be conducted yearly or every few years on two plots per section (square mile). Sites selected should be at a minimum of one-quarter mile apart. See USDA-Forest Service website for additional information at Uresk et al. (2010): http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml. Using this model to classify seral stages and monitor changes within and among seral stages, resource managers will be able to develop and evaluate their management plans.

**ACKNOWLEDGEMENTS**

This study was completed with the cooperation and partial support provided by the U.S. Army Corps of Engineers (IAG-RM-88-124). Thanks are extended to Dave Stricklan, Tony Hoag, Daryl Mergen, and Jody Javersak for data collections and analyses. Rudy King, Rocky Mountain Research Station statistician (retired), provided invaluable statistical advice throughout the study and statistical analyses.
LITERATURE CITED


MODEL FOR CLASSIFICATION AND MONITORING GREEN ASH—ECOLOGICAL TYPE IN THE NORTHERN GREAT PLAINS

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ABSTRACT

A multivariate statistical model was developed to classify seral stages and to monitor succession within the green ash (Fraxinus pennsylvanica Marshall)—chokecherry (Prunus virginiana L.)—western snowberry (Symphoricarpos occidentalis Hook.) ecological type on the northern Great Plains. Two key variables, green ash basal area (ft²/acre) and Prunus species (% canopy cover) (Prunus species = chokecherry + American plum (P. americana Marshall)), provide all the information required for the model to classify seral stages and to be used to monitor trends within the ecological type. The model quantitatively identified four seral stages (early to late succession), all significantly different (P < 0.001), with an overall accuracy of seral stage assignment of 95%. It also showed that succession is not linear, but goes through multiple states among the four seral stages. These four defined seral stages provide resource managers with options to quantitatively evaluate and manage resources to meet objectives and monitoring plans. The model provides coefficients for application and input to qualitative state and transition models and is simple to use, reliable, repeatable, accurate and cost effective.

Keywords

Ecological type, succession, woodlands, monitoring, seral stages, diversity, state and transition models

INTRODUCTION

The study of vegetation dynamics has received increased emphasis over the last few decades. Investigation has been facilitated by advances in our knowledge of natural systems and by our increased capabilities to quantitatively analyze, model, and monitor community processes and functions (Glenn-Lewin and van der Maarel 1992). Concurrently, increased public awareness of natural resource management has dictated that public and private land managers be provided economical, yet powerful, quantitative tools to classify and monitor vegetation changes resulting from management decisions and activities.
Steady state and transition models to evaluate vegetation changes due to management activities and environmental conditions with ecological site descriptions have received much attention in recent years (Bestelmyer et al. 2003; Briske et al. 2005). However, these models are qualitative and based on expert opinion and personal judgments (Twidwell et al. 2013). Subjective estimates to determine vegetation trends and steady states of plant succession vary among observers, making it difficult to obtain consistent interpretations of successional processes (Kershaw 1973; Block et al. 1987).

State and transition models can be quantified by using multivariate statistical models that represent vegetation change related to environmental factors, management and plant succession (Uresk 1990; McLendon and Dahl 1983; Huschle and Hironaka 1980; MacCracken et al. 1983; Friedel 1991; Benkobi et al. 2007; Uresk et al. 2010a). These multivariate models with cluster analyses provide discrete groupings (plant phases or seral stages) that are related to key plants distributed throughout the ecological type. These models of plant succession allow resource managers to obtain quantitative measurements to evaluate ecological conditions found in rangelands and other environs. The approach outlined in this study can be applied to quantify state and transition models for community phases or seral stages and incorporated into current federal interagency ecological site descriptions (Bestelmeyer et al. 2003).

The concept of plant succession has been used in classification studies for western forests and rangelands for many years (Sampson 1919; Daubenmire 1952; Girard et al. 1989). Further, rangeland condition and classification methodologies have given managers a framework for evaluating vegetation changes in response to natural and man-induced disturbances.

Multivariate statistical models may offer a way to analyze quantitative data and to evaluate patterns of plant succession in an objective manner (Uresk 1990). Multivariate and ordination techniques have been successfully used to develop vegetation classifications, but none has provided practical tools for managers to use to quantify and monitor successional trends. The National Research Council (1994) provides reviews that discuss the values and limitations of these techniques.

Wooded draws, a complex of prairie woodlands composed primarily of the green ash ecological type, are generally a minor, but important component of the grasslands of the Great Plains. Although concentrated in some areas, they occupy approximately 1% of the total area in the Northern High Plains, which include Wyoming, North and South Dakota and Montana (Jakes and Smith 1982). These unique vegetation types are important wildlife habitats (Lesica and Marlow 2013). They not only provide forage and shelter for livestock, but also sustain soil and watershed stability, are a source of firewood, and enhance visual and species diversity in the prairie landscape (Girard et al. 1989). Livestock grazing is a predominant use of grasslands and associated woodlands, but has been implicated as the primary causative factor in degradation of the green ash ecological type (Severson and Boldt 1978; Lesica and Marlow 2013). The values of woodland habitats in Great Plains grasslands (Bjugstad and Sorg 1985) have dictated that these habitat types be properly managed. Knowledge of the current seral status and successional trend of green ash stands is a prerequisite
for resource managers to determine compliance with desired plans for vegetation conditions and to implement management guidelines.

The purpose of this study was to develop a model that can be used easily by resource managers within a tree dominated green ash (*Fraxinus pennsylvanica* Marshall)-chokecherry (*Prunus virginiana* L.) - western snowberry (*Symphoricarpos occidentalis* Hook.) ecological type on the northern Great Plains and to determine resource conditions. The objectives were: 1) to develop an ecological classification and monitoring model for the green ash ecological type, 2) to define and describe the seral stages, and 3) to provide sampling and monitoring protocols.

**STUDY AREA**

The study was conducted in southwestern North Dakota, western South Dakota, and western Nebraska along the Missouri River, Lake Sharpe, Oahe Reservoir, and associated tributaries. Green ash stands were inventoried and sampled on the drainages of the Little Missouri, Heart, Cannonball, Grand, Moreau, Cheyenne, White, and Niobrara Rivers, all of which drain into the Missouri River.

**Vegetation**—This ecoregion is a moderately dense, short to medium-tall grassland dominated by western wheatgrass (*Pascopyrum smithii* (Rydb.) Á. Löve), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths), green needlegrass (*Nassella viridula* (Trin.) Barkworth), and buffalograss (*Buchloe dactyloides* (Nutt.) J.T. Columbus) (Kuchler 1964). Drainages may be dominated by shrubs or, in more mesic situations, trees. Common shrubs include silver buffaloberry (*Shepherdia argentea* (Pursh) Nutt.), western snowberry, chokecherry, Saskatoon serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.) and skunkbush sumac (*Rhus trilobata* Nutt.). Trees may include green ash, American elm (*Ulmus americana* L.), boxelder (*Acer negundo* L.), hackberry (*Celtis occidentalis* L.), and bur oak (*Quercus macrocarpa* Michx.). Plains cottonwood (*Populus deltoides* W. Bartram ex Marshall) and willows (*Salix* L. spp.) are common codominants on floodplains of lower order drainages. Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) is found on shallow soils of steep north facing slopes along drainages leading to the major rivers (Severson 1981). Plant nomenclature followed USDA-NRCS (2014).

**Climate**—The climate of the northern Great Plains is semi-arid continental and characterized by wide daily and seasonal fluctuations in temperature and by erratic precipitation. Average annual precipitation ranges from 13.8 in (354 mm) in southwestern North Dakota (Medora) to 18.3 in (464 mm) in northwestern Nebraska (Harrison). May and June are the wettest months and 75% of the annual precipitation falls from April through September. Locally severe thunderstorms are common in summer (Hansen et al. 1984). Mean annual precipitation at Bismarck, ND, is 16.4 in (417 mm) with an average maximum temperature of 52.7 °F (11.5 °C) and minimum temperature of 29.8 °F (-1.2 °C). Mean annual precipitation at Pierre, SD, is 17.7 in (450 mm); annual maximum and minimum temperatures are 59.2 °F (15.1 °C) and 35.2 °F (1.8 °C), respectively. At Chamberlain, SD, mean annual precipitation is 23.6 in (599 mm) with aver-
age maximum and minimum temperatures of 59.5 °F (15.3 °C) and 34.8 °F (1.6 °C), correspondingly (HPRCC, 2015).

**Physiography and Vegetation**—Topography is the most important factor delineating the distribution of the green ash-chokecherry-western snowberry ecological type (Girard et al. 1989; Hansen et al. 1984). In North Dakota, green ash is restricted to the bottoms, lower sides, and north-facing slopes of intermittent drainages; hence, stand areas are generally long and narrow. The largest trees occur near the bottom of the stand where there is greater soil moisture (Hansen et al. 1984; Girard et al. 1989; Lesica and Marlow 2013). Southward into South Dakota and Nebraska, this type tends to be found only in bottoms and on lower north-facing slopes. Shrubs on upper drainages may replace trees where moisture becomes more limiting (Severson 1981).

Green ash is the dominant tree in all stages, but American elm has been found in enough stands to warrant the designation of a separate phase in North Dakota (Girard et al. 1989). The status of these communities is, however, nebulous because of the presence of Dutch elm disease which has significantly impacted American elm trees in some areas of North Dakota with a large number of trees dead or dying (A. Duxberry, 2015. ND Game and Fish, personal communication). While many trees have not been infected, the nature of these woodlands will change if the disease reaches epidemic proportions. Boxelder, hackberry, and bur oak also occur in these habitats; the latter two becoming more prevalent in South Dakota. Scattered Rocky Mountain junipers will also be found in some green ash habitat types.

A shrubby border between the woodlands and grasslands also characterizes this ecological type. The border is in stair-step form beginning with the shorter grasses on the uphill side to shrub species of western snowberry, Wood’s rose (*Rosa woodsii* Lindl.), skunkbush sumac, and silverleaf buffaloberry; then to taller species such as chokecherry and American plum. The border then grades into the green ash woodland (Hansen and Hoffman 1988; Girard et al. 1989).

Chokecherry, western snowberry, American plum, Saskatoon serviceberry and Wood’s rose are the most common shrubs in the woodland understory. The herbaceous layer contains many species and dominance is commonly shared among them in stands that exhibit little disturbance. Girard et al. (1989) identified 48 species in the herbaceous layer of the green ash/chokecherry ecological type. Lesica and Marlow (2013) reported 137 species occurring in green ash woodlands. Kentucky bluegrass (*Poa pratensis* L.) becomes more prevalent and even dominant when the stand is disturbed (Hansen et al. 1984; Hansen and Hoffman 1988).

**Soils**—Soils of this habitat type are generally unstable. Since this habitat type is formed in an erosional topography along intermittent drainages, headcuts (gullies) are common in the bottoms and small slumps are often found along the sides (Girard et al. 1989). In the North Dakota badlands, side area soils have been described as Entisols or intergrades such as Entic Haploborolls and bottom soils as Fluvaquentic Haploborolls (Butler et al. 1986). Surface soils of green ash draws in northwestern South Dakota were moderately fertile with high nutrient levels, except for phosphorus and nitrogen which were low. Soils were fine-textured with moderately high cation exchange capacity and saturation.
percentages. They were nonsaline-nonalkaline with low amounts of exchangeable sodium (Voorhees and Uresk 1992).

METHODS

Data collection and analyses followed procedures described by Uresk (1990) with additions to this design to account for tree parameters. A preliminary survey of the study area was undertaken to assess the range of variability within the green ash ecological type. Study sites were selected so the full range of seral stages based on plant succession of this type could be accounted for in the sampling design.

Data were collected initially on 23 sites. Each site was randomly selected within one of three perceived seral stages, early, mid, and late (Cochran 1977; Thompson et al. 1998; Levy and Lemeshow 1999). Within each site, a single 65.6 ft X 131.2 ft (20 m X 40 m) macroplot was established. In green ash woodlands with narrow draws, two plots were established, each 32.8 ft X 131.2 ft (10 m X 40 m). The two plots were combined and analyzed as one plot. Diameter at breast height (dbh) was measured on all trees within the macroplot that had a dbh greater than 1 inch (2.54 cm). These data were converted to total basal area for the 65.6 ft X 131.2 ft (20 m X 40 m) macroplot and then to basal area per acre.

Two parallel 99 ft (30 m) transects were set 66 ft (20 m) apart within the macroplot. Canopy cover class (Daubenmire 1959) was obtained for each plant species (other than tree species), total graminoid, forb, shrub, and plant litter. Canopy cover was determined in 30, 7.9 in X 19.7 in (20 cm X 50 cm) frames on each transect for 60 microplots. Overstory tree cover (%) was collected at 1 m intervals along each transect by a box prism (moosehorn). We recorded presence or absence of overstory and estimated percent cover from the number of positive hits. All macroplot data were averaged by variable for data analyses.

Preliminary data examination of the grand means for canopy cover (%) for 23 sites removed minor species and annuals with < 1% canopy cover and mean basal area for American elm (1 ft²/a or 0.2 m²/ha). Total cover for graminoids, forbs, shrubs, and plant litter were not included in model development. Preliminary examination reduced the number of variables to 11 for further analyses. Stepwise discriminant analyses were used for initial data reduction of the 11 variables on the three perceived seral stages from field observations (early, mid, late) (Uresk 1990). This initial data reduction resulted in two variables for model development-- green ash basal area and canopy cover of Prunus species (chokecherry + American plum). These two variables were subjected to a non-hierarchical clustering procedure, ISODATA (Ball and Hall 1967; del Moral 1975) which grouped the 23 macroplots into four distinct clusters (seral stages). However, two seral stages had limited sample sizes of 3 and 4 sites. Based on these analyses, an additional 26 sites were sampled for green ash basal area and Prunus species and western snowberry canopy cover. The resulting 49 sites were re-analyzed with cluster analyses (ISODATA) which grouped the sites into four clusters (seral stages). Stepwise discriminant analysis applied to the four clusters (seral stages)
estimated the compactness of the clusters and identified key variables (green ash basal area and Prunus) for the model. The analysis provided Fisher classification coefficients for seral stage classification and monitoring within the green ash ecological type (SPSS 2003; Uresk 1990). All variables were entered in the final analyses to determine if the two selected variables would be consistent in the model development. Misclassification error rates were estimated with SAS (1988, 2012) and SPSS (2003) using a cross validation procedure or “leave one site out”. The cross validation procedure was repeated for each of the sites for a true error rate. The developed model was subjected to field-testing by collecting data from additional sites (approximately, 20-30 sites) in western North and South Dakota, including sites outside the original study area.

RESULTS

A total of 35 plant species were sampled for canopy cover (%) in addition to basal area of green ash and overstory canopy cover (%). Cover of total graminoid, forb, shrub, and litter was not included in the analyses. After initial data reduction, 11 variables are presented with means, minimum, and maximum values (Table 1). The mean basal area of green ash averaged 37 ft²/acre (8.5 m²/ha) and ranged from < 1 to 101 ft²/acre (23 m²/ha). Prunus species had a mean canopy cover of 24 % and ranged from 0 to 71%. Western snowberry was common throughout most of the green ash woodland system, ranging from 0 to 75% canopy cover with a mean of 15%. Green ash overstory cover ranged from 0 to 92% with a mean of 50%.

The non-hierarchical cluster analysis (ISODATA) grouped the 49 sites into 4 distinct seral stages (P < 0.001) based on 2 variables (Table 2). Stepwise discriminate analysis defined 2 key variables (basal area of green ash and Prunus species) for model development as the best predictive variables for classification of seral stages and monitoring within the green ash ecological type. The distributions of the two variables throughout the seral stages show the biological dynamics from late to early succession (Figure 1, Table 2). Green ash basal area dominated the late and early intermediate seral stages with means of 84 ft²/acre (19 m²/ha) and 41 ft²/acre (9 m²/ha), respectively. Prunus species were most abundant only in the late intermediate seral stage with 50% canopy cover. Both green ash and Prunus species were minor components in the early seral stage with a basal area of 13 ft²/acre (3 m²/ha) for green ash and a canopy cover of 6% for Prunus species. Each key variable individually and collectively characterized the vegetation dynamics of the model within the green ash ecological type.

Fisher’s discriminant function coefficients (SPSS 2003) provided the biotic potential of the 2 key variables for predicting and classifying seral stage dynamics within the green ash ecological type (Table 3). An example for applying the Fisher discriminant functions with new field data collected for the two key variables is presented in Table 4. Site values for green ash basal area (ft²/acre) and canopy cover (%) of Prunus species were 44 ft²/acre (10 m²/ha) and 26, respectively. To determine seral stage assignment, one multiplies green ash basal area and Prunus species canopy cover by the coefficients for each seral stage (row),
Table 1. Canopy cover (%), basal area (ft²/a), standard error (in parentheses) and range of common plant species for Green Ash ecological type (n = 23 sites).

<table>
<thead>
<tr>
<th>Species or variable</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western wheatgrass (%)</td>
<td>1.4 (0.6)</td>
<td>0.0</td>
<td>11.5</td>
</tr>
<tr>
<td><em>Pascopyrum smithii</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sideoats grama (%)</td>
<td>2.0 (1.2)</td>
<td>0.0</td>
<td>18.8</td>
</tr>
<tr>
<td><em>Bouteloua curtipendula</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedge species (%)</td>
<td>1.0 (0.3)</td>
<td>0.0</td>
<td>6.5</td>
</tr>
<tr>
<td><em>Carex</em> spp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada wildrye (%)</td>
<td>1.7 (0.5)</td>
<td>0.0</td>
<td>9.8</td>
</tr>
<tr>
<td><em>Elymus canadensis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green needlegrass (%)</td>
<td>1.2 (0.5)</td>
<td>0.0</td>
<td>10.3</td>
</tr>
<tr>
<td><em>Nassella viridula</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green ash (BA in ft²/a)¹</td>
<td>37.4 (4.0)</td>
<td>0.1</td>
<td>100.9</td>
</tr>
<tr>
<td><em>Fraxinus pennsylvanicus</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prunus (%)²</td>
<td>24.1 (3.2)</td>
<td>0.0</td>
<td>70.9</td>
</tr>
<tr>
<td><em>Prunus</em> spp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western snowberry (%)²</td>
<td>15.0 (2.4)</td>
<td>0.0</td>
<td>75.2</td>
</tr>
<tr>
<td><em>Symphoricarpos occidentalis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saskatoon serviceberry (%)</td>
<td>2.4 (1.2)</td>
<td>0.0</td>
<td>23.6</td>
</tr>
<tr>
<td><em>Amelanchier alnifolia</em> (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skunkbush sumac (%)</td>
<td>1.6 (0.6)</td>
<td>0.0</td>
<td>11.0</td>
</tr>
<tr>
<td><em>Rhus trilobata</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overstory ash cover (%)</td>
<td>50.1 (6.5)</td>
<td>0.0</td>
<td>91.7</td>
</tr>
<tr>
<td>Graminoid cover</td>
<td>13.2 (2.6)</td>
<td>&lt;1</td>
<td>49.2</td>
</tr>
<tr>
<td>Forb cover</td>
<td>4.5 (1.0)</td>
<td>0.0</td>
<td>16.1</td>
</tr>
<tr>
<td>Shrub cover</td>
<td>34.6 (3.7)</td>
<td>7.1</td>
<td>69.9</td>
</tr>
<tr>
<td>Litter cover</td>
<td>74.6 (3)</td>
<td>34.6</td>
<td>97.5</td>
</tr>
</tbody>
</table>

¹ Key variables in model, n = 49. Prunus species (chokecherry + American plum)
² Important variable within green ash ecological type, n = 49.

and the products are summed (+ and -), including the constant for the score. The greatest positive or least negative score when all scores are negative is the seral stage assignment. In this example the seral stage assignment was early intermediate with a score of 3.975. Cross validation results of the model showed an overall accuracy of 95% (SAS 2012). Additional information on data collection, plot establishment, seral classification, trend monitoring and programs may be downloaded from the USDA Forest Service website (Uresk et al. 2010b): http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml and may be used on personal data assistants (PDAs) and personal computers to directly assign the seral stage.
DISCUSSION

Successional change in green ash woodlands is generally a slow process, and visual estimates to determine successional stages are highly variable among observers. However, whereas an early successional stage can be determined from a late successional stage, but with limited accuracy, other seral stages are very difficult to define by observations alone. The model developed herein has the advantage of accurate seral stage classification. It is quantitative and can be used to describe tree and other plant dynamics throughout the woodland system using only two key variables, basal area of green ash and % cover of Prunus species.
This green ash model for classification of seral stages and monitoring with the key variables, basal area of green ash and canopy cover of Prunus species, provides a quantitative tool for management. Data collections for these two key variables are required to provide input to the model, which has an accuracy of 95% in classifying seral stages. Data collection for these two variables may be conducted on plots yearly or once every few years with a suggested minimum of two macroplots per section or per mile of woodlands within the ecological type. See the USDA-Forest Service website for additional information on establishment of plots for data collection at Uresk et al. (2010b): http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

The model coefficients developed herein can be incorporated into the conceptual state and transitions models currently used by USDA Forest Service, Natural Resource Conservation Service (NRCS), and Bureau of Land Management (BLM) (USDA-NRCS 2013) that are qualitative (Twidwell et al. 2013). The green ash model with the key variables is displayed as nonlinear in Figure 1 when they progress through all four seral stages. Ash succession may progress from late to early stages by passing through the intermediate stages rapidly or may be static for many years at a seral stage.

Finally, monitoring trends of the green ash system over time can be quantitatively documented and validated for recovery or deterioration of resource areas as

### Table 3. Fisher’s classification discriminant function coefficients used for classification of seral stages based on basal area (ft²/acre) of green ash and canopy cover (%) of Prunus spp. (American plum, chokecherry) in a Green Ash ecological type.

<table>
<thead>
<tr>
<th>Species</th>
<th>Late</th>
<th>Late Intermediate</th>
<th>Early Intermediate</th>
<th>Early</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green ash</td>
<td>0.497</td>
<td>0.099</td>
<td>0.260</td>
<td>0.072</td>
</tr>
<tr>
<td>Prunus spp.</td>
<td>0.071</td>
<td>0.350</td>
<td>-0.033</td>
<td>0.022</td>
</tr>
<tr>
<td>Constant</td>
<td>-23.415</td>
<td>-11.632</td>
<td>-6.607</td>
<td>-1.905</td>
</tr>
</tbody>
</table>

### Table 4. An example of assigning seral stages by using Fisher’s discriminant coefficients with basal area 44 (ft²/acre) of green ash and canopy cover 26 (%) of Prunus spp (American plum, chokecherry) with new data collected from the field.

<table>
<thead>
<tr>
<th>Seral Stage</th>
<th>Green Ash</th>
<th>Prunus spp</th>
<th>Constant</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late</td>
<td>(0.497 * 44) + 0.071 * 26) - 23.415 = 0.299</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Intermediate</td>
<td>(0.099 * 44) + 0.350 * 26) - 11.632 = 1.824</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Intermediate</td>
<td>(0.260 * 44) - 0.033 * 26) - 6.607 = 3.975</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>(0.072 * 44) + 0.022 * 26) - 1.905 = 1.835</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Coeff = Fisher’s coefficients used for classification.
2 Var = variable, basal area (ft²/acre) and canopy cover (%).
3 Assigned seral stage.

This green ash model for classification of seral stages and monitoring with the key variables, basal area of green ash and canopy cover of Prunus species, provides a quantitative tool for management. Data collections for these two key variables are required to provide input to the model, which has an accuracy of 95% in classifying seral stages. Data collection for these two variables may be conducted on plots yearly or once every few years with a suggested minimum of two macroplots per section or per mile of woodlands within the ecological type. See the USDA-Forest Service website for additional information on establishment of plots for data collection at Uresk et al. (2010b): http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

The model coefficients developed herein can be incorporated into the conceptual state and transitions models currently used by USDA Forest Service, Natural Resource Conservation Service (NRCS), and Bureau of Land Management (BLM) (USDA-NRCS 2013) that are qualitative (Twidwell et al. 2013). The green ash model with the key variables is displayed as nonlinear in Figure 1 when they progress through all four seral stages. Ash succession may progress from late to early stages by passing through the intermediate stages rapidly or may be static for many years at a seral stage.

Finally, monitoring trends of the green ash system over time can be quantitatively documented and validated for recovery or deterioration of resource areas as
affected by livestock grazing, fire or climatic changes. Overgrazing the green ash understory (shrubs and young trees) by livestock has been a source of degradation of green ash woodlands that has affected the vigor of plants and diversity and abundance of species. The early intermediate seral stage resulting in a greater basal area of green ash is the result of livestock grazing, leaving only trees with very few understory plants. This is common throughout the northern Great Plains. However, shrub-ash tree stands have also degenerated because they are reaching the end of their life spans (Boldt et al. 1978). Disease and construction of livestock ponds (influencing hydrology of wooded draws) are other factors that negatively influence the ecology of green ash woodlands.

Although livestock have been implicated as a damaging agent, it is possible that, when carefully managed, they could be used to alter seral stages to meet management objectives (Severson and Urness 1994; Uresk and Boldt 1986). The statistical model developed for classification and monitoring the green ash ecological type can be used to quantify the relationship of livestock grazing at various intensities, including no grazing. Monitoring successional trends in green ash woodlands can be used to determine grazing levels and/or stocking rates necessary to restore or maintain a desired successional status to meet management objectives.

Green ash succession, progressing from an early to the late seral stage, can be a slow process and may require mechanical or herbicide treatment to control invasive grasses and shrubs (Boldt et al. 1978; Severson and Boldt 1978; Uresk and Boldt 1986; Uresk et al. 2009; Lesica 2009; Lesica and Marlow 2013). Herbicides applied to densely formed grass sod of Kentucky bluegrass and smooth brome (*Bromus inermis* Leyss.) had a positive effect on survival of green ash seedlings in ash woodlands (Lesica 2009; Lesica and Marlow 2013). In addition, control of Russian olive trees (*Elaeagnus angustifolia* L.), a non-native species, may be necessary where this species has invaded.

Management for all four ecological seral stages within the ecological type enhances plant and animal diversity. A mosaic of desired seral stages of green ash woodlands across the landscape is considered optimal for plant and animal species (Lesica and Marlow 2013; Rumble and Gobeille 1998; Rumble and Gobeille 2001; Severson and Carter 1978; MacCracken and Uresk 1984). A single seral stage will not be practical for multiple-use management because plant and animal species vary among seral stages. To meet plant and animal species diversity, we recommend that 10-15% of the green ash woodlands be in early and late seral stages and the remainder within early intermediate and late intermediate stages as a mosaic across the landscape (Kershaw 1973, Mueller-Dombois and Ellenberg 1974).

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**LITERATURE CITED**


PRAIRIE OR WOODLAND? RECONSTRUCTING PAST PLANT COMMUNITIES AT GOOD EARTH STATE PARK VIA SOIL CORE AND TREE RING ANALYSIS

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ABSTRACT

The hills and ravines of Good Earth State Park, located in southeastern South Dakota, currently support extensive woodlands interspersed with small upland prairies. Analysis of stable carbon isotopes from soil cores suggests that the prairies were much more extensive in the past and that the woodlands have expanded in recent years. Soil carbon isotope values (δ13C) from forested ravines and upland prairie sites show a strong C4 native grass signature, around -16‰ at the deeper depths, suggesting widespread prairie dominance throughout the park in the past. At the forested sites, δ13C values decreased significantly towards the soil surface reaching average values from -23 to -25‰. Such values are characteristic of C3 woody plants, providing evidence that over time, woodlands have replaced the native prairies. By contrast, soil cores from the few remaining upland prairie sites showed consistent δ13C values from top to bottom, around -16‰, suggesting these sites have remained dominated by prairies for many years.

Tree core samples taken from the larger bur oaks (Quercus macrocarpa) at Good Earth yielded maximum ages of approximately 125 years. The apparent absence of older trees in the park is consistent with the stable isotope analysis suggesting that the woodlands at Good Earth have appeared rather recently.

The expansive prairies of the past were reliant upon frequent wildfires which, coupled with tree harvest by Native Americans, likely prevented forest encroachment. Following abandonment of the Blood Run site around 1700, the settlement by European immigrants throughout the region and subsequent suppression of prairie fires, the woodlands have expanded considerably. If recent trends continue, the few remaining tracts of native prairie at Good Earth will disappear within a few decades. We applaud recent efforts by park management to begin restoring some of the lost prairie habitat.
Keywords

stable isotopes, soil cores, forest encroachment, prairie loss, Blood Run

INTRODUCTION

Established in 2013, Good Earth at Blood Run is South Dakota’s newest state park. It is located 10 miles southeast of Sioux Falls, SD, at 48072 270th St. The park is situated in the vicinity of a historic Native American community within the Blood Run National Historic Landmark. The park contains several small native prairies that appear to be remnants of more extensive grassland habitat. Throughout the upper Midwest less than 1% of the once extensive tall-grass prairie remains (Samuels 1999), making it one of the most endangered biomes on Earth (Samson et al. 2004). Most of the prairie loss has resulted from agricultural development. The remaining prairie remnants face additional threats including forest encroachment and the spread of invasive species. The tall-grass prairie is dependent upon periodic fires. Before European settlement, frequent prairie fires kept forests from encroaching into the prairies, as first recorded in the journals of Lewis and Clark (Thwaites 1905). In the absence of prairie fires, shrubs and trees gradually replace prairie vegetation through the process of ecological succession (see reviews by Collins and Wallace 1990; Samson and Knopf 1994).

Many of the remaining native tall-grass prairie tracts in the upper mid-west are concentrated on hilly landscapes that were not easily plowed and converted to row-crop agriculture. In southeastern South Dakota, some of the best native prairie remnants are found in the dissected landscapes of Good Earth and Newton Hills State Parks. A number of studies have been conducted at Newton Hills documenting present and historical plant communities. For example, in 1863, land surveyors noted crossing extensive, grassy prairies on the ridges with scattered timber stands in the ravines (Rogers 1972). Recent studies have documented the dramatic loss of these ridge-top prairies at Newton Hills due to expansion of forests from the ravines (Tieszen and Pfau 1995; Steck and Spencer 2003; Spencer et al. 2009). Historically, fires swept off the broad flat prairies to the west and onto the ridges of Newton Hills, helping maintain the prairie vegetation (Spencer et al. 2009). These fires likely burned part-way down the flanks of the ridges, but did not appear to travel down to the bottoms of the ravines, due to wetter conditions and protection from wind. Consequently, the ravines and valley bottoms were historically forested at Newton Hills (Spencer et al. 2009) and other similar sites throughout the mid-West (Anderson, 1990). In the absence of wildfires over the last 150 years, forests have moved up from the ravines and eliminated much of the upland prairie habitat of Newton Hills (Spencer et al. 2009), and elsewhere (Anderson 1990).

Evidence for plant community change described above is based in part on analysis of stable carbon isotopes in soil cores (Dzurec et al. 1985; Tieszen 1991; Spencer et al. 2009). The dominant native grasses of the tall-grass prairie use a $C_4$ photosynthetic pathway which produces $\delta^{13}C$ values ranging from -12 to -14‰, while woody plants use a $C_3$ pathway which yields $\delta^{13}C$ values ranging from -26
to -28‰ (Cerling et al. 1989; Tieszen 1991). These characteristic isotope “signatures” are retained following incorporation of plant material into soil organic matter (Balesdent et al. 1988); consequently, changes in $\delta^{13}C$ with depth in soil cores have been used as evidence of plant community change. For example, a number of studies have reported $C_3$ forest expansion into $C_4$ dominated grasslands as evidenced by decreasing $\delta^{13}C$ values in more shallow soil layers at Newton Hills (Tieszen and Pfau 1995; Spencer et al. 2009) and elsewhere (Steuter et al. 1990; McPherson et al. 1993; Biggs et al. 2002).

The present study evaluates evidence of plant community change at Good Earth, using the same carbon isotope techniques employed at Newton Hills (Spencer et al. 2009). Located 25 kilometers south of Good Earth, Newton Hills contains very similar landscape and topography, with rolling hills and steep ravines, which support a mosaic of woodlands and prairies. We initially hypothesized that the history of plant community change at Good Earth would be similar to that of Newton Hills with past communities characterized by greatly expanded prairies in the upland areas and woodlands restricted to the ravines.

**STUDY SITE**

The western half of Good Earth State Park is characterized by upland farmland (Figure 1). Historical land surveys in 1863 described this area as “gently rolling prairie,” with soils variously rated as “first rate” or “second rate” for farming (Mellin 1863). Following settlement by European immigrants, this area was largely converted to agricultural use including row crops and pastureland. These uses continued up until 2013 when the park opened. The eastern half of the park consists of steeper topography characterized by ridges and steep ravines. Mellin (1863) reported scattered trees on some of the “bluffs” in this area. The upland ridges and bluffs lead down to a riparian floodplain along the Big Sioux River, which forms the eastern boundary of the park (Figure 1). The broad floodplain in the northeastern part of the park previously supported row-crop agriculture and pastureland.

Our study focused on the dissected landscape of woodlands and prairie between the upland agricultural land and the floodplain. The ravines in this area currently support dense woodlands which extend up the flanks of the ravines all the way to the top in some places. The woodlands are classified as Northern Bur Oak Mesic forest (Ode 2010). They are dominated by bur oak (*Quercus macrocarpa*), along with scattered basswood (*Tilia americana*), American elm (*Ulmus americana*), and an understory including ironwood (*Ostrya virginiana*), and more recently invasive, non-native species including buckthorn (*Rhamnus cathartica*), garlic mustard (*Alliaria petiolata*) and Dame’s rocket (*Hesperis matronalis*).

Native prairie remnants exist on a few isolated ridges which extend east from the flatter agricultural land, and form some scenic overlooks over the Big Sioux River (Figure 1). A few of the more isolated ridges support a good mix of native species dominated by big bluestem (*Andropogon gerardi*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*), along with a few scattered native forbs such as purple...
coneflower (*Echinacea purpurea*), and prairie violet (*Viola pedatifida*). Adjacent pasturelands are dominated by non-native grasses such as smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*), and these grasses are expanding onto the prairie ridges. Pioneer tree and shrub species that are found along the margins of the prairies include eastern red cedar (*Juniperus virginiana*) and smooth sumac (*Rhus glabrus*), along with occasional large open-grown bur oak trees.

**Blood Run**—Although much of the Native American settlement of Blood Run was concentrated on the east side of the Big Sioux River in present day Iowa, a series of interrelated villages paralleled both sides of the Big Sioux River for nearly three and a half miles, extending through the present day borders of Good Earth State Park (Henning and Schnepf 2014). The community was likely established in the 1400’s and flourished until the early 1700’s. The community appeared to serve as a major regional trading center for pipestone and other goods. At its peak, the population of Blood Run was thought to exceed 6,000 people (Henning and Schnepf 2014).
METHODS

During the summer of 2014, three replicate soil cores were taken at each of four sites in the Park. Three of the sites were located in forested ravines and one site was located on a prairie ridge (Figure 1). The soil type at all sites was classified as Steinauer-Shindler clay loam (Driessen 1971). Soil cores were taken at each site using a slide hammer core sampler (AMS Inc., American Falls, ID) down to an overall depth of 50 cm. Each soil core was separated into four sections; 0-1 cm (the O horizon was scraped off before sampling), 1-6 cm, 10-15 cm, 15-25 cm, and 35-50 cm. The preparation of soil samples followed procedures outlined by Von Fischer and Tieszen (1995). Percent C was determined via automated Dumas combustion using an NA 1500 elemental analyzer (CE Elantech, Inc., Lakewood, NJ). Carbon content of the mineral soil (fine roots were removed by hand) was determined from 2.4 cm diameter soil cores. Samples were decarbonated with HCl prior to stable isotope analysis. Carbon isotope ratios were measured on a VG SIRA series II triple trap isotope ratio mass spectrometer (GV Instruments, Hudson, NH and Manchester, UK) and values were expressed per mil (‰) $\delta^{13}C$.

Comparisons of carbon isotope values and percentage of carbon between different depths and sites were analyzed using analysis of variance techniques and Kruskal-Wallis tests with a significance level of 0.05 (JMP®, Version 7, SAS Institute Inc., Cary, NC). Post-hoc multiple comparison analyses were determined using Tukey-Kramer HSD tests.

RESULTS AND DISCUSSION

Average $\delta^{13}C$ values from soil cores collected at the upland prairie site showed minor variation with depth, fluctuating between -15.1 and -16.6‰ from the surface to the bottom (Fig. 2). The site currently supports prairie vegetation, and is dominated by C$_4$ grasses which are relatively enriched in $^{13}C$ and typically yield $\delta^{13}C$ values in soil organic carbon ranging from -15 to -17‰ (Cerling et al. 1989; Tieszen 1991). Measurement of similar $\delta^{13}C$ values around -16‰ across all depths in our prairie site provides evidence that this area has supported prairie vegetation for many years. By contrast, the three forested ravine sites showed significant decreases in $\delta^{13}C$ in the more shallow depths, providing evidence of plant community change over time (p<0.05, Figure 2). Average $\delta^{14}C$ values in the deeper soil strata below 15cm ranged from -14.1 to -17.5‰, suggesting that these sites were once dominated by prairie vegetation (Figure 2). Above 10 cm, there was a decrease in $\delta^{13}C$ reaching minimums of -23.1 to -24.9‰ near the surface (Figure 2). These surface values are characteristic of soils derived from C$_3$ plants such as trees (Cerling et al. 1989; Tieszen 1991). The decrease in $\delta^{13}C$ towards the surface is consistent with steady replacement of the once-dominant C$_4$ grasses by encroaching C$_3$ woodland species. Although other processes may cause shifts in the $\delta^{13}C$ values in soil over time in the range of 1-3‰ (Friedli et al. 1987; Trolier et al. 1996; Ehleringer et al. 2000), our study showed much greater average shifts of 6-8‰ in the forested sites (Figure 2). This indicates that
the predominant cause of the observed shift in δ13C in our soil cores has been forest encroachment into former prairie habitat.

Other stable isotope studies from the Midwest report similar findings. In Iowa, Wang et al. (1993) reported similar δ13C values of -16 to -19‰ below 20 cm soil depths and upper soil values between -22 to -27‰ and concluded that forests had expanded into areas previously dominated by tall-grass prairie. In nearby Newton Hills State Park, Tieszen and Pfau (1995) and Spencer et al. (2009) reported similar declines in δ13C in soil cores from upland sites which were attributed to forest encroachment into prairie habitat. Numerous authors from these and other studies have suggested that the primary stimulus for forest encroachment into prairie habitat is suppression of wildfires following settlement by European immigrants (see reviews in Collins and Wallace 1990).

As hypothesized, our δ13C data showed evidence of forest encroachment into the upland prairies at Good Earth which is consistent with similar evidence from nearby Newton Hills (Spencer et al. 2009). However, other results from Good Earth were not consistent with results from Newton Hills. In particular, cores from the forested ravines at Good Earth had average δ13C values from -14 to -17‰ at the 35-50cm depths (Figure 2) compared to much lower values around -23‰ at similar sites and depths at Newton Hills (Spencer et al. 2009; Tieszen and Pfau 1995). Based on these depleted values and other evidence, including land survey records of 1863, previous studies concluded that the ravines at Newton Hills have been at least partially forested for many years (Spencer et al. 2009; Tieszen and Pfau 1995). By contrast, the more elevated δ13C values in the deeper soil horizons at Good Earth provide evidence that the ravines there were historically dominated by prairies rather than woodlands and that forests have appeared fairly recently (Figure 2).

Other evidence for the more recent appearance of forests at Good Earth includes the species composition of the woodlands. At Newton Hills, the largest trees in the ravines are dominated by climax species, including basswood, American elm, and black walnut (Juglans nigra), which is consistent with a forest that has been there for hundreds of years (Spencer et al. 2009). By contrast, 80% of the larger trees in the ravines of Good Earth are bur oak, with only scattered, smaller American elm and basswood trees, and a relatively low diversity of understory species (Ode 2010). This species composition is indicative of a younger forest. As the forest ages, the mid-successional stage oaks at Good Earth will be replaced by climax species such as basswood, and American elm through the process of ecological succession.

We offer several potential explanations for the differences in present and past plant communities at Good Earth and Newton Hills. First, it is possible that prairie fires, which typically do not carry into steep ravines due to moist conditions and lack of wind, were somehow able to penetrate down into the ravines at Good Earth and prevent the woodlands from growing there. Although both areas are characterized by similar dissected landscapes, subtle differences in slope, aspect, moisture, wind, or other factors could have altered fire behavior at Good Earth.

A second explanation for the historical lack of forests in the ravines at Good Earth may have been timber harvest activities by Native Americans. Beginning
in the 1400’s, the Native American community of Blood Run existed in and around the present day boundaries of Good Earth State Park (Henning and Schnepf 2014). The site contained more than 65 lodges, a fortification, and over 200 mounds, making it one of the largest Native American communities in the area (Henning and Schnepf 2014). Previous studies of other Native American settlements along the Missouri River concluded that deforestation was significant around these communities (Abel 1939; Griffin 1977). Given the needs for fuel and building materials for the community at Blood Run, archeologists have suggested that nearby woodlands would likely have been deforested there as well (Adrien Hannus, personal communication). Prolonged harvest of trees over the 300 year history of Blood Run may have allowed prairies to dominate the ravines, replacing the woodlands that otherwise may have been found there. Unlike Good Earth, we are unaware of evidence for the existence of permanent Native American communities near Newton Hills. Thus, forests appeared to have historically dominated the ravines there due to the absence of fires and timber harvest. Following European settlement, selected timber harvest likely took place at Good Earth and Newton Hills until the parks were established.

**Figure 2.** Relationship between $\delta^{13}$C and soil depth for cores collected in Good Earth State Park from four sites shown in Figure 1. Three of the sites were located in forested ravines and one was on a prairie ridge. The uppercase letters indicate statistical differences (for a given depth) between the four sites and lowercase letter indicate statistical differences with soil depth within a site. Each point represents the mean (+ SE).
Tree core samples taken from the larger bur oaks at Good Earth yielded a mean age of 125 years (n = 3). The apparent lack of older trees is consistent with our other evidence that the forests at Good Earth have appeared rather recently.

SUMMARY AND IMPLICATIONS

Stable carbon isotope data provide evidence that forests are encroaching into the remaining prairies of Good Earth State Park. Similar community changes have been documented at nearby Newton Hills and a number of other prairie sites throughout the Midwest (Collins and Wallace 1990; Briggs and Gibson 1992; Gehring and Bragg 1992; Spencer et al. 2009). If recent trends continue, the few remaining native prairies at Good Earth will disappear within the next several decades. Responding to this threat, park managers at Good Earth and Newton Hills have begun to take steps to reclaim lost prairie habitat by clearing encroaching trees and shrubs and utilizing prescribed burns in an attempt to limit forest expansion and slow the spread of non-native species. In other parts of Good Earth, the upland agricultural land is being replanted to native prairie, and the agricultural land in the riparian zone along the river is being replanted with native trees.

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LITERATURE CITED


CLOUD SEEDING AS A POTENTIAL WATER MANAGEMENT TOOL IN WESTERN SOUTH DAKOTA

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ABSTRACT

Following several dry years in the late 1980’s, cloud seeding was suggested as a potential tool for making more water available for use in the Black Hills region. Early estimates were that cloud seeding over the Pactola Reservoir watershed could produce 20,000-40,000 additional acre-ft of precipitation. Cloud seeding over the entire Black Hills was estimated to be capable of producing up to 10 times this much water equivalent on the ground. We refine several assumptions that were used in making these early estimates. Our primary refinement is that we use actual daily conditions during two winter seasons to assess whether seeding should be effective or not on that day, compared to the climatological weekly mean conditions used in previous work. We also refine the temperature threshold for effective cloud seeding. We arrive at significantly lower estimates for additional precipitation compared to the earlier ones. For the two winters studied, we estimated 3,000 to 7,500 acre-ft increase in precipitation into the Pactola catchment, and again 10 times this or more if seeding is conducted over the entire Black Hills region. Even though lower than the previous estimates, these new estimates are significant amounts of water in the context of the hydrological budget for the region. Both the earlier study and the study discussed here used several simplifying assumptions. Additional study using sophisticated numerical models of the atmosphere and its response to seeding is recommended to better define the potential impact of cloud seeding.

INTRODUCTION

Water management is an important consideration for economic and social development in semi-arid regions where total annual precipitation is less than 20” per year, such as western South Dakota. Typical sources of water in these regions include direct precipitation, surface water, and ground water. Management tools include reservoirs and canal systems to capture, store, and transport water. Indirect management tools include laws, regulations, and fees to control use of water for domestic, agricultural, industrial, navigation, and recreational purposes. In addition, users typically have a range of options for adapting their
water usage to the available water, for instance, in the case of agriculture, by choice of crops planted. In the western United States, and several other semi-arid regions around the world, another practice sometimes adopted is cloud seeding to enhance natural precipitation.

The most common approach to cloud seeding is to disperse sub-micrometer particles of silver iodide from ground-based generators or from aircraft into clouds to accelerate the formation of precipitation. Less frequently, dry ice is dropped from aircraft into clouds in order to produce this acceleration. The conceptual model for cloud seeding is based on the reasoning that when precipitation development is accelerated, clouds start producing precipitation earlier and produce it more efficiently over a longer period, compared to natural (unseeded) clouds. The end result is more precipitation on the ground. In semi-arid regions, more precipitation on the ground can lead directly to increased crop yield, more water in storage in reservoirs for use for irrigation, municipal water supplies, hydroelectric power generation, and other beneficial uses. More precipitation also helps increase aquifer recharge.

In this preliminary study we summarize evidence to support the conceptual model for wintertime orographic precipitation enhancement by cloud seeding with an emphasis on results from recent studies that have provided strong support for this model. Then we summarize earlier work by Orville and Miller (1992) concerning the extent to which cloud seeding can be used to enhance wintertime precipitation over the Black Hills. We use the increased understanding of cloud seeding that has developed over the past two decades and examine daily weather records for a recent wet winter and a recent dry winter to re-evaluate the potential contributions of such cloud seeding to water resources in the Black Hills region.

How does precipitation form?—When water vapor condenses in saturated regions of the atmosphere to form clouds, microscopic water droplets are formed on micrometer and submicrometer dust particles called cloud condensation nuclei. These droplets grow by vapor deposition to sizes on the order of 20-30 micrometer diameter. Droplets in this size range have negligible fall speeds. In order for this condensed water to be precipitated from the cloud to the ground, the water must be aggregated into much larger drops or ice particles, of the order a millimeter or more in diameter. There are two main growth pathways from small cloud droplets to precipitation-size particles.

The first pathway is for liquid droplets of slightly different sizes having slightly different fall speeds to collide and coalescence. Initially this process is slow, because all the droplets are small and of similar sizes; consequently the differential fall speeds are also small. This process snowballs as the products of early collisions grow and fall faster, meaning they collide and coalesce with smaller droplets more quickly, and grow at faster rates. A few “lucky” droplets that get an early start and experience a rapid sequence of coalescence events can reach precipitation sizes while millions of vapor-grown droplets in the same region remain at small sizes still not having collided with another droplet. When there is a reasonably wide range of droplet sizes in a cloud region, this stochastic process can produce precipitation-size drops within tens of minutes of cloud formation. The wider the initial size range, the faster the development. This collision-coalescence pro-
cess is described in more detail in many standard texts. Two recently published examples are Lamb and Verlinde (2011) and Wang (2013).

The second main growth pathway is for ice particles to fall into, or form directly within, a region of supercooled liquid droplets. Small droplets of the order of 20 micrometers in diameter can supercool and persist for many minutes without freezing, down to temperatures below -30 °C. In a cloud of supercooled liquid droplets, the droplets are in metastable equilibrium in a region that is saturated with respect to the liquid phase of water. If an ice particle forms near a supercooled droplet, the equilibrium water vapor pressure over the ice particle will be lower than that over the neighboring liquid droplet. The droplet will start to evaporate and the ice particle will grow. If there is a concentration of ice particles on the order of 1 per liter in a region where the cloud droplet concentration is on the order of 10^6 per liter (typical for a supercooled region in a young cumulus cloud), the water mass of a million droplets will evaporate in a matter of tens of seconds and deposit on the one ice particle, causing the ice particle to grow rapidly to precipitation size. This process is known by various names. We will call it the mixed-phase process. It also is commonly called the Bergeron-Findeisen process in honor of two scientists who, in the 1930's developed an understanding of how it works. Again, standard texts such as Lamb and Verlinde (2011) and Wang (2013) describe this process in greater detail.

**How can cloud seeding increase precipitation?**—The goal of cloud seeding is in essence accelerating the precipitation formation processes just described. By manipulating the aerosol particle population in the cloud region, the cloud seeder seeks either to (1) broaden the size spectrum of cloud droplets that condense initially in order to accelerate the collision and coalescence process, or (2) introduce ice particles into supercooled cloud regions to accelerate the mixed-phase process.

The first approach, broadening the cloud droplet size distribution, is addressed by introducing hygroscopic aerosol particles, typically particles composed of salts. Droplets relatively larger than those that condense on typical natural aerosols grow by condensing on these hygroscopic aerosols. This accelerates the collision and coalescence growth process.

The second approach, causing the formation of a low concentration of ice particles in a supercooled cloud region, is affected by introducing artificial aerosols that are good ice nucleators into a cloud, or by introducing very cold materials, such as dry ice pellets or liquid propane droplets, that accelerate the formation of ice particles in their vicinity. This approach is referred to as glaciogenic seeding.

There are two main processes for introducing these particles into clouds. First, small particles produced by combustion, vaporization, and condensation may be dispersed using propane-fueled burners from the ground fed with an acetone solution of silver iodide. This is relatively inexpensive. After release from a burner the particles are transported by winds and turbulent mixing up into the bases of clouds overhead.

Second, they may be dispersed from aircraft inside or in close proximity to the clouds. Wing-mounted burners consuming a solution of silver iodide in acetone can be used to produce the silver iodide aerosol. The aerosols can also be generated by burning pyrotechnic flares doped with silver iodide. Burners or flares fixed
to an airplane circling under a cloud can release aerosol that gets carried upward and into the cloud by the convective circulations, or upstream of orographic clouds forming over mountains where airflow carries them into the clouds.

Finally, dry ice pellets can be dropped into supercooled cloud regions from above causing strong local cooling and enhanced formation of ice particles.

Airborne seeding methods are more costly and sometimes more hazardous to execute, but targeting can be more reliable, compared to use of burners on the ground. More detailed descriptions of both delivery methods, and variations and combinations of them, can be found in Dennis (1980) and ASCE (2006).

**The Black Hills Situation**—The meteorology and cloud physics of precipitation formation differs with season in the Black Hills region. Different cloud seeding approaches are needed in different seasons.

a. **Winter**—The winter season in the Black Hills region typically begins in October or November and lasts into April and sometimes May. The dominant precipitation type at the ground in winter is snow, although rain can occur in any month and can dominate in the earliest and latest months of the season. Precipitation most often is produced by synoptic-scale surface low pressure systems that track northeastward out of Colorado across the High Plains, and also by low pressure systems tracking southeastward out of the Alberta region and passing across the northern Black Hills. Counterclockwise circulation around the Colorado Lows as they pass to the east of the region results in upslope flow along the eastern flank of the Hills. Counter clockwise circulation around the Alberta Lows (also called Alberta Clippers) impinges on the Hills from the north and west. In both cases, moist air near the ground rises and cools as it flows toward and over the Hills, producing clouds due to this orographic lifting induced by the generally NNW-SSE oriented Hills. Precipitation generally results if the moist layer is deep enough and upslope flow is strong enough. Maximum amounts typically fall on the windward flanks of the Hills. Orographic forcing is the major component of the forcing that produces these clouds, but convective processes can also contribute.

These clouds are cold, and snow develops by the mixed-phase process. Glaciogenic seeding is appropriate for enhancing precipitation from these clouds. It can be used to initiate precipitation sooner and extend it for a longer period as the storms pass near and over the Hills. Glaciogenic seeding can also be effective for enhancing precipitation from orographic systems with embedded convective elements. For summaries of results from orographic seeding projects, see reviews in Dennis (1980, Section 7.4), Bruintjes (1999), National Research Council (2003), and Silverman (2010). Although these summaries generally support the efficacy of orographic cloud seeding, they highlight several uncertainties. The main two concerns are the variable statistical support for increases in precipitation from different projects, and weak demonstration of physical links between the release of seeding material and increased precipitation on the ground.

Two recently-completed orographic seeding experiments, using observations from more advanced and more comprehensive systems of instruments than have been used in the past show very encouraging results and address concerns expressed in the earlier reviews cited above. The first was the Snowy Mountain project (Manton et al. 2011), conducted from 2005-2009 in the Snowy Moun-
tain region of southeastern Australia. The Snowy Mountain project was designed to evaluate the effect of cloud seeding on precipitation in a region closely similar to the Black Hills in topography and climate. It included much improved monitoring of movement and effectiveness of seeding materials after release, and more complete precipitation measurements compared to earlier studies. Randomized seeding was conducted in 5-hr experimental units when conditions were appropriate for seeding. Two-thirds of these units were seeded and one-third unseeded. Manton et al. (2011) and Manton and Warren (2011) suggest precipitation increases during seeded experimental units of 14% with observations to support a clear physical link between the seeding and the precipitation increase.

The other project was the Wyoming Weather Modification Pilot Project (WWMPP) conducted in Wyoming from 2007-2014. The main focus of the WWMPP was wintertime snowfall in the Sierra Madre and Medicine Bow mountain ranges, although some work was also done in the Wind River Range. Although close to the Black Hills, these mountain ranges are taller than the Black Hills and snow falling on them originates higher in the atmosphere where conditions are colder. Breed et al. (2013) describe the evaluation procedure used to assess results from the project. As in Manton et al (2011), the Wyoming experiment identified limited-duration experimental units (of 4 hrs length in this project) when conditions were conducive to precipitation enhancement by seeding, and compared precipitation from seeded units and unseeded units. Extensive meteorological measurements, as well as monitoring of the transport of seeding material, were conducted. Although the project was just completed in 2014 and formal publication of results has not yet occurred, a draft executive summary of results from the project was released in December 2014. It is available from the Wyoming Water Development Commission at http://wwdc.state.wy.us/weather-mod/WYWeatherModPilotProgramExecSummary.pdf.

Preliminary results from the WWMPP were not as strong statistically as for the Snowy Mountain project, but the best estimate of the percent precipitation enhancement is in the range 3-17% for events in which seeding material was most effectively targeted. Detailed process studies show clear links between the generation and dispersal of seeding aerosol and enhanced precipitation.

b. Summer—In summer, when a moist near-surface boundary layer is heated as it passes over sunlit terrain, warm moist air currents rise above the surface. If the air above the boundary layer is sufficiently cool, then these rising currents accelerate and thunderstorms form. Typical Black Hills region thunderstorms are warm in their lower portions and cold in their upper portions. Experiments have been done on convective clouds in the region using hygroscopic seeding techniques to enhance precipitation produced by the collision and coalescence process in the lower warmer regions, and glaciogenic seeding techniques to enhance precipitation produced in the upper mixed-phase regions of convective clouds. Conversion from supercooled liquid to ice in the upper regions of these storms, caused by introduction of ice nuclei, can release additional latent heat of fusion (the so-called dynamic seeding effect) earlier in the storm lifetime, and can invigorate the convection and lead to additional precipitation compared to unseeded storms due to the cloud being more vigorous and longer lasting. Experiments using both glaciogenic and hygroscopic seeding were conducted in
the Black Hills region from the 1960’s into the early 1970’s with mixed results. (See, e.g., Dennis et al. 1975).

Development of precipitation in summer convective storms is much less predictable than in winter storms because it depends more on unpredictable small-scale variations and interactions in cloud circulations and cloud microphysical characteristics, and on chance interactions between the circulations of neighboring storms. Because natural precipitation from summer convective storms is quite variable, the impact of cloud seeding on precipitation can be difficult to separate from the natural variability between storms. It is therefore more difficult to discern the impact of cloud seeding on summer convective storms than for winter storms. Further, even though there have been experimental programs demonstrating precipitation increases from seeding of convective clouds, the physical chain-of-events connecting the seeding to the precipitation increase is not well understood. See reviews in Dennis (1980, Section 7.5); Bruintjes (1999); Silverman (2001); National Research Council (2003); and Silverman (2003) for further discussion of the issues. This reduces confidence in the predictable use of cloud seeding to enhance precipitation from summer convective clouds.

For purposes of this study, we will not include the potential impact of summertime seeding on summer rainfall. We will focus on wintertime seeding for which there is stronger scientific support.

**What could be the impact of cloud seeding on wintertime precipitation in the Black Hills region?**—Results summarized in the reviews cited above, as well as recent results from the Snowy Mountain project and WWMPP, lead to the expectation that seeding of wintertime orographic cloud systems can lead to increases in precipitation from those systems on the order of 5-15%. This range is incorporated into the Weather Modification Association’s Capabilities Statement on Weather Modification, adopted September, 2011, available at http://www.weathermodification.org/capabilities.php#Winter. This percentage range is based on analyses of the results of a large number of experimental and operational winter seeding programs in a variety of regions. Precise results are in general dependent on specific meteorological and topographical characteristics of the region, along with specific procedures followed and seeding materials used in particular projects. It cannot be assumed that this range of increases is likely in all orographic seeding situations.

Orville and Miller (1992) were the first to publish a study on the potential for cloud seeding to enhance winter precipitation over the Black Hills. Hereafter we will refer to this work as OM. This preliminary study was done in response to Black Hills region water shortages that occurred during a series of relatively dry years spanning the late 1980’s to 1990. Their approach was very simple: They assumed wintertime precipitation was predominantly orographic and assumed total winter precipitation could be increased by 10% by cloud seeding. They estimated the months of the year during which glaciogenic seeding was feasible based on climatological average temperatures at the highest elevation of the Black Hills, took the climatological average precipitation occurring in those months, and assumed an additional 10% of this could be coaxed from wintertime clouds over the Black Hills by seeding. They focused their attention on precipitation
into the Pactola Reservoir watershed, the main reservoir on Rapid Creek. Their main conclusions are:

- Glaciogenic cloud seeding over the Black Hills in winter could lead to 20,000-40,000 acre-feet of additional precipitation into the Pactola/Deerfield watershed in the central Black Hills. If 22.5% of this runs off into the reservoir, the additional water to be stored is 4500 – 9,000 acre-ft. [Compare this precipitation to the average annual inflow into the Pactola Reservoir, which is 35,000 acre-ft.] This is a potentially significant addition.
- From November through May mean temperatures near the highest elevations in the Black Hills indicate glaciogenic seeding is possible. There are on average 50-70 days with precipitation. They assumed that conditions over the Black Hills were suitable for precipitation enhancement by seeding on all of these days during these months.
- Seeding over the Black Hills is unlikely to diminish precipitation over regions downwind of the Hills.
- Seeding will be most effective if a combination of ground burners and airborne dispersion of seeding materials is used.
- The expected cost (in 1992 dollars) of conducting seeding operations over the entire Black Hills would be on the order of $250,000/year. Scientific analysis of meteorological and hydrological data to assess the effectiveness of the seeding would cost about the same, leading to a total of $500,000/year to conduct seeding and monitor its effects.
- A study should cover at least 5 years for the experiments to span a range of meteorological regimes and for a large enough number of events to occur for a 10% increase in precipitation to be detected.
- Periodic, intensive, special scientific studies to pursue better understanding of the detailed physical processes by which cloud seeding enhances precipitation (similar to what actually happened during the Snowy Mountain and WWMPP projects described above) could add another $500,000 in costs during the years they are conducted.

In the present study, we revisit this topic after a quarter century of additional studies of cloud seeding since OM. We present new analyses of the potential for precipitation enhancement, apply insights gained in the Snowy Mountain and WWMPP projects, and update the conclusions of OM.

METHODS

Estimate frequency of opportunities for glaciogenic cloud seeding in the Black Hills region—In their earlier work, OM looked at the number of days per winter with precipitation events at all reporting stations in the Black Hills. The numbers ranged from the upper 50’s to the low 70’s in the southern Black Hills to the low 100’s at Lead and Hardy Ranger Station in the higher elevations of the northern Black Hills.
Artificial ice nuclei will only nucleate ice particles at in-cloud temperatures significantly below 0 °C. Based on climatological weekly mean temperature at the 700 hPa level (corresponding to 3.0 km altitude above mean sea level, and roughly 1 km above the highest elevations in the Black Hills from the Rapid City radiosonde record being -5 °C or lower, OM deduced that precipitation should be forming by the mixed-phase process and conditions should be suitable for seeding for all precipitation events from October through May. They assumed that all precipitation falling during the months November through May, accounting for roughly 50% of total annual precipitation, could be enhanced by seeding. Although it is not clear from OM, in Orville (1992), it is apparent that the impact of seeding on precipitation is taken to be a 10% +/- 3.3% increase in total precipitation during this period. In this way they arrive at an increase of precipitation into the Pactola Reservoir drainage basin of 20,000-40,000 acre-ft. Of this increase, OM estimate 15-30% will run off and collect in the reservoir. If we take the OM mean estimated precipitation increase of 30,000 acre-ft and a mean estimate of 22.5% run-off, this amounts to 6,750 additional acre-ft of water added to the reservoir each winter season.

If seeding were conducted over the entire Black Hills region (covering approximately 15,000 km²), the corresponding estimated increase in water equivalent of winter precipitation is 10% of half of an estimated 6,000,000 acre-ft falling over the entire Black Hills region annually, or 300,000 acre-ft. of water. If 22.5% runs off, there would be an extra 67,500 acre-ft ending up in Black Hills streams and surface reservoirs. A roughly similar amount would recharge the important aquifers exposed in different locations in the Hills, and the rest will evaporate or be transpired through plants back into the atmosphere.

**A look at two daily seeding scenarios**—OM recommends that these estimates can be refined by looking at daily temperature and precipitation data. Their assumption that all precipitation events from October – May are orographic and seedable is an optimistic first order approximation. In response to this recommendation, we looked at daily precipitation data for two stations in the central Black Hills, Pactola Dam and Custer, along with the vertical temperature profiles from the Rapid City sounding during precipitation events.

Daxiong and Finnegan (1989) show that a high percentage of artificial nucleating particles generated using current technology really only become active at temperatures of -10 °C and below. For each day with snow and a liquid equivalent precipitation amount recorded, we assume that precipitation could have been enhanced by seeding if the temperature at 700 hPa (within 1 km above the highest elevations of the Black Hills) was -10 °C or lower sometime during the precipitation event on that day. This is a lower (colder) temperature threshold than the -5 °C utilized by OM and can be expected to reduce the estimate of how frequently cloud seeding can be carried out. At the level of the approximations we are using, however, we believe it is more realistic based on studies of nucleation of silver iodide aerosol particles.

For purposes of our study, we assume that ice nuclei will be dispersed from ground generators placed on the upwind flanks of the Black Hills. Such seeding aerosol releases will normally not reach regions higher than 1 km above the highest elevations in the Black Hills, if that far, in the absence of embedded con-
vection. OM suggest that airborne seeding could be used to reach higher, colder altitudes in clouds, if the clouds extend upward that far. However, in another work, Orville (1992) notes the increased expenses and physical difficulties of airborne dispersal of ice nucleants in orographic clouds in winter storm conditions. We assume that economics and safety concerns will likely dictate the use of ground seeding only.

Finally, we did a day-by-day analysis of whether or not cloud seeding can be expected to enhance precipitation, rather than use weekly and monthly mean conditions. Winter weather can be quite variable in the Black Hills region and we attempted to capture that variability with this approach. We chose two sites in the central Black Hills with good precipitation records, Custer and Pactola Dam, and looked at daily precipitation amounts for two winter seasons, along with temperature and dew point profiles between the ground and the 700 hPa level on the Rapid City radiosonde. Details are given below.

Figure 1 shows monthly precipitation over the entire Black Hills region from January, 2011 through March, 2015. It can be seen that winter 2011-2012 was the driest winter during the period, while winter 2012-2013 was wetter, particularly the later winter months of March – May in 2013. We analyzed these two winters as representative of a typical range of weather conditions in the Black Hills region. Although this may not perfectly represent the long-term area climatology, it is a refinement over the OM assumption.

Atmospheric soundings from the Rapid City National Weather Service office are available at 0000 or 1200 Universal Time (1700 local standard time the previous day, and 0500 local standard time of the current day). We assume these are representative of conditions over the Black Hills. If temperature anywhere between the ground and the 700 hPa level was -10 °C or below, and dewpoint was within a few degrees of the air temperature over some portion of this layer, we considered the day seedable. Even if these conditions were met, but surface temperatures were above 10 °C (50 °F) at both sounding times, then the day was considered unseedable. We also reviewed the national surface weather composite weather map available from UNISYS (http://weather.unisys.com) for a general characterization of synoptic-scale weather conditions in the region on days with precipitation.

OM applied an enhancement percentage to the total precipitation falling from November through May. However, for purposes of this study, we will assume an average 10% increase in precipitation on days when precipitation was observed and the day was seedable according to the above criteria. In other words, we assume seeding can increase precipitation only on days when it is cold enough and cloud conditions are suitable. Our criterion for “cold enough” is admittedly crude, but the concept that seeding may be feasible on some days and not others during the winter season is a refinement compared to the study of OM.

Data sources were:

- National Centers for Environmental Information (formerly the National Climatic Data Center) for daily precipitation. Observations of 24 hr precipitation amounts were recorded near the start of the work day at the Pactola
Dam at 0800 local time, and at 1300 local time at the U.S. Forest Service office in Custer.

- University of Wyoming weather web site, http://weather.uwyo.edu, for the Rapid City radiosonde sounding records.
- UNISYS weather web site, http://weather.unisys.com, for national surface weather composite charts valid at 0000 and 1200 Universal Time.

RESULTS

A map of the Black Hills region with topographic contours and with the locations of the observing sites depicted is shown in Figure 2. Although on days with substantial precipitation both stations usually reported precipitation, on days with light precipitation sometimes only one of the two stations reported precipitation. On occasion, data were flagged as missing. In addition, it is clear from comparing the records at the two sites, and reviewing the composite surface charts, that reports on some days at one or the other station represented precipitation for the current period and one or more prior ones. This was more likely to occur over weekends than on weekdays. This introduces some uncertainty into our analysis, but we do our best to minimize the impact on our results.

In Table 1 we compare the precipitation during what we will call the winter period (October – May) to precipitation during the entire water year (October – September). It can be seen that annual and seasonal precipitation amounts at the two sites are similar, with Pactola having slightly lower total water year precipitation in both seasons. The water year precipitation totals were 20 to 30% higher.
Figure 2. Topographic map of the Black Hills region with bold dashed isoheights indicating elevations in feet. The location of Custer is labeled and the outline of the Pactola Reservoir drainage basin is indicated by a light dashed line with the dam at the east end of the outline. Source: Orville (1989).
in 2012-2013 compared to 2011-2012. Winter (October – May) precipitation represents roughly half of the water year total precipitation at both sites in both water years.

Table 1. Water Year (Oct-Sept) and Winter (Oct-May) precipitation in inches at Custer and Pactola Dam for the seasons 2011-2012 and 2012-2013.

<table>
<thead>
<tr>
<th></th>
<th>2011-2012 Water Year</th>
<th>2011-2012 Winter</th>
<th>2012-2013 Water Year</th>
<th>2012-2013 Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custer</td>
<td>14.06</td>
<td>7.08</td>
<td>16.64</td>
<td>8.48</td>
</tr>
<tr>
<td>Pactola</td>
<td>12.23</td>
<td>7.31</td>
<td>15.65</td>
<td>8.07</td>
</tr>
</tbody>
</table>

The results of analyzing the situation for seedable days, as described above, are shown in Table 2. Total days in the season with precipitation were added up as days with precipitation at either Custer or Pactola. Seedable days were days with precipitation and temperature conditions at either Custer or Pactola suitable for seeding. The seasonal precipitation, October- May, is the average of the seasonal precipitation at the two sites. (See Table 1.) The observed precipitation on days suitable for seeding is the average of this quantity for the two sites for 2011-2012, and the precipitation at Pactola only for 2012-2013. In 2012-2013 precipitation observations at Custer were missing for most of the month of January, while there were 11 days that month with precipitation at Pactola. Although the missing data probably did not have a big effect on water year totals (Table 1), it had a significant impact on the number of seedable days and total precipitation on all seedable days. So for 2012-2013 we use Pactola data to represent seedable days.

Table 2. Analysis of precipitation on seedable days in winter (October – May).

<table>
<thead>
<tr>
<th></th>
<th>Precipitation Days</th>
<th>Seedable days</th>
<th>Seasonal precipitation (in.)</th>
<th>Precipitation on seedable days (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011-2012</td>
<td>78</td>
<td>30</td>
<td>7.20</td>
<td>1.90</td>
</tr>
<tr>
<td>2012-2013</td>
<td>90</td>
<td>64</td>
<td>8.28</td>
<td>4.61</td>
</tr>
</tbody>
</table>

Table 2 shows the two winter seasons to be very different. There were twice as many seedable days in 2012-2013, and more than twice as much total precipitation on seedable days, compared to 2011-2012. As weather varies from season to season, the results from seeding will also vary. Precipitation on seedable days was 26% of total winter precipitation for 2011-2012, while it was 56% of total winter precipitation for 2012-2013.

There were no seedable days in October, 2011, and only one in October, 2012. There were no seedable days in April, 2011, but 10 in April, 2013. There were no
seedable days at all in either May, 2012, or May, 2013. Almost all seedable days occurred during the months November to April.

We assume a 10% increase in precipitation can be produced on seedable days, and use the precipitation amounts on seedable days as representative of precipitation falling into the Pactola Dam catchment. If we assume a catchment area of 800 km² (OM), then we can convert this precipitation into acre-ft of additional water falling into the catchment. If we assume 22.5% of this additional precipitation ends up in the reservoir, we can estimate the contribution of seeding to water stored in the reservoir, following the same line of reasoning as OM. Results of this calculation are shown in Table 3. These results mirror the distinct differences between the two winters seen in the precipitation and seedable day statistics shown in Table 2. Using the assumptions made in this study, we estimated the additional storage due to enhanced precipitation produced by seeding to be less than 1000 acre-ft for winter 2011-2012, and not quite 2000 acre-ft for 2012-2013.

Table 3. Estimates of seeding effects on precipitation (P) and storage at Pactola.

<table>
<thead>
<tr>
<th>Winter</th>
<th>P (in.)</th>
<th>P (acre-ft)</th>
<th>Storage (acre-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011-2012</td>
<td>0.19</td>
<td>3130</td>
<td>704</td>
</tr>
<tr>
<td>2012-2013</td>
<td>0.461</td>
<td>7594</td>
<td>1709</td>
</tr>
</tbody>
</table>

These estimates are the product of very simple assumptions about the characteristics of days on which seeding can be effective, and the precipitation increase resulting from seeding. Evaluating whether seeding can increase precipitation on a daily basis, and using a lower temperature criterion for effective seeding, have produced dramatically lower estimates of the impact of seeding compared to those of OM. Both estimates of increased winter precipitation into the watershed, roughly 3000 acre-ft for 2011-2012 and roughly 7500 acre-ft for 2012-2013, are far below the estimates of Orville and Miller (1992) of an additional 20,000-40,000 acre-ft over an average winter.

If seeding is conducted over the entire Black Hills region, estimating the potential increase in precipitation to the ground is more challenging. The northern Black Hills on average receive more winter precipitation, and have a higher number of days per winter with precipitation, compared to the central and southern Black Hills regions (Orville and Miller 1992). If we assume the statistics derived above based on precipitation at Custer and Pactola are somewhere near an average between the northern and southern Black Hills region, and apply the precipitation increases in Table 3 to the entire region, covering roughly 15,000 km², then the additional precipitation on the entire region would be 59,000 acre-ft in a winter with the characteristics of 2011-2012, and 142,000 acre-ft for a winter like 2012-2013. This water would be an additional contribution to the regional water budget. Some would end up in one or more of the several smaller reservoirs around the Black Hills, but most of it would be much less manageable than the water falling into the Pactola basin.
SUMMARY AND CONCLUSIONS

This study seeks to further evaluate the potential utility of cloud seeding as a water management tool in the Black Hills region by refining earlier work by Orville and Miller (1992). A review of the literature on cloud seeding suggests that for this region wintertime seeding is likely to produce consistent precipitation increases; the impact of summertime seeding is not as certain. We extend the earlier work by considering seedability of storms on a daily basis and re-evaluate estimates of the quantity of additional precipitation that might be produced by a wintertime cloud seeding program. We use daily weather records for a dry winter and a wet winter. In addition, we assume precipitation enhancement requires lower temperatures than were assumed in the earlier study. By estimating precipitation enhancement on a daily basis, we arrive at a lower but still significant precipitation enhancement compared to Orville and Miller (1992). By our estimates, cloud seeding could contribute from one to several thousand additional acre-ft per winter to water stored in the Pactola reservoir in a typical winter. This is to be compared to the average annual inflow to the reservoir of 35,000 acre-ft. If clouds over the entire Black Hills region are seeded, when conditions are conducive to precipitation increase, in the neighborhood of 100,000 acre-ft can be added to the water budget of the Black Hills region. In all but already very wet years, this addition would be beneficial. Orville and Miller (1992) estimate that the incremental increase in cost to seed over the entire Black Hills regions compared to seeding just over the Pactola catchment is just 25%. For future studies, it would be best to plan on seeding over the entire region in order to get maximum return on investment in the form of additional water on the ground from the seeding.

Although it would be possible to proceed at this point to a multi-year physical study, like the Snowy Mountain or WWMPP studies, another option at this stage of consideration is performing numerical simulations of several seasons of weather, with parameterization of dispersal of seeding material and its impact on precipitation included in the simulation along with the normal natural meteorological processes. Cotton et al. (2006), Saleeby et al. (2007), Xue et al. (2013a) and Xue et al. (2013b) have recently demonstrated that current numerical weather prediction models are sufficiently sophisticated to incorporate a seeding mechanism and produce results from seeding in reasonable agreement with observations. It would be possible to numerically simulate several winter seasons over the Black Hills and compare results with and without seeding, for less than the cost of one year of a physical seeding study. It would be useful to have insights from these numerical studies to help refine the design of an experimental or operational seeding project.

Before seeding operations are implemented, consideration also needs to be given to socio-economic impacts of seeding. Orville and Miller (1992) discussed some of these issues, such as impact on driving conditions, wildlife, and the ski industry. We defer further discussion of these issues to a subsequent publication.

Overall, we find the potential benefits of cloud seeding over the Black Hills to be significant and advocate for continued discussion and study of how best to achieve them.
LITERATURE CITED


COMPARATIVE STUDY OF THERMALLY TREATED SILICON ANODE NANOSTRUCTURES BASED ON POLYACRYLIC ACID AND POLYANILINE FOR LITHIUM ION BATTERY APPLICATION

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ABSTRACT

A comparative study between a nonconductive thermoplastic, polyacrylic acid (PAA), and an electronic-conducting polymer, polyaniline (PANI), has been conducted related to their function as binders for Silicon Nanoparticle (SiNP)-based anodes in Li-ion battery application. SEM analysis was used to understand the morphological differences associated with dispersion of PAA/PANI with SiNPs. Further, thermogravimetric analysis was conducted in order to understand the thermal degradation and to choose their associated heat-treatment temperatures of 400 °C (PAA) and 300 °C (PANI). The electrochemical performance of the resultant silicon-based electrodes assembled in Lithium-half-cell configuration was evaluated in terms of their specific capacitance and cycle-stability. The results indicated that PANI-based SiNP anodes heat-treated at 300 °C demonstrate the highest specific capacitance and the lowest capacity loss over 10 cycles, which could be attributed to higher electrical conductivity and improved adhesion.

INTRODUCTION

Silicon has attracted substantial attention in lithium ion battery (LIB) research due to its exceptional theoretical specific capacitance (4200 mAhg⁻¹) which is the highest among any known material. However, Si undergoes a 300-400% volume expansion during the lithiation process which causes mechanical deterioration of the silicon macrostructure and loss of LIB performance. Furthermore, loss of electrical conductivity of silicon particles during delithiation implies that the conductivity factor should be considered at nanoscale. Finally, the solid electrolyte interface (SEI) layer (Kawamura, Okada, & Yamaki, 2006) formed on the anode surface and within the anode interior introduces additional challenges,
such as reduced Li-ion transport, separation of silicon nanoparticles from the conductive carbon and/or polymer phase, and anode delamination from the Cu support. These challenges can be addressed by (1) using silicon nanostructures (<50 nm) that sustain their mechanical integrity during lithiation-delithiation and (2) choosing an appropriate binder with sufficient electric conductivity, high elastic modulus, and mechanical strength to keep Si-nanoparticles in intimate contact with the conducting phase. Conventional binders, such as polyvinylidene fluoride (PVDF), carboxymethyl cellulose (CMC), sodium salts of CMC, combinations of Na-CMC with butadiene block copolymers, and polyacrylic acid (PAA) (Magasinski et al. 2010) partially eliminate the problems and improves LIB performance and cycling behavior. Conductive polymers such as polyaniline (Li et al. 2014; Wang et al. 2013) and poly(3,4-ethylenedioxythiophene) (Kim et al. 2014) were applied for both LIB cathode and anode materials to improve conductivity and provide mixed ion-electronic pathways for Li cations and electron transport. SiNP-PANi half cells (Wu et al. 2013) with 1600 mAh g⁻¹ capacity at high currents (up to 6 Ag⁻¹) demonstrated close to zero capacity loss after 1000 cycles. However, the SiNP-PANI half-cell specific capacitance (1600 g⁻¹) was significantly lower than Si-nanotubes (Cui et al. 2009) (3200 mAh g⁻¹) or nanowires (4277 mAh g⁻¹). Earlier it was shown that thermal treatment of PANI, PAA, and PANI/PAA blends (Lu et al. 2003) can significantly change their electrical conductivity (3.2 mS cm⁻¹ for polyacrylic acid/graphite nano-platelet (Tang et al. 2009) and PANI ~103 -102 mS cm⁻¹).

The purpose of this study was to identify the effects of heat-treatment on the SiNP based anodes prepared with two binders, specifically PAA and PANI, and characterize the effects in terms of electrochemistry. The chemistries involved with heat treatment of PAA and PANI are starkly different. Heat treatment of PAA results in the partial dehydration and in some cases decarboxylation of the carboxylic acid groups. Heat treatment of PANI, specifically the PANI-phytic acid hydrogel previously introduced (Wu et al. 2013), results in the oxidation of phosphate groups found on phytic acid and the evolution of water. In both cases, the eliminated functional groups are acidic in nature, which, in an electrochemical cell, can result in the activation of organic carbonates used as electrolyte solvents. This increases the likelihood of electrolyte reduction and the deposition of insoluble products (SEI) onto the anode surface. It is our hypothesis that elimination of acidic functional groups by heat treatment may have a beneficial effect on cell performance by minimizing electrode-electrolyte interaction.

METHODS

The SiNP-based anode slurries with PAA as a binder were synthesized by homogenization of 0.2 g SiNP (US Research Nanomaterials) with 5 mL of distilled water (2 hr) followed by addition of a 2.5 g of graphitized carbon and exfoliated carbon in 1:1 weight ratio under stirring conditions (2 hr). An aqueous solution of PAA from Alfa Aesar (Av. M.W. 240,000) in distilled water was prepared and added to the initial SiNP-water mixture under stirring conditions resulting in an SiNP-PAA slurry. The SiNP-PANi nanocomposites were processed in three steps.
First, 0.08 g of SiNP (US Research Nanomaterials) were homogenized with distilled water. Then, 0.00837 g of the aniline monomer (Sigma-Aldrich) and 0.01782 g aqueous phytic acid solution (50% by wt., Sigma-Aldrich) were added to the SiNP-water suspension and sonicated. Finally, 0.00856 g of ammonium persulfate (Sigma-Aldrich) was added to initiate radical polymerization of the oxidized aniline. After about 3 minutes of continuous stirring, we observed a color change from brown to green indicating formation of an electrically conductive emeraldine. The slurries were deposited onto carbon coated Cu foil (MTI) using a Systematic Automation screen printer and allowed to dry under ambient conditions for 1 hour. Once dried, the PANI electrodes were soaked in deionized water for 1 hour to remove excess phytic acid. The electrodes were heated in a vacuum oven at various temperatures and constant pressure covered with Teflon and a stainless steel plate. The electrodes were cut into disks (active area 0.907 cm$^2$) and degassed overnight in a vacuum. CR2023 stainless steel coin cells with a K1640 Celgard polyethylene membrane (16 µm thick) were assembled in an argon glove box with O$_2$ and H$_2$O concentrations < 1 ppm. Lithium foil reference electrodes (Alfa Aesar) were used with SiNP-PANI and SiNP-PAA working electrodes. During the half-cell assembly, 30 µL of an electrolyte solution from Solvionic containing 1.0 M LiPF$_6$ in 1:1 v/v ethylene carbonate: dimethyl carbonate with 2% wt. vinylene carbonate was deposited on both sides of the separation membrane.

Thermogravimetric analysis was performed using an SDT Q600 (TA Instruments). Impedance spectroscopy data were obtained from PARStat 2273 (Princeton Applied Research). Galvonostatic charge/discharge cycling and cyclic voltammetry measurements were performed using 580 Battery (Scribner Associates). The images of the electrode surfaces and nanocomposites were taken using a Supra 40VP (Zeiss) field emission scanning microscope equipped with EDX.

RESULTS AND DISCUSSION

Morphological characterization—The SEM images for SiNP-PAA and SiNP-PANI (Figure 1) indicate satisfactory coverage of the Cu support and an even distribution of the silicon nanoparticles with a mean diameter of about 50 nm within the anode layer. The “in-situ” PANI impregnation resulted in higher dispersion and better distribution than the simple stirring process used for PAA. The SiNPs-C-PAA nanocomposite revealed “islands” of PAA indicated by the circle in Figure 1.

Thermogravimetric analysis (TGA) and dynamic scanning calorimetry (DSC) were performed on SiNP-PAA and SiNP-PANI composites to elucidate the temperatures at which their acidic groups evolve. The results of TGA/DSC are presented in Figure 2. In the case of PANI, the significant weight loss below 100 °C corresponds to the evaporation of moisture and ambient monoatomic molecules. The steady weight loss between 100 and 300 °C corresponds to the decomposition/evaporation of synthesis byproducts (e.g. ammonium persulfate, ammonia, sulfuric acid, and aniline). The massive drop in weight percent between 300 and 400 °C which parallels the DSC peak at 362 °C most likely corresponds to the
Electrodes were cut into disks (active area 0.907 cm²) and degassed overnight in a vacuum. The electrodes were heated in a vacuum oven at various temperatures and constant pressure covered with Teflon and a stainless steel plate. The temperature to remove excess phytic acid. The electrodes were heated in a vacuum oven at various temperatures to remove excess phytic acid. The electrodes were heated in a vacuum oven at various temperatures to remove excess phytic acid. The SiNPs-C-PAA nanocomposite revealed “islands” of PAA indicated by the impregnation resulted in higher dispersion and better distribution than the simple stirring process nanoparticles with a mean diameter of about 50 nm within the anode layer. The “in-situ” PANI (Figure 1) was deposited on copper support. Islands of PAA are enclosed within the oval in A.

![Image](image_url)

Figure 1. FESEM images for non-heat treated (A) SiNPs-C-PAA and (B) SiNP-PANI deposited on copper support. Islands of PAA are enclosed within the oval in A.

Figure 2. TGA and DSC profiles of (A) SiNP-PAA and (B) SiNPs-PANI inks.

Thermal dehydration of phytic acid, which coincides with the recent study by Daneluti and Matos 2013. The slight drop in weight percent between 500 and 600 °C corresponds to the partial pyrolysis of phytic acid. Based on these results, the chosen heat-treatment temperature for SiNP-PANI was 300 °C. Upfield shifts in the DSC peaks were assumed to be present due to the 10 °C per minute scan rate. Because of this, 300 °C was chosen as there should be sufficient energy to initiate the dehydration of phytic acid, yet avoid the side reaction seen at 475 °C where the weight percent slightly increases, suggesting oxidation of silicon. In the case of SiNP-PAA anodes, the heat treatment temperature was chosen to be 400 °C to parallel the strong DSC peak which most likely represents the dehydration/decarboxylation of the PAA. Heat treated anodes were compared to a control group of non-heat treated SiNP-PAA and SiNP-PANI anodes. We hypothesized that degradation of these acidic groups may improve cell performance by decreasing the amount of electrolyte decomposition and SEI formation.

**Electrochemical characterization**—Heat treated and non-heat treated SiNP-PAA and SiNP-PANI half cells were galvanostatically charged and discharged at 0.1 Ag⁻¹ from 0.1 to 1 V. The specific capacitance values as well as coulombic efficiency can be seen for the first 10 cycles in Figure 3. For all cells, heat treated and non-heat treated, the initial specific capacitance was approximately 2000 mAhg⁻¹.
with the exception of non-heat treated SiNP-PANI which was approximately 2300 mAhg⁻¹. However, initial specific capacitance values can be misleading since a fraction of that value is contributed by the reduction of the organic electrolyte solvent by the Li reference electrode to form SEI. From an engineering perspective, minimizing capacitance loss after the first cycle is more important for anode performance than striving to achieve exceedingly high specific capacitance values. The demand for batteries that exhibit greater stability and cycle life greatly outweighs the demand for higher specific capacitance, especially since cathodes, not anodes, are the capacitance defining electrodes in a full cell. In all of our cells, the original specific capacitance values drop after the first cycle. This difference can be accounted for by electron exchange between the reference electrode and the electrolyte solvent. For all non-heat treated cells, the capacity continues to drop even after the first cycle and every cycle thereafter. We hypothesize that this continual drop in capacitance is due to the catalyzation of further electrolyte reduction by the acidic groups in the binder. Greater amounts of insoluble SEI products deposited on the surface of the working electrode accelerates the rate at which the open circuit potential of the cell drops during the lithiation process. Therefore, the potential for Li insertion into the bulk of the SiNP diminishes as well. In the case of SiNP-PAA, carboxylic acid groups in polyacrylic acid donate a proton to activate the organic carbonates found in the electrolyte solvent. In the case of SiNP-PANI, it is the phosphate groups found in phytic acid that donate protons. It was expected that heat treatment would weaken this catalytic effect. However, it is apparent that for heat treated SiNP-PAA cells, the specific capacitance violently drops after every cycle and approaches zero. This poor performance is due most likely to the loss of ion-conductivity throughout the electrode. The ion conductivity of PAA is directly dependent on cation exchange through the carboxylic acid group. When Li ions cannot conduct through the interior of the electrode, the cell voltage quickly drops before maximum capacity is reached. Therefore, heat treatment of PAA does not improve the performance of the SiNP-PAA electrode. For heat treated SiNP-PANI cells, the ion conductivity of polyaniline is not dependent on the acidic groups found in phytic acid. Therefore, Li cations can still make their way into the interior of the Si bulk. The flat line specific capacitance following the first cycle shows that a limited amount of Li is irreversibly consumed and the open circuit potential does not change from cycle to cycle.

Another hypothesis is that the composites undergo morphological changes when subjected to heat treatments. PAA has a glass transition temperature of 106 °C and PANI has a glass transition of 160-300 °C (Qi et al. 2009) depending on the doping level, anion, chain length, and crosslinking. Heat treatment of the polymer binders may cause nanostructure changes, such as the amount of surface contract between the SiNP and the polymer. This may impact the ion and electron transport processes in these electrodes. In the case of SiNP-PAA, this effect would be harmful, because PAA covering the SiNP surface would block ion and electron transport. In the case of SiNP-PANI, this effect may be beneficial as it would improve electron transport to the SiNP.

The improved performance of SiNP-PANI can also be explained by the in-situ synthesis process which promotes a high level of homogenization and thorough
dispersion of polyaniline throughout the electrode interior. The same level of homogenization cannot be achieved by simply mixing silicon nanoparticles with a polymer, such as is the case with polyacrylic acid. This distinction is clearly visible in SEM images, where islands of polyacrylic acid are found remotely from the SiNP. Furthermore, phytic acid has the ability to oxidize multiple polyaniline chains, therefore crosslinking (Figure 4) them and creating a three-dimensional “caged” nanostructure that confines each silicon nanoparticle to a limited volume (Pan et al. 2012; Wu et al. 2013). The caged nanostructure helps control volume expansion by inhibiting outward growth and, in turn, minimizing discontinuity caused by fracture and pulverization. The homogenous nature of the polymer network ensures that there is Si-polymer interface throughout the electrode interior, promoting stable electron/ion pathways to each Si nanoparticle in the structure.

Additional evidence for the advantages of PANI- vs. PAA-based systems was obtained from the cyclic voltammetry (CV) data (Figure 5A and Figure 5B, respectively) that provided valuable information about the morphological changes within silicon-lithium alloy upon lithiation and delithiation, ionic and electronic transport at the interface of SiNP and solid electrolyte interface (SEI), and an indication of the ionic and electronic transport at the interface of SiNP and the binding polymer.
In the case of PAA (Figure 5A), a small anodic peak at 0.25 V corresponds to delithiation of the carbon phase and the flow of electrons into the SiNPs-C-PAA working electrode. It is necessary to emphasize that this peak is visible from the very beginning (Cycle 1), representing high reactivity for Li-ion insertion into the carbon phase as opposed to the silicon phase, which does not present a peak until Cycle 5 at 0.52 V. However, with the growing number of cycles, the second anodic Si peak at 0.38 V becomes clearly visible. The existence of two Si peaks indicates that with time more pronounced gradual phase transformation takes place. In this case, two steps corresponding to different energies and crystal structural modifications of silicon –lithium LixSiy alloy in the presence of PAA and carbon are assumed.

Regarding the PANI-based electrode (Figure 5B), a very different electrochemical picture is observed. Since the PANI-based electrode does not contain carbon, the first peak in the lower voltage range is absent. However, two silicon peaks are

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**Figure 4.** A fragment of the cross-linked PANI-phytic acid network within SiNP-PANI nano-composite.

**Figure 5.** Cyclic voltammetry plots for PAA-based working electrode (50%SiNP-35%C-15%PAA) (A) and PANI-based working electrode (50%SiNP-50%PANI) (B) in CR2023 stainless steel coin cells vs. Li/Li$^+$ reference electrode at room temperature.
present from the very beginning (Cycle 1), suggesting that a better electronic and ionic transport takes place at the interface with SiNPs in the presence of PANi, making Li exchange more favorable. The second “high energy” peak (0.48V) disappears with cycling, suggesting that the system reaches an equilibrium and that the delithiation process requires less energy consumption. Furthermore, comparison of the major silicon peaks after multiple cycles in SiNP-PAA (0.52V) and SiNP-PANI (0.33V) show that more energy is required for delithiation of PAA- vs. PANI-based electrodes.

Based on our observation, the stability of the PANI-based electrodes can be explained by the improved ratio of the ionic and electronic conductivity at the interface between the PANi and SiNPs.

CONCLUSIONS

The superior performance of PANI as a conductive binder for Li-ion battery anode has been demonstrated in comparison to PAA. The effects of heat treatment were investigated for both materials, indicating that heat treatment of PAA is detrimental to electrode performance, while the heat treatment of PANI greatly improves cycle stability. It is assumed that the heat treatment decreases the acidity of both polymer binders, therefore reducing the presence of parasitic SEI forming reactions. In comparison to the PAA, SiNP-PANi -based electrodes demonstrate the most stable cyclic stability with almost zero capacity loss between cycles. However, heat treatment negatively affected the conductivity of PAA, and ultimately decreases its performance. The results confirmed by the CV analysis indicate that PANi is superior to PAA as a binder due to its electrically conductive properties and that the electrode performance can be optimized with heat treatment.

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LITERATURE CITED


IDENTIFICATION AND CHARACTERIZATION OF DROUGHT-TOLERANT ALFALFA (*MEDICAGO SATIVA* SUBSP. *FALCATA*) GERMPLASM

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ABSTRACT

Alfalfa is one of the most important forage legumes worldwide. However, its use in the semiarid and arid regions is limited due to its poor stand establishment and persistence under drought conditions. Development of drought-tolerant alfalfa cultivars is of great need for improving forage and livestock production in these regions. Morphological and physiological mechanisms play a critical role in drought tolerance by influencing seedling survival, stand establishment, and recovery from drought. Assessment of physiological response variability among germplasms to drought is an essential precondition for developing drought-tolerant cultivars. A greenhouse study was conducted to evaluate the variations in stomatal conductance, chlorophyll content, and root to shoot (R/S) ratio of eleven alfalfa populations under drought treatments. Eleven entries included one *sativa*-based commercial cultivar, six *falcata*-based populations, and four rangeland naturalized populations. Uniform seedlings of each population were watered to attain drought treatment regimes of 100, 50, and 25% of field capacity. Two *falcata*-based germplasms that had originated under annual precipitation of 165 mm and 250 mm (natural environmental conditions) demonstrated drought-tolerant associated traits. They exhibited either the lowest stomatal conductance or the greatest increased leaf chlorophyll content change under severe drought among the 11 populations. Both populations also showed the highest R/S ratio and least reduction of total biomass under the severe drought condition. The results indicated that reducing water loss through minimizing transpiration while increasing root water absorption, and the ability of delaying leaf senescence thus retaining photosynthesis are some key traits that may contribute to drought tolerance in these *falcata*-based alfalfa populations.

Keywords

alfalfa seedling, drought tolerance, stomatal conductance, root to shoot ratio, chlorophyll, falcata
INTRODUCTION

Alfalfa is an important economical and ecological forage crop for livestock in agricultural systems. It is high in vitamins, magnesium, minerals, fiber and protein (Balliette and Torell 1998). Along with its high nutritive diet value to livestock, alfalfa provides ecosystem services by fixation and addition of nitrogen to the soil. However, lack of soil moisture and frequent drought, especially prevalent in the semi-arid region of the Northern Great Plains (NGP), are the primary limiting factors for alfalfa establishment and persistence, and production (Kang et al. 2011; Misar et al. 2015). The development of drought-tolerant cultivars with improved yield biomass and feed quality has been demanded for some time.

Drought was defined as prolonged dry weather when precipitation is less than 75% of the average annual amount (Society for Range Management 1989). Studies have shown that drought can reduce crop yields by 69% (Boyer 1982) and cause extensive economic loss for farmers and ranchers. Global climate change is a major driver of more frequent drought. Otkin et al. (2015) used a probabilistic drought intensification forecast model and demonstrated that drought will occur more frequently and intensely in the future. Compared to Medicago sativa (predominantly taprooted), M. falcata is considered to better tolerate drought, cold, and grazing due to its broad, deep-set crowns, and well-developed rooting rhizomes and numerous branch root system (Berdahl et al. 1989; Garver 1922; Heinriches 1954). Development of alfalfa cultivars with an improved drought-tolerant seedling stage is crucial for successful stand establishment (Misar et al. 2015).

Plants have evolved diverse physiological and morphological mechanisms to adapt to drought-stress conditions (Blum 1996). One of these mechanisms is altering resource allocation between root and shoot systems, resulting in an increased root to shoot biomass ratio (R/S) (Harris 1992). Under drought conditions some plants reduce shoot production to minimize water loss through transpiration, while other plants increase root biomass investment for exploiting soil water (Erice et al. 2010). Another mechanism developed to combat drought involves regulating stomatal conductance, which controls CO₂ uptake and water loss. The better a plant can regulate stomatal conductance under drought conditions the less it will lose water through evapotranspiration (Montague et al. 2008). The ability of a plant sustaining chlorophyll content under drought condition is an important adaptation for maintaining photosynthesis to support growth, particularly root growth. Chlorophyll deterioration, an early indicator of leaf senescence (Kang et al. 2011), leads to loss in photosynthetic capacity and ultimately to plant death. To identify variability of drought resistance characteristics among the populations and to understand the underlying mechanisms are essential preconditions for developing drought-tolerant cultivars. The main objective of this study was to examine physiological traits associated with drought tolerance among 11 alfalfa populations under different drought-stress treatments.
METHODS

Seed Source—Eleven alfalfa populations were evaluated in this study, including Persist II, SD201, SD202, SD203, Wind River, NE1010, five plant introductions (PIs) (PI631677, PI631678, PI631682, PI502441, and PI538984). Persist II seeds were purchased from Millborn Seeds Company (Brookings, SD). It is a commercial M. sativa type. Seeds of SD201, SD202, SD203, and NE1010 were collected from the experimental plots at Felt Family Farm of South Dakota State University Agricultural Experimental Station (Brookings, SD). SD201 was pure M. falcata. SD202 and SD203 were naturalized populations in northwestern SD and have a predominantly M. falcata base. Wind River seeds were purchased from Wind River Seed (Manderson, WY) and are predominantly M. falcata base. All PIs were acquired from National Germplasm System (Pullman, WA). Selection of PIs was based on their original natural distribution latitudes and climate similarity to South Dakota (Table 1).

Table 1. Description and marketer/origin of 11 alfalfa populations used to evaluate physiological traits for drought resistance at a greenhouse of South Dakota State University

<table>
<thead>
<tr>
<th>Entry</th>
<th>Description</th>
<th>Marketer/Origin*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI631677</td>
<td>M. sativa subsp. falcata, NPGS</td>
<td>Mongolia, Lat. 49°49'32” N, Long. 92°3’48”E Elev. 1,141m</td>
</tr>
<tr>
<td>PI631678</td>
<td>M. sativa subsp. falcata, NPGS</td>
<td>Mongolia, Lat. 49°46’40” N, Long. 91°53’52”E Elev. 1,463m</td>
</tr>
<tr>
<td>PI631682</td>
<td>M. sativa subsp. falcata, NPGS</td>
<td>Mongolia, Lat. 48°10’33” N, Long. 91°45’29”E Elev. 1,232m</td>
</tr>
<tr>
<td>PI502441</td>
<td>M. sativa subsp. falcata, NPGS</td>
<td>Russian Federation, Lat. 46°11’24” N, Long. 43°53’24”E Elev. 55m</td>
</tr>
<tr>
<td>PI538984</td>
<td>M. sativa subsp. falcata, NPGS</td>
<td>Kazakhstan, Lat. 46°11’24” N, Long. 43°53’24”E</td>
</tr>
<tr>
<td>NE1010</td>
<td>M. sativa subsp. falcata, NPGS</td>
<td>Brookings, SD, Lat. 44°18’41” N, Long. 96°47’53”W</td>
</tr>
<tr>
<td>SD201</td>
<td>M. sativa subsp. falcata, NPGS</td>
<td>South Dakota State University experimental for forage and wildlife habitat</td>
</tr>
<tr>
<td>SD202 (Coiled)</td>
<td>Predominantly M. sativa subsp. falcata</td>
<td>South Dakota State University experimental with coil shaped seed pods collected from a feral population in native rangeland in northwest SD</td>
</tr>
<tr>
<td>SD203 (Sickle)</td>
<td>Predominantly M. sativa subsp. falcata</td>
<td>South Dakota State University experimental with sickle shaped seed pods collected from a feral population in native rangeland in northwest SD</td>
</tr>
<tr>
<td>Wind River (WR)</td>
<td>Predominantly M. sativa subsp. falcata</td>
<td>Wind River Seed, Manderson, Wyoming, developed by Norman G. Smith, Lodgepole, South Dakota</td>
</tr>
<tr>
<td>Persist II</td>
<td>M. sativa, Cultivar, Conventional Hay-Type</td>
<td>Millborn Seeds Inc.</td>
</tr>
</tbody>
</table>

* indicates the information of PIs from USDA-ARS National Genetic Resources Program
**Experimental Procedure and Treatments**—A completely randomized design was used for this experiment. The experiment consisted of eleven populations with seven replications under three drought regimes (100, 50 and 25% of field capacity) and two drought durations (15 days and 30 days). The 50 and 25% of field capacity treatments created mild and severe drought-stress with soil volumetric water content of 12 and 2.2% (Kang et al. 2011).

For each population, 150 uniform seeds were selected under a dissecting scope and were hand scarified three times with 320 grade sandpaper for 5 seconds. Scarified seeds were germinated between moistened blotters in a growth chamber for seven days at 20 °C. Two uniform seedlings were transplanted into 164 ml plastic cone containers (Ray Leach “Cone-containers”; Stuewe and Sons, Inc., Tangent, OR) filled uniformly with ~46 g of Sunshine Mix #3 potting soil (Sun Gro Horticulture Canada Ltd. Seba Beach, AB, Canada). Drought regime by drought duration combination treatments were replicated 7 times (7 cone containers for each drought regime by duration treatment). All containers were maintained in greenhouse under 24 ± 3 °C, 16 hour light and 8 hour dark photoperiod for the entire course of the experiment and were watered with a Miracle-Gro® nutrient solution (one tablespoon (15 g) per gallon (3.79 L) of water). The position of all containers was randomly rotated daily to minimize the effect of the variations of microenvironmental factors in the greenhouse.

Two seedlings in each cone-container grew ten days under 100% of field capacity after transplanting, then they were thinned to one seedling per cone-container to ensure plants were relatively uniform in size. Seedlings grew 11 more days under 100% of field capacity to reach trifoliate stage with concomitant root development prior to drought treatment application.

For the 100% of field capacity treatment, plants were watered with the same amount of water (21 ml) every other day at the same time of the day from the beginning of the experiment. Plants were subjected to 50% (mild drought) and 25% (severe drought) of field capacity treatments by withholding water for 7 and 12 days, respectively. After the initial 7 and 12 days, plants were rewatered with 11 ml and 7 ml of Miracle-Gro® nutrient solution every other day for 50 and 25% of field capacity, respectively.

**Data Collection**—Stomata conductance (SC) was measured using a SC-1 Leaf Porometer (Decagon Devices, Inc. Pullman, WA) between 9 am and noon 15 days after drought treatments were initiated (n = 3 per population). Chlorophyll content measurements were taken during 9 am to noon on 16 days after drought treatments using a SPAD 502 Plus Chlorophyll Meter (Konica Minolta, Inc.) (n = 7 per population).

Plants were harvested at the end of each drought duration regime of 15 and 30 days (n = 7 per population per duration regime). Soil was carefully removed from the roots with flowing water. Roots and shoots were separated at the crown and oven dried at 60 °C for 72 hours. Root to shoot (R/S) ratio was calculated by dividing the root biomass by the shoot biomass for each plant.

**Statistical Analysis**—Percent change in chlorophyll content was calculated by finding the difference between the mean chlorophyll content indices of 100 and 25% of field capacity divided by the mean of 100% of field capacity chlorophyll content. Differences in physiological traits (stomatal conductance, chlorophyll
content index, and R/S ratio) among populations were determined by one-way analysis of variance and Duncan Multiple Comparison Test (P < 0.05) using procedures in SAS Institute, Inc. (1990) for each drought duration treatment (15 d and 30 d) and each drought regime. Levene’s test was used to test for homogeneity of variance.

**RESULTS**

**Stomatal Conductance**—Stomatal conductance (SC) (mmol m\(^{-2}\) s\(^{-1}\)) was significantly different among the 11 populations for the 15-day drought duration treatment at each drought level (Figure 1). The stomatal conductance ranged from 71.9 to 135.0 (mmol m\(^{-2}\) s\(^{-1}\)) \((P < 0.0001)\), 56.5 to 109.3 (mmol m\(^{-2}\) s\(^{-1}\)) \((P < 0.0001)\), and 11.3 to 36.2 (mmol m\(^{-2}\) s\(^{-1}\)) \((P < 0.0001)\) for plants under well-watered (100% of field capacity), mild drought-stress (50% of field capacity), and severe drought-stress (25% of field capacity) treatments, respectively. Mild and severe drought stresses reduced the stomatal conductance by 8 to 20% and 68 to 84%, respectively. The stomatal conductance of all 11 populations showed a similar response pattern to drought treatments: *falcata*-based populations demonstrated lower stomatal conductance compared to *sativa*-based populations, particularly under severe drought-stress. PI502441 had the lowest stomatal conductance and Persist II had the highest stomatal conductance (Figure 1).

![Figure 1. Stomatal conductance for 25, 50, and 100% of field capacity and 15 days drought duration treatment (n = 3) (** indicates P < 0.0001 within each field capacity). Bars indicate standard errors.](image)
**Chlorophyll Content**—The values measured by the SPAD-502 meter are proportional to the amount of chlorophyll present in the leaf (Ling et al. 2011). We used these values as the chlorophyll content index (CCI). CCI was found to be significantly different among 11 populations under well-watered ($P < 0.0001$) and water stress conditions (50 and 25% of field capacity) ($P < 0.01$). Persist II and Wind River had high CCI under well-watered condition among 11 populations, but a reduction in CCI under drought stress (50 and 25% field capacity). In contrast, PI502441 exhibited an opposite pattern: it showed highest CCI under severe drought. Changes in percent of CCI from well-watered to severe drought among 11 populations ranged from decreasing by 25.9% in Persist II to increasing by 8.7% in PI502441 (Figure 2). CCI increased under severe drought at 15 days drought duration treatment for all PIs (*falcata* -based populations) except for PI631682, indicating that these *falcata* -based populations have the ability of delaying leaf senescence, thus retaining photosynthesis.

**Biomass**—There were significant differences in shoot, root, and total biomass among the 11 populations for each drought regime and duration ($P < 0.0001$) except for root biomass under severe drought for 30 duration ($P = 0.094$). For 30 days drought duration, shoot biomass decreased as field capacity decreased from well-watered (0.8424g to 1.9007g, $P < 0.0001$) to mild drought (0.3826g to 0.6638g, $P = 0.0154$) to severe drought (0.1261g to 0.3867g, $P < 0.0001$). The root and total biomass followed a response pattern similar to that of drought stress. Among 11 populations, PI502441 showed the least reduction (17%) in total biomass when field capacity decreased from well-watered to severe drought.
(25% field capacity), while Wind River had greatest biomass reduction (60.6%) (Figure 3).

**Root to Shoot Ratio (R/S ratio)**—Root to shoot ratio did not differ significantly under the 15-day drought duration treatment among 11 populations at 100% field capacity ($P = 0.2362$), but differed under mild and severe drought ($P = 0.0008$ and $P = 0.0082$, respectively). They were also found to differ significantly for the 30-day drought duration treatment, in which the R/S ranged from 0.2289 to 0.9732 under 25% field capacity ($P < 0.0001$). PI538984 had the highest R/S ratio and Persist II had the lowest (Figure 4). In addition, there was a noticeable trend: pure *falcata* populations had the highest R/S ratio, followed by Predominantly *falcata*- then by *M. sativa*-based populations. There was no obvious pattern among 11 populations for the 50% of field capacity treatment, R/S ranging from 0.356 to 0.7635 ($P = 0.0215$). For the 100% of field capacity treatment, the R/S ratio was generally lower compared to other two drought intensity treatments, and among 11 populations ranged from 0.1067 to 0.2779 ($P < 0.0001$) (Figure 4).

![Figure 3. Above- and below-ground biomass comparison for 25, 50, and 100% field capacity in 30 days drought duration treatment (n = 7). Horizontal line separates aboveground and belowground. Bars indicate standard errors.](image-url)
Plants respond to drought in a variety of ways. Previous studies reported yellow-flowered alfalfa (*falcata*-based) is more winter-hardy, drought tolerant, and grazing tolerant than other alfalfas due to its deep-set crown and fibrous root system (Hansen 1909; Oakley and Garver 1917; Heinrichs 1963, 1975; Berdahl et al. 1989, Misar et al. 2015). Our study showed some physiological adaptive traits to drought stress. The main physiological pathways for drought resistance include closing stomata, which may be caused by levels of xylem abscissic acid (Tardieu et al. 1992), and reducing shoot biomass to hinder water loss through transpiration, increasing allocation of biomass to the root system to facilitate water absorption (Xu et al. 2010), and delaying chlorophyll degradation to maximize resource utilization in other essential processes. Stomatal conductance declined under mild to severe drought and was lower for *falcata*- than *sativa*-based populations. PI502441 had the lowest stomatal conductance under severe drought (Figure 1). Thus, *falcata*-based populations are better at regulating transpiration loss under unfavorable soil moisture. Similar results were found by Kang et al. (2011).

Percent change of chlorophyll content increased under severe drought for all PIs except PI631682. PI502441 had the greatest increase in chlorophyll content, indicating delayed leaf senescence and continued photosynthesis (Figure 2). In contrast, Persist II chlorophyll content decreased more than 25% under severe drought compared to 100% field capacity, suggesting chlorophyll degradation, leaf senescence, and reduction of photosynthesis. All of these physiological processes indicated that *falcata*-based populations are more drought tolerant than *sativa*-based populations. This concurs with results reported by Kang et al. (2011).
Root to shoot ratio increased under severe drought for *falcata*-based populations. PI538984 had the greatest R/S ratio, suggesting greater resource allocation to root growth to access water (Figure 4), the limiting factor for growth under drought condition. Berdahl et al. (1989) found that *falcata*-based alfalfa became dormant during midsummer drought and grew slower than *sativa*-based alfalfa, allowing the *falcata*-based alfalfa to persist through drought conditions and to conserve energy. Slower growth in both above- and below-ground biomass under mild to severe drought condition (Figure 3) is consistent with results for alfalfa by Wang et al. (2012). A possible explanation for seven of eleven of the entries having a higher root to shoot ratio at 50% field capacity than at 25% field capacity is because 50% field capacity may be the threshold beyond which they no longer can respond physiologically to drought.

*Falcata*-based alfalfa was also found having capacity to develop adventitious shoots from root segments (Kannenberg et al., unpublished data), which is a favorable trait for stand persistence due to vegetative reproductive capability. Heinrichs (1963) suggested that plants producing new shoots from rootstalks may be an important survival mechanism for alfalfa in rangelands. Our results support the value of testing to identify additional traits in PI502441 and PI538984 that may be used for potential drought–tolerant cultivar improvement, but further investigations, such as water use efficiency, leaf water potential, relative water content, root morphology, ability of recovery from drought, and capability to produce adventitious shoots from rootstalks, are needed.

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LITERATURE CITED


IDENTIFYING PROMISING NEW FALCATA ALFALFA POPULATIONS FOR USE IN SEMIARID RANGELANDS

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ABSTRACT

Alfalfa (Medicago sativa L.) is a valuable crop worldwide. In addition to use as forage, the nitrogen fixation capabilities of root nodules make it a valuable component in maintaining soil health. Unfortunately, the semi-arid region of the Northern Great Plains introduces a number of environmental stresses that are detrimental to stand establishment and persistence. This study aimed to identify alfalfa populations possessing the ability to produce adventitious shoots from root segments. The ability to produce adventitious shoots from roots is generally considered a favorable trait for increasing stress resistance. Seven Plant Introductions (PIs), selected from the National Plant Germplasm System, and one commercial cultivar (Persist II) as a control, were evaluated. Two six-centimeter root segments, originating at one and seven centimeters below the cotyledonary node, were cut from one year old plants. Root segments were planted in Miracle-Gro® potting soil, and cultivated under greenhouse conditions for 16 weeks. Adventitious shoot emergence was recorded throughout the experimental period. At the end of the experimental period, the number of adventitious shoots, shoot survival, flowering status, and non-shoot-bearing root segment decay were determined. Six of the seven PIs produced adventitious shoots. No shoots were produced by Persist II and PI494662. Among the six populations, the frequency of generating adventitious shoots ranged from 3.8% to 57%. Shoot survival ranged from 33% to 100%. Speed of regeneration from roots and viability of root segments in soil varied among populations. PI631678 had the greatest frequency and speed of regeneration from roots, as well as high survival and flowering rates. Adventitious shoot regeneration and survival was not affected by origin distance below the cotyledonary node within in the same populations.

Keywords
alfalfa, adventitious shoot growth, stress resistance, root segment
INTRODUCTION

Alfalfa is a valuable forage crop worldwide. A high protein content makes it an excellent complement to corn silage, lessening and sometimes eliminating the need for protein supplements. Also possessing relatively high concentrations of calcium and other minerals, alfalfa is particularly valuable for dairy cattle (Jennings 2014). In addition to the nutritive value alfalfa has as a forage crop, the nitrogen fixation properties of alfalfa roots make it a valuable component in soil fertility management. In the semi-arid regions of the Northern Great Plains, yellow-flowered alfalfa (YFA) (*Medicago sativa* subsp. *falcata*) holds a particular interest.

YFA has become naturalized to semiarid climate conditions in the Grand River National Grassland of South Dakota (Xu et al. 2005), but has traditionally been plagued by difficulties in seed germination and stand establishment in this region. These difficulties stem from drought, extreme cold and grazing pressures from cattle. Overcoming these difficulties would be beneficial for this valuable forage crop.

Adventitious growth is vegetative reproduction that occurs from a living portion of the parent plant, instead of from a seed. This ability is generally considered a favorable trait for increasing stress resistance in plant populations, particularly in environments where seed production is unreliable due to grazing, and stand establishment and persistence are poor.

Adventitious shoots produced on the roots of alfalfa is an uncommon phenomenon. The first reports were made in South Dakota by Oakley and Garver (1913) on a strain of YFA originating from Orenburg, Russia, and later on a strain from Semipalatinsk, Siberia (Oakley and Garver 1917). Inspired by previous observations, Smith (1950) further studied the capability of YFA to produce adventitious shoot growth from root segments. Heinrichs (1954) suggested the adventitious shoot production on alfalfa is genetically conditioned. If this trait could be cultivated in commercial YFA populations, the stress resistance of this crop could be increased. Alfalfa has been shown to respond to intersubspecific hybridization (Riday and Brummer 2006), and it is hoped that environmental difficulties may be overcome by introducing stress resistant traits such as adventitious growth potential (Berdahl et al. 1989; Oakley and Garver 1917).

The objective of this study was to identify Plant Introduction (PIs) populations of YFA possessing the ability to produce adventitious shoot growth from root segments, and to evaluate the effect of root segment origin distance below cotyledonary nodes on adventitious shoot regeneration and survival.

METHODS

The eight population entries used in this study were PI491407, PI494660, PI494661, PI494662, PI631677, PI631678, PI631682 and Persist II. Seeds of the seven PIs were obtained from the National Plant Germplasm System. Per-
sist II seeds were purchased from a commercial seed company (Millborn Seeds, Brookings, SD) and served as a control. PIs were selected based upon latitudes of origin and climates similar to South Dakota (Table 1).

For each entry, 100 uniform seeds were selected, sand scarified three time for five seconds with 320 grade sandpaper, and inoculated with *Rhizobium* bacteria before planting in individual 164 ml plastic cell containers (Ray Leach “Cone-containers”; Stuewe and Sons, Inc., Tangent, OR) filled with Miracle-Gro® potting soil. Seedlings completed first year growth and dormancy under ambient day and night photoperiod cycle in a greenhouse at Brookings, SD.

Twenty-five to 50 healthy one-year-old plants from each entry were randomly selected and excavated from cone-containers for assessment of the ability of root segments to produce adventitious shoots. After removal of soil and lateral roots, each taproot was cut into two six centimeter segments, which originated at one and seven centimeters below the cotyledonary node. The number of root segments at each cut level for each population used in the study is given in Table 2. Three root segments of each entry were planted upright in 11.5 cm dia. X 9.5 cm depth plastic pots filled with Miracle-Gro® potting soil. Pots were maintained in a greenhouse with 16h light/8h dark photoperiod, 24 ± 3 °C temperature, and were watered by daily misting.

**Table 1. Description and geographic origin / seed marketer for 8 alfalfa populations evaluated for possessing the ability to produce adventitious shoots from root segments (USDA 2010).**

<table>
<thead>
<tr>
<th>Entry</th>
<th>Description</th>
<th>Marketer/Origin*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI491407</td>
<td><em>M. sativa</em> subsp. <em>Falcata</em>, NPGS</td>
<td>China, Nei Monggol (Inner Mongolia)</td>
</tr>
<tr>
<td>PI494660</td>
<td><em>M. sativa</em> subsp. <em>Falcata</em>, NPGS</td>
<td>Romania, Lat. 46°46’0&quot; N, Long. 23°36’0&quot;E</td>
</tr>
<tr>
<td>PI494661</td>
<td><em>M. sativa</em> subsp. <em>Falcata</em>, NPGS</td>
<td>Romania, Lat. 46°46’0&quot; N, Long. 23°36’0&quot;E</td>
</tr>
<tr>
<td>PI494662</td>
<td><em>M. sativa</em> subsp. <em>Falcata</em>, NPGS</td>
<td>Romania, Lat. 44°19’0&quot; N, Long. 23°48’0&quot;E</td>
</tr>
<tr>
<td>PI631677</td>
<td><em>M. sativa</em> subsp. <em>Falcata</em>, NPGS</td>
<td>Mongolia, Lat. 49°49’32&quot; N, Long. 92°03’48&quot;E</td>
</tr>
<tr>
<td>PI631678</td>
<td><em>M. sativa</em> subsp. <em>Falcata</em>, NPGS</td>
<td>Mongolia, Lat. 49°46’40&quot; N, Long. 91°53’52&quot;E</td>
</tr>
<tr>
<td>PI631682</td>
<td><em>M. sativa</em> subsp. <em>falcata</em>, NPGS</td>
<td>Mongolia, Lat. 48°10’33&quot; N, Long. 91°45’29&quot;E</td>
</tr>
<tr>
<td>Persist II</td>
<td><em>M. sativa</em>, Cultivar, Hay-Type</td>
<td>Millborn Seeds Inc.</td>
</tr>
</tbody>
</table>

* indicates the information of PIs from USDA-ARS National Genetic Resources Program
Table 2. Number of alfalfa root segments from separate plants used for each cut level of each population entry. Level 1 = 1cm cut below cotyledonary node, Level 2 = 7cm cut below cotyledonary node

<table>
<thead>
<tr>
<th>Population</th>
<th>PI491407</th>
<th>PI494660</th>
<th>PI494661</th>
<th>PI494662</th>
<th>PI631677</th>
<th>PI631678</th>
<th>PI631682</th>
<th>Persist II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>38</td>
<td>27</td>
<td>49</td>
<td>38</td>
<td>41</td>
<td>28</td>
<td>21</td>
<td>35</td>
</tr>
<tr>
<td>Level 2</td>
<td>36</td>
<td>26</td>
<td>44</td>
<td>32</td>
<td>40</td>
<td>26</td>
<td>19</td>
<td>34</td>
</tr>
</tbody>
</table>

Shoot emergence was recorded daily and tallied weekly. Shoot-bearing root segments were removed from planting group pots to individual pots after one to two weeks emergence to determine the exact root segment that produced the shoot (Figure 1). At the end of the 16-week period following planting, the number of root segments that produced shoots and shoot survival and status of flowering on surviving shoots were determined. The non-productive samples were excavated to detect whether root segments had decayed over the course of the project or were simply unproductive.

Frequency of shoot regeneration from root segments was calculated using the number of root segments producing adventitious shoots that appeared above the soil surface divided by the total root segments planted for each distance below the cotyledonary node.

Percentage of shoot survival was calculated based on the number of shoot-bearing root segments whose shoots survived to the end of the 16-week period. Percentage of surviving shoots producing flowers was calculated at the end 16-week study as well. Entries of Persist II and PI494662 were excluded from data analysis because no shoots had generated from their root segments. Frequency of generating shoots from root segments was analyzed using PROC FREQ (SAS 1990). A Chi-square ($\chi^2$) analysis was used to detect the differences ($P < 0.05$) among the six populations and among distances below the cotyledonary node.

**Figure 1.** Adventitious buds on the roots of PI63168 (left photo) and adventitious shoot-bearing root segments (right photo). Photos credit: L. Xu
RESULTS

Of the eight populations of alfalfa used in this study, no shoots generated on PI494662 and Persist II root segments. Frequency of generating shoots from root segments differed significantly from 11.11% to 57.15% among six PIs for cuts one centimeter below the cotyledonary node ($P = 0.0067$) and 3.85 to 46.15% for seven centimeters cut below the cotyledonary node ($P = 0.0144$) (Figure 2). Shoot regeneration from the root segments occurred most frequently in PI631678 (57.15% and 46.15%) for both cutting distances below the cotyledonary node, and least frequent in PI494660 (11.11% and 3.855%) (Figure 2).

Once adventitious shoots had appeared above the soil surface, survival rates were similar among the productive populations, with the exception of PI631682 (Figure 3). Furthermore, most surviving plants produced flowers (Figure 4). Rate of emergence of shoots varied among the six populations. PIs from Mongolia (PI631678, PI631677 and PI631682) emerged the fastest, as early as the first week following planting. These populations also produced between 80% and 100% of regenerated shoots by the eighth week. The populations from Romania (PI494661 and PI494660) produced shoots that emerged much slower. The first occurrence of shoots from these populations was in the seventh week after planting. Seventy-five to 96% of shoot-bearing roots occurred between the seventh and fourteenth weeks. The population from Inner Mongolia of China (PI491407) produced 76% of its shoots between the fourth and eighth weeks. For all six PIs, the highest occurrence of regeneration occurred during the seventh week. PI631678 had the greatest speed of adventitious shoot production.
In addition, it produced adventitious growth over a longer time span than the other populations (Figure 5). Viability of root segments in soil varied among the populations (Figure 5). Viability of PI494661 root segments were maintained for 16 weeks (Figure 5) and had lower a percentage of non-shoot bearing root segment decay (37%) compared to other populations (52% to 87%).

Figure 3. Survival rate of adventitious shoots from cuts 1 cm and 7 cm below the cotyledonary node after 16 weeks for 6 alfalfa PI populations.

Figure 4. Survival rate of flowering shoots produced from cuts 1 cm and 7 cm above the cotyledonary node after 16 weeks for 6 alfalfa PI populations. PI494660 produced no flowering shoots from the 7 cm cut.
DISCUSSION

Improving yellow-flowered alfalfa’s persistence in South Dakota’s climate will result in significant economic benefits for livestock producers. However, common hay-type alfalfas are limited by poor stress resistance and stand persistence under grazing (Misar et al. 2015). Therefore, the first step in increasing stress resistance of the commercial strains is by identifying populations that exhibit these desired traits.

In order to determine populations that would excel under South Dakota weather, we selected seven populations from latitudes and climates similar to those in South Dakota. Our results suggest stress resistance depends on adventitious shoot development. Once adventitious growth begins, survival and flowering rates were approximately equivalent across the populations (Figure 3, Figure 4).

Of these populations, the Mongolian strains had a higher potential for adventitious reproduction (Figure 2). Among the six populations, PI631678 exhibited the highest production of adventitious shoot, followed by PI631677 and PI494661.

Speed of adventitious shoot production and their persistence are important survival traits. In this study, PI631678 exhibited the fastest production (began at the first week) and the longest production period (about 12 weeks). However, PI494661 root segments demonstrated the longest viability in soil compared to other populations. From a management standpoint, these traits could have profound implications. In South Dakota, weather is seasonally unpredictable, experiencing late frosts, early thaws, and a wide variability of seasonal temperature and rainfall (Spuhler 1971). A long, strong production period and long viability in soil could increase the ability of the cultivar to resist the seasonal stresses found in South Dakota.

Preliminary results suggest that Mongolian strains like PI631678 and Romania strains like PI494661 may have a higher potential for adventitious reproduction.
than the other PIs examined in the study. Our results support the value of testing additional populations in the USDA Plant Introduction Collection for these traits. Once populations have been successfully identified as possessing the ability to produce adventitious shoots on roots, plant breeding programs can begin to integrate the desired traits into commercially available cultivars. Improving stand persistence increases the value of the alfalfa forage and this translates into increased profit for producers.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Spuhler, W. 1971. Climate of South Dakota, Agricultural Experiment Station. South Dakota State University, Brookings, SD.
GENOME-WIDE IDENTIFICATION OF DISEASE RESISTANCE GENES IN AEGILOPS TAUSCHII COSS. (POACEAE)

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ABSTRACT

Identifying disease resistance genes (R-genes) and revealing their functions are important for understanding a plant’s defense against pathogens. Aegilops tauschii, the contributor of wheat’s D-genome, has a recently available complete genome sequence, and genome-wide identification of R-genes in this plant would give insight into the evolution of wheat resistance genes. The main objectives of this project were to identify CNL (Coiled-coil, Nucleotide-binding site, and Leucine-rich region) R-genes within the A. tauschii genome, and elucidate their evolutionary relationships within Aegilops and across the genome of two model plants—Arabidopsis and rice. We conducted in silico analyses in which known CNL genes of Arabidopsis and rice were used to search for their orthologs in A. tauschii. We identified 402 CNL resistance genes within the A. tauschii genome and recovered three clades (A, B, and C) of A. tauschii CNL genes of which CNL C is the largest clade, a single member represents clade A, and clade D is entirely absent. Each of these clades was characterized by a consistent motif structure. The number of exons varied from 1 to 28 with an average number of 4.5. The majority of CNL genes were inferred to have originated by tandem duplications, and the historical gene duplication events perhaps diversified the members in response to a unique pathogen pressure. Identification of Aegilops R-genes would help us understand the evolution of R-genes, particularly those located in the D-genome of wheat, and has a potential implication in creating a durable R-gene in Aegilops, wheat, and other crop species in future.

Keywords
Disease resistance, NBS-LRR, R-genes, CNL genes, D-genome of wheat, Aegilops tauschii, bioinformatics

INTRODUCTION

Plant defense against pathogens involves complex signaling pathways that trigger resistance responses (Jones and Dangl 2006). Such responses typically lead to a hypersensitive response, but can also include the production of anti-pathogen
chemicals or cell wall fortification (Hammond-Kosack and Jones 1996). Hypersensitive response, in particular, is a general response that involves the programmed cell death of a section of tissue that has been infected by a pathogen to quarantine the affected area (Hammond-Kosack and Jones 1996).

Disease resistance genes, or R-genes, encode proteins that are involved in the detection of pathogen attacks and activation of subsequent downstream plant response signaling. The R-genes occur as multigene families, and multiple models have been proposed to describe their mechanism of action. The Gene-for-Gene Model describes plants having specific dominant resistance genes that counter corresponding pathogen avirulence genes in an evolutionary arms-race (Flor 1971). Introducing more molecular details, the Guard Model describes resistance genes bound to plant proteins and are activated when that protein is cleaved by a pathogen protein (Van Der Biezen and Jones 1998; Shao et al. 2003), while the Zig-Zag Model describes the pathogen evolving new avirulence genes that evade plant basal immunity (Jones and Dangl 2006). Recently R-genes have been classified into eight specific groups (Gururani et al. 2012). Among them, the overwhelming majority of the R-genes fall under the NBS-LRR type, the largest class of R-genes (Meyers et al. 2003; Meyers et al. 2005). The NBS-LRR genes can be categorized into two major types based upon whether they start with a Toll Interleukin Receptor (TIR-NBS-LRR or TNL; absent in monocots) or a Coiled Coil (CC-NBS-LRR or CNL; present in all plants) (Meyers et al. 2003).

Resistance genes evolve rapidly due to the high selection pressure put onto the plant population by a pathogen load (Bergelson et al. 2001) that causes faster gene diversification (Michelmore and Meyers 1998). This diversification is caused primarily by gene recombination and transposable elements’ activities (McGrann et al. 2014). Their loss is also possible by deficient duplications and the loss of lineages, as evidenced in cucumber and watermelon genomes that contain many fewer resistance genes (Lin et al. 2013). In addition, the evolution of R-genes occurs through a trade-off between physical, chemical, and molecular defenses in response to coevolving pathogens (Hammond-Kosack and Jones 1996).

The increasing availability of complete genome sequences of plants at various taxonomic levels allows us to carry out comparative analyses for identification of R-genes and for understanding the evolutionary processes involved. CNL R-genes have been identified for various plant species such as papaya (6; Porter et al. 2009), cucumber (18; Wan et al. 2013), rice (159, 149; Zhou et al. 2004; Benson 2014), Arabidopsis (55; Meyers et al. 2003), poplar (119; Kohler et al. 2008), Medicago (177; Ameline-Torregrosa et al. 2008), soybean (188, Benson 2014; Nepal and Benson 2015), potato (370; Lozano et al. 2012), and are yet to be identified in Aegilops tauschii Coss. (Poaceae), the D-genome contributor of bread wheat (Triticum aestivum L.). A. tauschii underwent hybridization with Triticum turgidum several thousand years ago, forming bread wheat (Jia et al. 2013). The objectives of this research were to identify A. tauschii CNL resistance genes and elucidate their evolutionary relationships within A. tauschii and across the genomes of Arabidopsis and rice, two model plant species.
METHODS

*A. tauschii* protein sequences were searched in the Ensembl Genomes site (Kersey et al. 2014). Previously identified *Arabidopsis* CNL resistance genes (Meyers et al. 2003) were obtained from the Phytozome database (Goodstein et al. 2012). First, fifty CNL genes of *Arabidopsis* were aligned in the program ClustalW and used to construct a Hidden Markov Model to search for the entire set of *A. tauschii* protein sequences with a stringency of 0.05. The *A. tauschii* genes were uploaded into the program Geneious (Kearse et al. 2012) and annotated with InterProScan (Jones et al. 2014) to identify NBARCs with the program Pfam (pfam.sanger.ac.uk) that allowed the exclusion of sequences with TIR motifs.

The protein sequences with NBARCs were used to construct a reiterative HMM to search the *A. tauschii* proteins for species-specific CNL genes at a stringency of 0.001. A total of 810 genes were identified through first HMM at a stringency of 0.05. Of these genes, 711 were determined to contain NBARCs through domain annotation with InterProScan. The reiterative HMM identified 779 genes and after removing gene duplicates, 711 of these 779 genes were determined to contain NBARCs, of which only 544 genes contained both NBARC and “DiseaseResist” domains. The NBARCs of these genes were then uploaded to MEME suite to perform MEME analysis (Bailey and Elkan 1994) and annotate the three characteristic domains of the CNL genes, i.e. P-loop, Kinase-2, and GLPL motifs. All genes containing these three motifs were aligned using ClustalW integrated in the program MEGA 6.0 (Tamura et al. 2011). *Arabidopsis* as well as rice sequences were also imported into MEGA 6.0 to make two phylogenetic trees (100 bootstrap replicates using the JTT+G Model for both trees) to look for evolutionary relationships between the genes. Exon structure was also determined using exon information and scaffold location data from the Ensembl Genomes site. Gene exon coordinates were used in the program Fancy-gene v1.4 to visualize the exon-intron structure.

RESULTS AND DISCUSSION

Of the 33,928 *A. tauschii* protein sequences analyzed, 402 genes (1.2% of the genome) were identified as CNL genes. All of these genes had P-loop, Kinase-2, and GLPL motifs, the characteristic domains of the CNL genes. Phylogenetic relationships of the identified CNL genes along with their orthologs in *Arabidopsis* and in rice are shown in Figure 1 and 2, respectively. The CNL genes were nested in three clades (A, B and C). The clade D found in *Arabidopsis* and other dicot species was completely absent. The CNL-A clade was severely reduced to one member in the *A. tauschii* genome, whereas *Arabidopsis* has six CNL-A members. While *A. tauschii* has a substantially larger genome than rice, the number of coding genes for *A. tauschii* and rice are quite similar, at 33,929 and 35,679 genes, respectively (Zhou et al. 2004; Jia et al. 2013). The CNL gene-content in the two genomes is not highly divergent, despite a huge difference in genome size between the two species. Table 1 shows that the number of CNL genes does
not necessarily correlate with genome size (G-value paradox; Michelmore et al. 2013). With the larger genome size (2.7Gb), however, the \textit{A. tauschii} genome contains a higher number of CNL genes. The rice genome (420 Mb) contains approximately 150 CNL genes (Zhou et al. 2004). All CNL clade information for the 402 identified genes is summarized in Table 2.

This study confirmed through MEME analysis (Figure 3) the presence of characteristic motifs (P-loop, Kinase-2, and GLPL) in all 402 CNL genes in \textit{Aegilops}. The motif compositions presented here are similar to that in \textit{Arabidopsis} (Meyers et al. 1999) and corresponded to the phylogenetic clustering represented in the phylogenetic tree (Figure 1, 3). For instance, Motif 8 (CPxxL) was common in the CNL-C4 clade but only in a few genes in the rest of CNL-C (Clades CNL-C1, CNL-C2, and CNL-C3). Since only the most prevalent motifs were labeled,
and few CNL-A and CNL-B genes were present, it is likely that motifs were present but not described by the MEME analysis.

Since *A. tauschii* genes have not been mapped onto their chromosomes, gene clustering analysis was not performed in the present study. It is highly likely that the genes exist in many clusters throughout the genome (Meyers et al. 2003), particularly in the extrapericentromeric regions of the chromosomes as documented in soybean (Benson 2014; Nepal and Benson 2015). Further analyses of NBS-LRR disease resistance gene clustering will need to be conducted once this information becomes available. Also not available yet are the alternate transcripts for each of the genes. This is evident because the number of protein sequences available is equal to the number of coding genes within the genome. In other genomes, such as the barley genome, many more protein sequences exist that give information on alternative splicing amongst the resistance genes. Alternative splicing would increase the possible resistance gene proteins, which would be highly useful while facing a quickly evolving pathogen. While information

Figure 2. Phylogenetic analysis of the CNL genes of *A. tauschii* and their orthologs in rice. The tree was constructed using the JTT+G model with 100 bootstrap replicates. *A. tauschii* and rice genes are shown with red and blue symbols, respectively. A high resolution readable TIF copy of this figure is available from the corresponding author. It can also be downloaded from the author’s lab website at [https://www.sdstate.edu/biomicro/people/faculty/madhav-nepal/nepal-lab.cfm](https://www.sdstate.edu/biomicro/people/faculty/madhav-nepal/nepal-lab.cfm).
Alternate splicing is not available for the *Aegilops* CNL genes, exon/intron information is available (Figure 4). The average exon content of 4.45 exons per gene is higher than previously found in *Arabidopsis* and CNL-C genes in soybean (Benson 2014; Nepal and Benson 2015). The number of exons varied from 1 (F775_00002) to 28 (F775_52438). Thirty five CNL genes had one exon, 77 had two, 83 had three, 58 had four, 44 had five, 28 had six, 23 had seven, 9 had eight, 14 had nine, 10 had ten, six had 11, seven had 12, three had 13, two had 14, one had 22 and one gene had 28 exons (Figure 5). With the multitude of genes with many exons, it can be hypothesized that alternate splicing has a large impact on the protein structure of the resistance genes, since multiple exons allow for a higher number of combinations during splicing (Tan et al. 2007). Alternative splicing has been shown to play an important role in resistance gene expression in *Arabidopsis* (Dinesh-Kumar and Baker 2000; Tan et al. 2007).

Phylogenetic analysis of *A. tauschii* CNL genes shows an expansion of the CNL-C group and a slight reduction of CNL-B members relative to *Arabidopsis* (Figure 1). There is a severe reduction of the CNL-A clade to a single member. These results in the *Aegilops* genome are consistent with the CNL genes in rice, another monocot species (Benson 2014; Nepal and Benson 2015). There was low interspecific nesting indicating the lower prevalence of segmental duplication.

### Table 1. Genome size and CNL gene content of selected plant species. This table was modified from Marone et al (Marone et al. 2013). Genome size and CNL gene references are both listed in the references column.

<table>
<thead>
<tr>
<th>Species</th>
<th>Genome Size</th>
<th>Number of CNL genes</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aegilops tauschii</em></td>
<td>4.4 Gb</td>
<td>402</td>
<td>Jia et al. 2013</td>
</tr>
<tr>
<td><em>Glycine max</em></td>
<td>1.115 Gb</td>
<td>188</td>
<td>Schmutz et al. 2010; Benson 2014; Nepal and Benson 2015</td>
</tr>
<tr>
<td><em>Solanum tuberosum</em></td>
<td>844 Mb</td>
<td>370</td>
<td>Consortium 2011; Lozano et al. 2012</td>
</tr>
<tr>
<td><em>Phaseolus vulgaris</em></td>
<td>587 Mb</td>
<td>94</td>
<td>Benson 2014; Schmutz et al. 2014</td>
</tr>
<tr>
<td><em>Vitis vinifera</em></td>
<td>487 Mb</td>
<td>203</td>
<td>Jaillon et al. 2007; Yang et al. 2008</td>
</tr>
<tr>
<td><em>Populus trichocarpa</em></td>
<td>423 Mb</td>
<td>119</td>
<td>Tuskan et al. 2006; Kohler et al. 2008</td>
</tr>
<tr>
<td><em>Oryza sativa</em></td>
<td>420 Mb</td>
<td>159, 149</td>
<td>Zhou et al. 2004, Goff et al. 2002; Benson 2014</td>
</tr>
<tr>
<td><em>Medicago truncatula</em></td>
<td>375 Mb</td>
<td>177</td>
<td>Ameline-Torregrosa et al. 2008; Young et al. 2011</td>
</tr>
<tr>
<td><em>Carica papaya</em></td>
<td>372 Mb</td>
<td>6</td>
<td>Ming et al. 2008; Porter et al. 2009</td>
</tr>
<tr>
<td><em>Brassica rapa</em></td>
<td>284 Mb</td>
<td>30</td>
<td>Mun et al. 2009; Wang et al. 2011</td>
</tr>
<tr>
<td><em>Brachypodium distachyon</em></td>
<td>272 Mb</td>
<td>102</td>
<td>Vogel et al. 2010; Tan and Wu 2012</td>
</tr>
<tr>
<td><em>Cucumis sativus</em></td>
<td>244 Mb</td>
<td>18</td>
<td>Huang et al. 2009; Wan et al. 2013</td>
</tr>
<tr>
<td><em>Arabidopsis lyrata</em></td>
<td>207 Mb</td>
<td>21</td>
<td>Guo et al. 2011; Hu et al. 2011</td>
</tr>
<tr>
<td><em>Arabidopsis thaliana</em></td>
<td>125 Mb</td>
<td>55</td>
<td>Initiative 2000; Meyers et al. 2003</td>
</tr>
</tbody>
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Table 2. List of all Aegilops tauschii CNL genes according to clade.
Aegilops gene
F775_00002
F775_00003
F775_00009
F775_00012
F775_00020
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F775_00089
F775_00261
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F775_00445
F775_00504
F775_00542
F775_00546
F775_00591
F775_00649
F775_01012
F775_01226
F775_01227
F775_01584
F775_01810
F775_02378
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F775_02497
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F775_02796
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F775_04060
F775_04135
F775_04483
F775_04549
F775_04571
F775_04590
F775_04976
F775_04978
F775_04989
F775_04991
F775_05010
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F775_05085
F775_05094
F775_05363
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F775_05818
F775_05820
F775_05946
F775_06146
F775_06149
F775_06253
F775_06279
F775_06285
F775_06326
F775_06411
F775_06721
F775_06827
F775_06830
F775_06989
F775_07053
F775_07156
F775_07165
F775_07193
F775_07248
F775_07285
F775_07399
F775_07702
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F775_07864
F775_07949
F775_08064
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F775_08252
F775_08345
F775_08380
F775_08523
F775_08534
F775_08544
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F775_08722
F775_08786
F775_08856
F775_08907
F775_08994

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Aegilops gene
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Aegilops gene
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F775_13594
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F775_14564
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Aegilops gene
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Aegilops gene
F775_25567
F775_25587
F775_25618
F775_25651
F775_25666
F775_25677
F775_25696
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F775_25723
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F775_25748
F775_25761
F775_25787
F775_25792
F775_25799
F775_25826
F775_25860
F775_26631
F775_29542
F775_31118
F775_31260
F775_32992
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F775_33066
F775_33089
F775_33131
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F775_33159
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F775_52304
F775_52483
F775_52537

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Figure 3. MEME analysis of the 402 A. tauschii genes. The block diagrams show the characteristics three motifs used to identify CNL genes (P-Loop, Kinase-2, and GLPL) along with other highly prevalent motifs, split according to clade as shown by the tree (lower right) color-coded to represent the domain compositions in Figure 1. CNL-B, A, C1, C2, C3, and C4 are colored pink, blue, brown, green purple, and red, respectively. A high resolution readable TIF copy of this figure is available from the corresponding author. It can also be downloaded from the author’s lab website at https://www.sdstate.edu/biomicro/people/faculty/madhav-nepal/nepal-lab.cfm.
Figure 4. Exon content of the 402 A. tauschii genes showing splice locations between exons (gray bars) and introns (dashed lines). Genes are listed by accession. A high resolution readable TIF copy of this figure is available from the corresponding author. It can also be downloaded from the author's lab website at https://www.sdstate.edu/biomicro/people/faculty/madhav-nepal/nepal-lab.cfm.
tions. Since chromosome location and gene clustering information were not available, instances of tandem versus segmental duplications could not be determined with a high degree of certainty. Genes that are nested together within a clade and occurring within the same gene clusters are likely to have originated through tandem duplications. The current study presented several instances of tandem duplication: for example, because F775_14065 and F775_14066, are sister members (Figure 1), and subsequently accessioned, it is highly likely that they originated by tandem duplication. Other examples of tandem duplications include F775_11136 and F775_11137, F775_02795 and F775_02796, F775_10498 and F775_10499, F775_10336 and F775_10337, and three genes F775_17386, F775_17388 and F775_17389.

Orthologs of some *A. tauschii* CNL genes have been previously characterized. For example, RPM1 of *Arabidopsis thaliana* is involved in the resistance response to *Pseudomonas syringae* (Mackey et al. 2002). As shown in Figure 1, the *Arabidopsis* RPM1 ortholog in *Aegilops* has three paralogs (F775_10347, F775_14260, and F775_13161) indicating an expansion of this particular gene. It could be hypothesized that *A. tauschii* evolved the three genes in response to diversifying *P. syringae* strains or similar pathogens since the split of common ancestors of *Arabidopsis* and *A. tauschii*. The diversification of RPM1 orthologs in *Aegilops* might have resulted from the selection pressure imposed by different pathogens in *A. tauschii*’s life history. Figure 2 shows expansions of several *Aegilops* CNL genes: for example, eleven *A. tauschii* paralogs (F775_10913, 12507, 12011, 05946, 06830, 13024, 33089, 06253, 11684, 09360, and 21401) are related to rice gene LOC_Os08g10260. This shows that *A. tauschii* might have evolved as many as 11 genes in response to the same pathogen as in rice, perhaps diversifying in the *Aegilops* niche.

Due to the growing problem of Ug99 stem rust in wheat production of East Africa and the Middle-East, the CNL resistance gene SR33 has been identified as
a possible solution (Periyannan et al. 2013). Our result determines that accession F775_10122 represents the SR33 gene in *Aegilops*, which could be the gene of interest for developing a durable resistance in wheat. Other genes (F775_13548, F775_16813, and F775_18040) closely related to SR33 might contain valuable traits as well. Further investigation of these genes, along with the splice variants of F775_10122 is warranted if SR33 proves to be useful in agricultural production. *In silico* analyses of R-genes such as presented here are integral stepping-stones toward the use of these identified genes as weapons against evolving pathogens. While further investigation of gene expression data and genomic composition is important for understanding functional characterization, the present study provides information on the diversity and evolutionary history of the CNL genes in *A. tauschi* genome, and has a potential implication in future wheat crop improvement with durable resistant genes.

**ACKNOWLEDGEMENTS**

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MORPHOLOGICAL AND ECOLOGICAL DISCRIMINATION OF TWO STENODIPLOSIS (DIPTERA: CECIDOMYIIDAE) ON ALOPECURUS ARUNDINACEUS, A. PRATENSIS AND BROMUS INERMIS (POALES: POACEAE) IN EASTERN SOUTH DAKOTA

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ABSTRACT

Two of four species of Stenodiplosis (Diptera: Cecidomyiidae) known in eastern South Dakota are non-native introductions occurring on introduced grasses: Stenodiplosis bromicola is associated with Bromus inermis and S. geniculati associated with Alopecurus arundinaceus and A. pratensis. Stenodiplosis bromicola is newly reported from South Dakota. Inflorescences of the host grasses were observed, and gall midges and parasitoids were found ovipositing. Morphological differences between the gall midges were found in the circumfila, distribution of posterior setae on tergites, width to length ratio of female cerci, and gonostylus shape in males. A key is presented to separate these species from each other and the two native species, S. spartinae and S. wattsi. Both introduced Stenodiplosis species are parasitized by species of Eulophidae (Hymenoptera). Stenodiplosis bromicola and S. geniculati both host an apparently undescribed Aprostocetus sp. 1. Aprostocetus, a Quadrastichus sp., and Tetraestichus bromi were found parasitizing only S. bromicola, Aprostocetus sp. 3 and an undetermined Aphelinidae hyperparasitoid emerged from S. geniculati. Evaluation of morphological and ecological traits supports the recognition of two sympatric species in space and time, with a mostly similar parasitoid guild differing by one species.

INTRODUCTION

Gall midge species of the genus Stenodiplosis Reuter are defined in part by their larval feeding habits on ovules and developing caryopses of grasses. Gagné and Jaschhof (2014) listed 6 species in the genus for North America, three being native to North America (S. albescentis Gagné, S. phragmonicola Sinclair and Ahee, S. wattsi Gagné), and additional undescribed species known, and another three introduced to North America (S. bromicola Marikovskij and Agafonova, S. geniculati Reuter, S. sorghicola Coquillett). The two species of interest here are in this second group of introduced species, S. bromicola and S. geniculati.
Stenodiplosis species are separated most reliably from those in Contarinia Ron-ndani, by the lack of lateral setae on the adult abdominal tergites, reduced size of larval papillae, and lack of a larval instar spatula (Gagné 1994). Stenodiplosis bromicola and S. geniculati were recently discovered in South Dakota and were found to be difficult to separate without their previously associated host plants. Stenodiplosis bromicola is associated with Bromus inermis Leyss. (smooth brome-grass) and S. geniculati is associated with Alopecurus arundinaceus Poir. and A. pratensis L. (foxtail grasses). The published descriptions of S. bromicola and S. geniculati do not provide direct comparisons of these species and there is no morphology-based review of the species of Stenodiplosis, thus making adult differentation difficult.

Few ecological details are known of these gall midges other than recorded host plants (Reuter 1895, Barnes 1946) and larval feeding. Most available information is for S. bromicola on B. inermis in agronomic circumstances (e.g., Agafonova 1962; Neiman and Manglitz 1972). The feeding on grass ovules and developing caryopses is apparently a generalized habit for all Stenodiplosis species (Coquillett 1899; Agafonova 1962; Neiman and Manglitz 1972; Boe 1991; Ahee et al. 2013). Summer-developing larvae overwinter and pupate in florets on the plant or in soil (Neiman and Manglitz 1972; Gagné 1989). Parasitoid wasps of the genus Aprostocetus Westwood (Hymenoptera: Eulophidae) were reared from several Stenodiplosis species (Coquillett 1899 [as “Apostrocetus”]; Boe and McDaniel 1990; Johnson et al. 2015). Although Agafonova (1962), Neiman and Manglitz (1972), Vogel and Manglitz (1989) and others reported a “Tetrastrichus sp.” as a parasitoid of S. bromicola and S. wattsi, we believe those refer to one or more Aprostocetus spp. (Z. Yefremova, in litt.).

Our goal in this report is to provide a morphology-based key for differentiation of the introduced S. bromicola and S. geniculati from two native regional species, and provide additional ecological observations on phenology and parasitoids. This information is combined with host associations to further demonstrate species segregation and provide recognition of two species as taxonomic and ecological entities in our local populations.

METHODS

Adults were reared or collected by aspirator from inflorescences of Alopecurus arundinaceus, A. pratensis and Bromus inermis during the growing season of 2014 and May-Jun of 2015. Samples were taken at twelve sites in Brookings County, South Dakota. Larvae were dissected from florets where adult females perched and oviposition was observed, or larvae were reared using the methodology described by Perilla López et al. (2015). Gall midge and parasitoid specimens were stored in 100% alcohol. Eight males and females of each species were slide mounted for morphological analysis, generally following the method in Gagné (1989), except that potassium hydroxide was used as a clearing reagent instead of sodium hydroxide. Identifications were made using published literature and confirmed by R.J. Gagné, USDA-ARS-SEL, Washington, D.C. Specimen vouchers were deposited in the Severin-McDaniel Insect Research Collection (SDSUC),
RESULTS

A Key to the Adult Stenodiplosis of Eastern South Dakota

1. Sternites 2-7 with trichoid sensilla absent.................................................. 2
1'. Sternites 2-7 with trichoid sensilla present.................................................. 3

2. Palpus 1-2 segmented; Aedeagus as long as hypoproct or slightly longer; associated with Spartina pectinata................................. S. spartinae Gagné
2'. Palpus 4 segmented; aedeagus clearly longer than hypoproct; associated with Andropogon girardii, A. hallii, Schizachyrium scoparium and Sorghastrum nutans......................................... S. wattsi Gagné

3. Female flagellomeres with circumfila as irregular threads and sinuous (Figure 1a); cerci 2.2-2.7 times longer than wide, gradually tapered with 1 long seta near base, 2-4 setae gathered on the last third of it, and several setae with similar size along length (Figure 1c). Males with gonostylus in lateral view gradually tapering from broad base to narrowed apex with distal part approximately half of the width of the base; first through seventh tergites with latero-posterior 5 to 14 setae, having more (close to 11) in the third to fifth tergites, in two medially discontinuous rows that are not equally separated, with few setae in one irregular row; tergites, second through seventh sternites and the area surrounding each seta lightly pigmented; associated with Bromus inermis and B. riparius................ S. bromicola Marikovskij and Agafonova
3'. Female flagellomeres with looped circumfila (Figure 1b); cerci 3.3-4.0 times longer than wide, base narrower than S. bromicola with 1 long seta near base, several shorter setae gathered toward the distant half (Figure 1d). Males with gonostylus in lateral view wide and of nearly equal width throughout; first through seventh tergites with 3 to 7 posterior setae, sometimes having fewer on the third to fifth tergites, mainly in one row medially discontinuous equally distant between them. Tergites, second through seventh sternites and the area surrounding each seta is as pigmented as the thoracic areas; associated with Alopecurus arundinaceus, A. geniculati, A. pratensis................................. S. geniculati Reuter

Phenology—In 2014 the emergence of the first spring generation of adults of both species of gall midges coincided with the appearance of A. arundinaceus and B. inermis inflorescences during the first week of June. However A. arundinaceus inflorescences started their emergence in late May. Due to a delayed growing season, the first inflorescences were also available on the second week of June, causing simultaneous availability of A. arundinaceus and B. inermis inflorescences.
The *S. bromicola* adult emergence and activity period was extended by two weeks (3-18 July) due to the longer developmental time of *B. inermis* inflorescences. In 2015, adults of *S. geniculati* were active as soon the *A. arundinaceus* and *A. pratensis* inflorescences began exertion from the leaf sheath during the first week of May. Females were observed laying eggs in inflorescences when at least 20% of the inflorescence became exerted and through the pre-anthesis period. *Bromus inermis* inflorescences developed later, with the first oviposition by *S. bromicola* recorded on May 26. In both years, inflorescences of *B. japonicus* and *B. tectorum* were taken to the laboratory, however no midges emerged from these two annual bromes. The lack of gall midge association with annual bromes was also reported by Neiman and Manglitz (1972).

Eggs of both species were laid in unfertilized flowers before the stamens were exerted from the floret. For *S. geniculati*, only one egg was found in most of the florets dissected, with only 1% of infested florets having two larvae. In this latter case it appeared that internecine competition may prevent at least one larva reaching full development.

In eastern South Dakota, generational life cycles for *S. bromicola* and *S. geniculati* were similar in duration from 10 to 15 days, and similar to that described by Agafonova (1962) for *S. bromicola* in the Kursk Province of Russia. No evident symptoms or malformations were observed in the tissues of infested florets. This same observation was made on inflorescences of *Andropogon gerardii*, *Schizachyrium scoparium* and *Sorghastrum nutans* with larvae of *S. wattsi*, and larvae of *Stenodiplosis spartinae* on *Spartina pectinata*.

Contemporaneous with and following adult activity of *S. bromicola* and *S. geniculati*, adults of *Aprostocetus* wasps were observed walking on the inflorescence and ovipositing in the florets of *A. arundinaceus* and *B. inermis*. Examination of *Stenodiplosis* larvae in situ revealed the presence of ectoparasitoid larvae. Adult *Aprostocetus* were reared from all gall midge infested inflorescences of both *A. arundinaceus* and *B. inermis*.

**Parasitoids**—Totals of 823 *S. geniculati* and 689 parasitoids were reared from *A. arundinaceus*, and 129 *S. bromicola* and 315 parasitoids from *B. inermis* during the 2014 growing season. The sex ratios for both species were similar: 43-44% male and 56-57% female.

*Tetrastichis bromi* Kostyukov was found as the dominant species of parasitoid in *S. bromicola*. Originally from Ukraine and Russia, *T. bromi* was probably introduced to North America during the late 19th century in imported *B. inermis* seed infested with *S. bromicola* (Newell and Keim 1943; Newell 1973; Dunn 1985). This wasp was only recently recognized as part of our fauna, apparently previously confounded with *A. nebraskensis* (Girault). *Tetrastichis bromi* was reared from *S. bromicola* at an infestation at a rate of 29.5% throughout the emergence period in 2014. This is a low infestation rate compared to the proportions given by Agafonova (1962) who found that parasitism rates increased through each sequential gall midge generation.

Three additional eulophid parasitoid species were also reared from *S. bromicola*, two apparently undescribed *Aprostocetus* species designated morphospecies 1 and 2, and a *Quadrasticus* sp. *Aprostocetus* sp. 1 occurred at a 38% infestation
rate, and was also reared from *S. geniculati*. This is the only parasitoid reared from both species. At this time it is not is clear if this wasp is native or introduced. The total parasitism rate for *S. bromicola* was 71%. This occurrence of multiple species of parasitoids suggests inter-specific competition among *S. bromicola* parasitoids and could be a reason for differences between this rate and the *T. bromi* parasitism rates observed by Agafonova (1962).

The parasitism rate for *S. geniculati* by *Aprostocetus* sp. 1 was 44.8%. This was the most prevalent parasitoid and is shared with *S. bromicola*. A third apparently undescribed *Aprostocetus* species is *Aprostocetus* sp. 3. Additionally an undetermined species of Diapriidae (Hymenoptera) was reared once from this gall midge. The total parasitism rate for *S. geniculati* was 45.6%. During 2015, an undetermined species of Aphelinidae was reared from *A. arundinaceus* samples with *S. geniculati*.

**Seed Production**—The damage by these gall midges to grass seed production varies considerably from very low and undetectable to 100% infestation rates on *B. inermis* by *S. bromicola* (Agafonova 1962; Neiman and Manglitz 1972), and from 20-80% in *A. arundinaceus* by *S. geniculati*. These rates are significant for seed production and impact the commercial production of these grasses used as forage crops (Barnes 1946). Whether seed loss from gall midge predation impacts the biological control of unwanted *B. inermis* remains for evaluation.

**SUMMARY**

Previously unrecognized morphological differences were found in gonostylus shape, female circumfila and width-length proportions in the female cerci, distinguishing *S. bromicola* and *S. geniculati*. Phenologically, the two species have similar life cycles, seasonality, and they commonly co-occur in anthropogenic habitats, including their introduced host plants. The parasitoid *T. bromi* seems restricted to *S. bromicola*, with apparently undescribed species of *Aprostocetus* recovered from both gall midges species *S. bromicola* and *S. geniculati*. *Stenodiplosis bromicola* is host specific to *B. inermis*, and *S. geniculati* is restricted to at least two species of *Alopecurus*, i.e. *A. arundinaceus* and *A. pratensis*. The data analyzed and interpretations support the species distinction of *S. bromicola* and *S. geniculati*.

**ACKNOWLEDGMENTS**

We thank Raymond J. Gagné, USDA-ARS-SEL (retired) for technical assistance with gall midge systematics and review of the manuscript; Zoya Yefremova, Tel Aviv University, for *Aprostocetus* determinations and advice; Gary E. Larson, SDSU Professor and Curator of the C.A. Taylor Herbarium (retired) for review of the manuscript; and the North-Central Sun Grant Initiative through USDA-NIFA award number 2010-38502-2186.
LITERATURE CITED


Figure 1. a. Stenodiplosis bromicola, first female flagellomere (anterior). b. Stenodiplosis geniculati, first female flagellomere (anterior). c. Stenodiplosis bromicola, female cerci (dorsal). d. Stenodiplosis geniculati, female cerci (dorsal). Scale bar = 0.02 mm.
FIRST REPORT OF SEED PREDATORS OF PLATTE MILKVETCH
ASTRAGALUS PLATTENSIS NUTT. EX T. & G.

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ABSTRACT

Native legumes are important components of North American steppe and are highly desirable in revegetation plantings. However, seed predation by insects can substantially reduce the viable seed crop for many native legumes. Platte milkvetch (Astragalus plattensis Nutt. ex T. & G.) is drought tolerant, palatable to livestock, and may have potential for commercial use. The bruchid beetle Acanthoscelides fraterculus (Horn) (Coleoptera: Chrysomelidae: Bruchidae) and the seed wasp Bruchophagus mexicanus Ashmead (Hymenoptera: Eurytomidae) were found feeding on seeds inside mature pods of Platte milkvetch in northwestern South Dakota. Forty-eight percent of the seeds in a sample of 10 pods were destroyed by these two insects. Both insects may occupy a single locule of a host pod simultaneously. This report is the second known instance of Acanthoscelides fraterculus and B. mexicanus competitive cohabitation in pods of native Astragalus species. Commercial seed production of Platte milkvetch would likely be negatively impacted by one or both of these seed predators.

Key Words

Native legumes, seed predators, Acanthoscelides, Bruchophagus

INTRODUCTION

Many native legumes, in addition to being important forage producing and nitrogen fixing species of grassland plant communities in the northern Great Plains and more western areas, are desirable components of seed mixtures for revegetation of disturbed and denuded soils, augmentation or establishment of wildlife habitats, and beautification of parks and recreation areas (Boe and Bortonem 1998; Boe and Fluharty 1998). Astragalus Linnaeus is the largest genus of native Leguminosae in North America (ca. 370 species) (Barney 1964), and it is composed of at least 2,300 species worldwide (Lewis et al. 2005).

Bruchid (Coleoptera: Bruchidae) beetles and phytophagous eurytomid (Hymenoptera: Eurytomidae) wasps are being found to have important roles in the population biology of many native legumes as their identities and roles as major
seed predators are elucidated (e.g., Johnson 1979; Boe and Wynia 1985; Boe et al. 1988; McDaniel and Boe 1991; Kingsolver 2004). Evaluations of native legumes in forage production, conservation, and other plantings are dependent on the availability of adequate seed resources. Identification of seed predators and their parasites, quantification of seed loss to predation, and insights into behavior of seed predators are important prerequisites for understanding natural community dynamics involving these species. This also impacts seed collections and increases, and experimental evaluations of native legumes (Boe et al. 1988).

Platte milkvetch (Astragalus plattensis Nutt. ex. T. & G.) occurs on hillsides and bluffs from southwestern North Dakota to southern Texas in the Great Plains. It is palatable to livestock and decreases under heavy grazing. It produces thick-walled fleshy seed pods about 1.0 cm wide and 2.0 cm long that become woody when mature (Stubbendieck and Conard 1989). It is one of many native legumes with traits desirable for commercial purposes.

METHODS

During August 2000 a serendipitous opportunity allowed us to collect about 25 pods from a single plant of Platte milkvetch on the Grand River National Grassland near the community of Lodgepole in Perkins County in northwestern South Dakota. The pods were kept in a clear plastic bag at room temperature and monitored weekly until April 2001. Several adults of Acanthoscelides fraterculus (Horn) (Coleoptera: Chrysomelidae: Bruchidae) emerged from the pods during the winter. Species determination of the beetle was based on external morphology, characteristics of the aedeagus (Johnson 1970; Kingsolver 2004), and direct comparison with specimens of A. fraterculus in the Severin-McDaniel Insect Collection (SMIRC) at South Dakota State University. During April 2001, we dissected 10 pods and examined their contents. Numbers of normal and insect-damaged seeds were counted for each pod. The frequencies of damaged seeds attributed to each of A. fraterculus and Bruchophagus mexicanus Ashmead (Hymenoptera: Eurytomidae) were determined based on types of physical damage and variation in seed coat color between infested and normal seeds.

RESULTS

Pods contained about 10 seeds in each of the two locules. Forty-eight percent of the seeds were damaged by insects. Twenty-four percent of seeds were partially consumed by the larvae of Acanthoscelides fraterculus leaving only remnants of testas and another 24 % contained larvae or adults of Bruchophagus mexicanus Ashmead (Hymenoptera: Eurytomidae) (Figure 1). Several pods contained both the beetle and wasp in the same locule. Species determination for B. mexicanus was based on morphological characteristics (McDaniel and Boe 1991) and direct comparison with conspecific specimens reared from pods of two-grooved poisonvetch (Astragalus bisulcatus (Hook.) A. Gray) (Trease and Trease 1937)
Acanthoscelides fraterculus that fed on several seeds within a locule, each larva of Bruchophagus mexicanus fed inside a single seed. Seeds containing larvae of B. mexicanus were light brown and more terete (Figure 2) than normal; whereas, uninfested seeds were uniformly black. The cotyledons and embryo axes of infested seeds were consumed by the B. mexicanus larvae, thus infested seeds were essentially hollow shells composed of only discolored testas. There was no evidence of mutual use of a given seed. Adult B. mexicanus emerge by chewing a hole in the testa (Figure 2). Johnson (1970, 1979) listed Astragalus bisulcatus, A. drummondii Dougl. ex. Hook., A. racemosus Pursh, and A. crassicarpus Nutt. as host plants for Acanthoscelides fraterculus. Burks (1979) gave Astragalus mollissimus Torr. as a host for B. mexicanus, and Center and Johnson (1976) reared B. mexicanus from seeds of A. fucatus Barneby, A. lentiginosus Dougl., and A. praelongus Sheldon.

DISCUSSION

This is the third report of cohabitation of seedpods of an Astragalus species by Acanthoscelides fraterculus and B. mexicanus. Trelease and Trelease (1937) reared adults of both insects from a sample of Astragalus bisulcatus seed pods collected near Laramie, WY. Similarly, McDaniel and Boe (1991) found Acanthoscelides aureolus (Horn) and Bruchophagus grisselli McDaniel and Boe as cohabitants in several samples of Glycyrrhiza lepidota Pursh pods in the northern Great Plains. Johnson (1970) listed 11 species of North American legumes for which one or more species of Acanthoscelides and a Bruchophagus reared from each of the same seed lots. However, neither A. fraterculus or B. mexicanus were previously reported from pods of Platte milkvetch. Natural and commercial seed production of
Platte milkvetch in the northern Great Plains would undoubtedly be negatively impacted by one or both of these seed predators.

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LITERATURE CITED


RUNT EGG OCCURRENCES IN EGG COLLECTIONS OF 34 WILD NORTH AMERICAN DUCK SPECIES

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ABSTRACT

Runt eggs occasionally occur in wild bird clutches, but occurrence in wild duck clutches has rarely been documented. Most of the runt egg data from nests of wild waterfowl (Anseriformes) have been based on anecdotal observations by researchers and not on actual egg measurements. Using digital calipers, we obtained egg measurements from 34 wild duck species from museum collections made from 1859-1979 (N = 30,762) and from field research biologists during 1980-2010 (N = 36,775). Maximum length and width (± 0.01 mm) were obtained for each egg and then egg volume was calculated using the equation 0.51*LW² (Hoyt 1979). Eggs were defined as runts if their volume was less than 75% of the average egg volume for that species (Koenig 1980a). We found evidence of runt eggs in egg collection samples for 28 of the 34 duck species that we studied. Runt eggs were found in egg collections of five wild duck species for which runt eggs had not been previously documented. The rate at which runt eggs occurred within our samples varied from 0.1% to 8.7% among the 34 species we studied. The occurrence of runt eggs in our samples did not increase with larger sample size. This research indicates that runt eggs occurred more frequently in wild duck clutches then had been previously documented; however, factors which influence the creation of runt eggs are largely unknown.

Keywords

wild ducks, runt eggs, North America

INTRODUCTION

Noticeably small-sized eggs, otherwise known as runts (a.k.a., dwarf eggs; see Pearl and Curtis 1916), are rare but have been occasionally found in wild duck clutches. Eggs are typically defined as runts if their volume is less than 75% of the mean egg volume for that species (Koenig 1980a). Runt eggs often do not contain yolks and so they do not hatch (Koenig 1980a). The occurrence of runt eggs in clutches of several species of wild birds is reportedly about one in 1,000-
2,000 eggs (Mallory et al. 2004; Hernandez et al. 2006). Several researchers have found the incidence of runt eggs to be higher in museum collections than in the field studies, presumably due to the preference of oologists (collectors) to keep odd or unusual specimens (Koenig 1980b; Mallory et al. 2004; Rothstein 1973). In contrast, some would disregard or toss runt eggs from their collections. Mallory et al. (2004) compared the occurrence of runt eggs in the nests of wild waterfowl (0.039%) to the occurrence of runt eggs in museum collections of wild waterfowl (0.156%). Even though the occurrence was four times as high in museum collections, the rate was still quite low (<1%). They also found no relationship between the preponderance of runt eggs and the size of the clutch for a particular bird species, although runt eggs were found more often in nests of ground-nesting species than in those of cavity-nesting species. Neither do runt eggs occur more often at the beginning or the end of laying of a clutch (Kendeigh et al. 1956; Koenig 1980a). Romanoff and Romanoff (1949) hypothesized that runt eggs occurred as an occasional, random disturbance in the reproductive tract. This random occurrence could then occur with any species, and at the same minimal frequency. The possibility of runt eggs occurring due to nutritional or environmental stressors (e.g., drought) has not yet been proved or disproved. However, eight Blue-winged Teal (Anas discors) runt eggs were photographed by K. F. Higgins during a very dry nesting season in North Dakota in the 1970’s (Figure 1). As a rule, only a small proportion of the eggs in a clutch are runts. Very rarely is an entire clutch comprised of runt eggs, but some such occurrences have been documented in the following species: Song Thrush (Turdus philomelos; M’William 1927), Gray Catbird (Dumetella carolinensis; Rothstein 1973), Eastern Bluebird (Sialia sialis; Zeleny 1983) and Northern Bobwhite Quail (Colinus...
If a clutch contains runt eggs, the entire clutch or only the runt eggs that did not hatch could be abandoned, or incubation behavior could be prolonged 204-326% longer than average, as was noted with Northern Bobwhite Quail runt eggs (Hernandez et al. 2006). While conducting a research project relative to the effects of climatic variability on wild duck egg sizes in North America (DeJong 2013), DeJong noted a large number of runt-sized eggs and they are the basis for this publication.

Digital calipers were used to obtain maximum width (W) and length (L) measurements (± 0.01mm) from 30,762 wild duck eggs from museum collections and 36,775 wild duck eggs from field research studies (1980-2010). Eggs in museum collections were originally collected from various geographic locations throughout North America from 1859-1979 (DeJong 2013). Volume (cm$^3$) for each egg was calculated using the equation $0.51 * L W^2$ (Hoyt 1979). Eggs were not measured if they were cracked, broken, or if their identification was questionable. A runt egg was defined as an egg with a volume (cm$^3$) that was <75% of the mean volume of all the eggs measured from each species.

Runt eggs had been reported in the clutches of 28 of 34 duck species which were included in our study. Before our study, runt eggs had not been reported for American Wigeon (Anas americana), Green-winged Teal (Anas crecca), Ring-necked Duck (Aythya collaris), Harlequin Duck (Histrionicus histrionicus), Common Merganser (Mergus merganser), or King Eider (Somateria spectabilis) (Mallory et al. 2004). We found and measured one or more runt eggs for all of those species except for the Harlequin Duck. Therefore, inclusive of our findings and those of Mallory et al. (2004), runt eggs have now been documented for 33 of 34 North American wild duck species.

The highest occurrence of runt eggs in this dataset was 8.7% for the Ring-necked Duck, of which 63 runt eggs occurred in a sample of 722 eggs. All of the Ring-necked Duck runt eggs were found during field research in Minnesota during 1983. The second highest percentage of runt eggs in our dataset (5.0%) was for Steller's Eiders, of which nine runt eggs occurred in a sample of 180 eggs that were measured during field research. Total incidence of runt eggs in our 67,537 egg dataset was 0.78%, which is considerably higher than the 0.039% found by Mallory et al. (2004) and also higher than the 0.02-0.6% occurrence for wild birds in general (Mallory et al. 2004). For this project, runt eggs were found more frequently in clutches during field research studies than in museum collections of Common Eiders (Somateria mollissima), Greater Scaup (Aythya marila), Green-winged Teal, Long-tailed Ducks (Clangula hyemalis), Northern Pintails (Anas acuta) and Spectacled Eiders (Somateria fischeri).
Occurrence of runt eggs did not increase with larger sample size. The average percent occurrence of runt eggs for all 28 species was 1.1% (range 0.1-8.7%) even though sample size for some species was quite large. For example, only 0.8% of 15,335 Northern Pintail eggs were runts.

CONCLUSIONS

Unlike some of the previous runt egg studies, we were able to use egg metrics instead of visual judgment to determine if an egg was a runt (<75% of mean volume for that species). These results indicate that most species of North American ducks will occasionally lay runt eggs, and that the number of runt eggs will not necessarily increase with the number of eggs laid/sampled. Additionally, it appears that runt eggs occur more frequently than what was previously reported. Past researchers may not have measured runt eggs at nest sites because they were not considered viable. This would lead to the underreporting of the actual percentages and occurrences in wild ducks. What remains to be determined are the environmental, nutritional, and physiological causes of runt eggs. Some researchers theorize that runt eggs are produced as a “malfunction” in the hen’s reproductive tract during egg production (Pearl and Curtis 1916; Romanoff and Romanoff 1949; Mallory et al. 2004). If the occurrence is not related to “heredity, nest-site location, geographic location, or productivity” as Mallory et al. (2004) hypothesized, then this temporary malfunction could be related to weather extremes, the availability of suitable nesting habitat, and/or the subsequent nutritional source or dietary status of the hen. Unfortunately, since runt eggs are so rare, it is hard to determine if environmental factors play a major role in their production under natural conditions; however, under controlled laboratory research studies, cause and effect processes may be more readily assessed.

ACKNOWLEDGEMENTS

We thank the U.S. Fish and Wildlife Service’s Regions 3 and 6; the Wildlife and Fisheries Sciences Department and the South Dakota Cooperative Fish and Wildlife Research Unit at South Dakota State University, Brookings for personnel assistance and partial funding for this project; and the numerous museums, agencies and institutions in the U.S. and Canada that provided access to their egg collections in support of this project (see DeJong 2013 for specifics).
LITERATURE CITED


Table 1. Egg volume (Hoyt 1979) statistics for 28 species of North American ducks. Runt eggs were defined as having ≤ 75 % the amount of volume than the mean egg volume for that species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Scientific Name</th>
<th>Average Vol. (cm³)</th>
<th>Minimum Vol. (cm³)</th>
<th>Eggs Measured</th>
<th>Runs Measured</th>
<th>% of Total # Sampled</th>
<th>% From Museums</th>
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WATER GEOCHEMISTRY AND PRESSURE BUILDUP IN DRILL HOLES ON THE 4850-FT LEVEL AT THE SANFORD UNDERGROUND RESEARCH FACILITY

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ABSTRACT

Chemical and hydrological characterization of nine core holes (wells) on the 4850-ft level at Sanford Underground Research Facility have indicated decreasing flow rates with time, naturally buffered water, and existence of multiple flow systems. Flow rates for the wells all decreased by 17 to 63% over approximately nine months. The primary fluid pathway was most likely through ubiquitous secondary fracture permeability. pH was neutral to slightly basic at 7.75 with little variation. Core hole temperatures also stabilized at the drift temperature, decreasing by up to 31%. Oxidation reduction potential values of the water indicated reducing conditions and strong iron-holding capacity. All wells were fitted with pressure gauges and relief valves and were shut in to allow pressure to build. Analyses were conducted utilizing Horner time functions resulting in a maximum reservoir pressure of 1200 psi (~2800 ft head). There were strong indications that three isolated flow systems existed, including one that impacted a hole that was originally dry and began flowing and building pressure over time indicating hydraulic connectivity had occurred. These and supporting data have been utilized in the design of large underground excavations for future physics experiments.

Keywords
SURF, Ground Water, Pressure Buildup, Water Chemistry

INTRODUCTION

The former Homestake Gold Mine in the Black Hills of South Dakota operated continuously from 1876 to 2001. In that time, approximately 40 million oz (1136000 kg) of gold and 8 million oz (227000 kg) of silver were produced from surface to 8000 ft (2438 m) underground (Terry and Paterson 2010). The mine workings followed Homestake rocks along 4 miles (6.4 km) of plunge, penetrating through a volume of crust ~1.7 x 1.9 x 3.1 mi (2.7 x 3.0 x 5.0 km) with ~370 mi (590 km) of drifts (Campbell 2006; Roggenthen and Rahn
Arsenopyrite-pyrrhotite ore mineralization was hosted in the Homestake formation (Paterson 1996), a Proterozoic banded iron formation consisting of interbedded quartzite and sericite-biotite schists and phyllites (Campbell 2006) that were folded several times and tilted toward the southeast during the Precambrian (Redden and Lisenbee 2010; Terry and Paterson 2010). During Cretaceous Laramide tectonism in the interval 64 – 35 Ma (Terry and Paterson 2010), the Black Hills were uplifted to their current configuration and experienced brittle fracture (Redden and Lisenbee 2010), most likely creating the present fracture network observed throughout the mine. Later Tertiary alkalic volcanism in the interval 60 – 40 Ma (DeWitt and Duke 1996; Shurr et al. 1996; Terry and Paterson 2010) intruded into the folded and fractured rock and is considered as one of the proposed gold mineralization events (Paterson 1996). These fracture networks consist of open fractures having variable aperture and degree of healing. The open fractures are partly responsible for flow of water through the mine workings.

One hundred twenty-five years after gold was discovered in 1876, mining operations ceased in December 2001 (Davis et al. 2009). Two years later, on June 10, 2003, power was shut off to the underground water pumping system. Subsequent water level rise was monitored by a sensor network that had been installed every 600 feet (183 m) of depth and was used to determine inflow rates (Figure 1). An inflow model was constructed by Zahn (2002) and was modified for use here using slightly different precipitation values. Post-closure flooding resulted in rising water levels that reached the 4850-ft (1478 m) level in November of 2007 and ultimately reached the 4529-ft (1380 m) level on August 24, 2008, a total rise of 3621 feet (1104 m). Dewatering efforts lowered the water pool below

![Figure 1. Water inflow model (modified from Zahn 2002) and measured dewatering data from 2003 – 2014. Current water level is maintained to provide a one year inflow buffer for the 4850 science level.](image-url)
the 4850-ft (1478 m) level in early April 2009, resulting in the main scientific campus at SURF having been submerged for ~17.5 months and subjected to a total head equal to 321 feet (98 m) of water.

Development of the 4850 campus began soon after the water pool was below the 4850-ft (1478 m) level. New excavations were initiated and geologic mapping of existing drifts was completed to support future laboratory development, including the locating of laboratory modules and excavations to house large experiments. Currently, these data are being utilized to design the Long Baseline Neutrino Experiment (Popielak et al. 2015), now named the Long Baseline Neutrino Facility. Rock characterization included the drilling of nine geotechnical core holes (2.875 in; 7.3 cm) between late August and late November 2009 (Figure 2). Physical and mechanical properties of the rock were determined based on analysis of the core and included lithologies, discontinuities, rock quality designation, and later magnetic properties by South Dakota School of Mines and Technology faculty and students. Eight of the nine wells intercepted the groundwater system(s) and produced varying quantities of flow. The primary fluid pathway was most likely through the ubiquitous fracture permeability that currently could be viewed as secondary to the drift permeability, but prior to mining were the primary permeability pathways for water flow.

A well monitoring program was designed to provide data for pre-construction modeling of the excavations and included the following objectives: 1) determination of maximum water pressure in the fracture system(s), 2) measurement of changes in the flow system due to pressure buildup during the shut-in period, 3) define the basic water chemistry, and 4) assess the water origin. This paper contains the details of objectives 1, 3, and 4.

**METHODS**

The nine core holes represent a total of 5399 feet (1646 m) drilled and were structurally and geologically mapped. The outer 10 feet (3 m) of each drill hole was cased and pressure tested to 2000 psi (13.8 MPa), the theoretical maximum hydrostatic pressure for a flow system connected to the surface. The following data were derived from the well monitoring program objectives and address 1) measurement of flow rates and water quality, and 2) pressure build-up testing and analysis. Data for 1) were generated from the date of the well completion and continued until the wells were shut-in (Table 1). Data for 2) were generated by a shut-in (pressure build-up) period of ~60 days.

**RESULTS**

Analytical results were obtained from analysis of the well-water data that included flow rates, pH, temperature, conductivity (C), oxidation reduction potential (ORP), and total dissolved solids (TDS) that had been collected regularly for eight months after wells were drilled (Table 1).
**Flow Rates and Water Chemistry**—For all wells, flow rates decreased over the total flow period by 17 to 63%. In addition, flow decreased by a factor of 4, 3, and 1.5, respectively, for wells 3A, M, and N. This suggests that although all flow rates were low (L/min), the rate of diminishing flow decreased toward the southwest. Figure 3 contains flow data from the four wells with the greatest flows. pH remained within a narrow range between a minimum of 7.37 and a maximum 8.05. These slightly basic values indicated that the rock matrix within which the fluid flowed had a naturally strong buffering capacity. This was a result of the naturally high carbonate mineral content of the rocks which prohibited acid-mine drainage from occurring during the mine life. Initial temperatures,
averaging 25.70 °C ± 0.15 in all wells, were greatest immediately upon completion of the drilling. These values were representative of the maximum in-situ temperature inside the rock mass. As flow time increased, water temperature decreased by up to 31%. The decreasing temperature trend was a reflection of the ambient drift temperature (controlled through drift ventilation) penetrating back into the rock through the drill holes.

ORP is a measure of the ability of a solution to either gain or lose electrons when subjected to new species (elements) in the solution. ORP values in all holes remained negative throughout the measurement period indicating the tendency of the water to lose electrons to new species, thus, reducing them. The strong negative value also indicated the increased concentration of negative hydrogen ions. Common reducers include sodium sulfite, sodium bisulfate, and hydrogen sulfide. Water chemistry data indicated high sodium and sulfate content throughout the facility, and were related to rock composition. Bleed-water from well 3A contained noticeable olfactory detection of hydrogen sulfide gas. The general reducing environment contributed to the high iron-holding capacity of the mine inflow water, which averaged 28,000 µg/L in water sampled from the shafts. Water under reducing conditions and at normal pH values (matching the present conditions observed at the site) would tend to have more dissolved Fe²⁺. When the water becomes more oxidizing, through exposure to the atmosphere, Fe(OH)₃ forms and becomes more abundant. This compound then readily precipitates as amorphous ferric hydroxide and the oxidized iron is present as Fe³⁺. This common reaction occurs in all water pumped from the underground spaces of the mine.

Figure 3. Flow rate data for monitored wells all contained a decreasing trend throughout the measurement period.
Table 1. Water chemistry data from the four core holes at SURF having the greatest flow rates.

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Conductivity and TDS measurements indicated dissolved constituents in the water. Conductivity values increased during the measurement period by 15%, 19%, and 23%, respectively, for wells 3A, M, and N. These data indicate an increasing trend toward the southwest. Conversely, TDS values decreased by 19%, 18%, and 7%, respectively, for wells 3A, M, and N indicating a decreasing trend toward the southwest. These data support the observed decrease in flow rate toward the southwest. These trends could indicate multiple hydraulic systems existed, or, it may have indicated a decreasing fracture density toward the southwest. Decreased fracture density would potentially increase residence time of water in these fractures and, thus, the ability to dissolve constituents and supports a decreased flow rate. This would suggest changes in conductivity and TDS could be a function of more or less fractures for water to flow through.

**Pressure Build-Up Analysis**—Pressure gauges rated to 2000 psi (13.8 MPa) and pressure release valves set to 1899 psi (13 MPa) (calibrated using a Ruska Instruments Corporation pressure pump, calibration controller, and calibrated
weight stand) were installed on each wellhead prior to the shut-in period. At the end of the flow monitoring period, all valves on the wells were closed. The time to pressure varied for each well as a function of the flow rate. Funds were unavailable to place an air bleed line in the up-angle holes which resulted in increased time to pressure as trapped air was compressed due to inflowing water. Despite the compressibility problem, wells 3A and M began to take pressure on day six and eight into the shut-in period, respectively. These were delayed by <1 and <3 days from the calculated values based on a no air condition. These wells had the highest flow rates, which most likely aided in the fast time to build-up. The remaining wells had the following days of shut-in to pressure: B—30 days; C—40 days; 2A—76 days; J—no pressure; D—no pressure. The fact that wells D and J, which were drilled into the space between the exhaust and vent drifts (Figure 2), had no pressure may indicate fracture connectivity to both sides of these drifts, thus, allowing potential pressure to have previously escaped outward. Log-log plots of pressure build-up for all wells having pressure are contained in Figure 4.

Fundamental reservoir dynamics in the regions immediately surrounding and away from the wellbore are governed by permeability, reservoir pressure, and the fluid drive system. Analytical techniques provide an indication of all of these variables, although more specific testing would be required to parameterize each of these. There are two primary conditions to satisfy for pressure data to have meaning and are 1) inner boundary conditions, and 2) outer boundary conditions. Inner boundary conditions describe the condition of the well in immediate contact with the hole boundary. This region can extend into the rock face a small distance. Analytically, these conditions are referred to as early-time data and include primary functions of a well’s performance based on how much time may be required for the well to fill and begin to transmit pressure from the reservoir rock to the fluid-filled wellbore. Outer boundary conditions describe the general nature of the reservoir rock, or that portion of the formation from which the wellbore draws fluid flow. This region extends from the wellbore into the rock a distance that is determined by the pressure regime and the permeability. These features are referred to as late-time data.

Analysis of pressure-time responses utilize the Horner method, a log-time function plotted against the log of pressure (Ramey 1992). Early-time data for each well include the symbols on Figure 4 that are not connected by the straight line and represent effects during the time when fluid flowed into the wellbore and gas compression occurred. These conditions being satisfied, i.e., the wellbore has been filled, the pressurization of the wellbore represents hydraulic conditions away from the wellbore as reservoir pressure is transmitted to the wellbore over time. All log-log pressure plots will exhibit a change of shape in the pressure curve when wellbore effects have ceased and begin to fall on a straight line. Early-time data usually plot as a non-linear curve and late-time data plot as a straight line. A straight line fit through the late-time data extrapolated to the pressure axis provides the maximum reservoir pressure.

In practical terms, this implies that the pressurization period need only extend through the initial definition of the late-time data, which confirm the pressurization is from the reservoir. At that point, the test can be stopped and the extrapolated line through the late-time data to the pressure line provides P*, maximum reservoir pressure.
Well Pressure Analysis—Analysis will be presented for the three wells that achieved sufficient pressure to calculate a maximum reservoir pressure.

Well 3A: Pressure build-up began on day six of the shut-in period. Well 3A was an up-angle hole and either gas escaped through fracture pathways and gas compression inside the wellbore was at a minimum, or the rate of inflow and pressure drive was relatively high and gas compression was occurring. The Horner time function pressure plot (Figure 4) would appear to support that minimum gas compression was occurring owing to the gentle build-up curve. The well behavior indicates wellbore storage (filling and compression) occurred until log-time ~1.0, or ~30 days into the shut-in. Later time data exhibited a more-or-less linear build-up rate. The extrapolated line indicates a maximum reservoir pressure of ~700 psi (4.8 MPa).

Well M: Pressure build-up in well M began on day eight of the shut-in period. Well M was an up-angle hole and gas was trapped in the bore when the valves were closed. The slower than expected response to pressure indicated gas compressibility dominated the early pressure build-up with minimal gas escaping through fractures (or was escaping at low rates). At a point where gas compressibility became small, fluid pressure increases began to be observed on the gauge.
After ~30 days, a leak in a fracture next to the wellhead began to seep water. The pressure response was apparently affected by the seep and the resulting Horner time function pressure plot (Figure 4) is inconclusive and interpretation remains speculative. The general flat-lying shape of the build-up curve indicates that leaks have negated this well from producing actual reservoir pressures.

**Well N:** Pressure build-up in well N began immediately on day one of the shut-in period. Well N was a down-angle hole and water had already filled to the top of the wellhead when the valves were closed. The fast response to pressure is what is expected when wellbore effects are minimized. Well N also began to leak slightly at the grout-rock interface ~30 days into the shut-in period but had minimal analytical effects. The constant slope of the trend line indicated the pressure build-up rate was constant with increasing shut-in time. This condition would be representative of steady state conditions suggesting a constant pressure drive. A maximum reservoir pressure 1200 psi (8.3 MPa) was calculated. This pressure correlates to a head elevation of ~2765 feet (843 m), placing the top of the fracture system feeding this area near the 2000-ft (606 m) level. The pressure remained strong and continually built indicating that the pressure head was constant, i.e., it was being continually fed.

**CONCLUSIONS**

The data, as presented above, support the following conclusions. Maximum system pressure was 1200 psi (8.3 MPa) representing a pressure head originating near the 2000-ft (606 m) level and was continually fed, i.e., it appeared to be a constant head pressure system. The Horner plot indicated the strong possibility that the nine wells monitored represented at least three independent (isolated) systems. Wells 3A and 2A appeared to be hydraulically connected and wells D and J were affected by the pre-existing drifts and rock into which they were drilled. Neither wells D nor J built pressure. Well D was the longest well drilled at >1300 feet (396 m) and had a small non-measureable flow (casing was always wet and showed an extremely slow ‘drip’ rate). Well J was short, 450 feet (137 m), but supported flow, albeit the lowest of the other flowing wells (3A, M, and N). These two wells were drilled into the large triangular-shaped rock pier between the vent and exhaust drifts (Figure 2). The decades of exposure to the drifts have bled off any hydraulic pressure from within this area.

New excavations in this area of SURF will need to contend with a constant, albeit, low flow rate of mostly non-corrosive but highly reduced water. Pressure heads could possibly originate ~2800 feet (853 m) above the main science level and create high pressures if not allowed to flow freely from the area. Additional pressure testing should be performed to confirm the origin and nature of the isolated hydraulic systems indicated during this project. Planning to direct water flow away from structural steel and other materials will be a primary design consideration as this area is expanded for science experiments.
ACKNOWLEDGEMENTS

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REFERENCES


FERMI’S QUESTION

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ABSTRACT

There are approximately 4 X 10^{11} stars in the Milky Way galaxy and there may be at least as many exoplanets as stars. The probability of intelligent life presently on an exoplanet can be modeled as the product of the following four probabilities: (1) \( P_{hz} \), that an exoplanet orbits its parent star at a distance (habitable zone) where liquid water could exist, (2) \( P_{dl} \), that life developed on this exoplanet, (3) \( P_{il} \), that life evolved into intelligent forms, and (4) \( P_{pt} \), that this intelligent life presently exists on the exoplanet. The number of extraterrestrial civilizations (ETC) in the Milky Way equals the number of exoplanets (R) times these probabilities:

\[
ETC = R (P_{hz} \cdot P_{dl} \cdot P_{il} \cdot P_{pt})
\]

Despite great uncertainties in the actual probability values for this model, there may be some exoplanets in the Milky Way that meet these criteria. In order to answer Fermi’s Question (“Where are they?”), consideration must be given to the fact that the great distance to an exoplanet with intelligent life could essentially preclude any two-way communication.

Keywords

Extraterrestrial life, SETI, exoplanet

INTRODUCTION

The recent discovery of planets in the Milky Way galaxy increases our awareness of the issue that intelligent life may be found outside our Solar System. “Search for Extraterrestrial Intelligence” (SETI) is the collective name for a number of activities and programs engaged in listening for electromagnetic (radio or microwave) signals from a distant “exoplanet”, a planet outside our Solar System (Shostak 2014). Thus far, no signals have been observed (The Planetary Society 2015).

Early astronomical observations indicated that the Milky Way galaxy (Figure 1) contains a hundred billion stars (Menzel and Pasachoff 1983), but more recent
observations indicate there may be as many as 400 billion stars (Webb 2002; NASA JPL 2003; Bryson 2005). Since launching in March, 2009, the Kepler Space Telescope monitors a small area of the sky containing 150,000 observable stars. On January 6, 2015, Kepler confirmed its 1,000th exoplanet discovery, along with over 4,000 additional exoplanets considered candidates for further study (NASA 2015). In the Milky Way Galaxy there may be as many exoplanets as stars. Bovaird et al. (2015) indicate there may be as many as two exoplanets per star in the habitable zone. An updated database of new discoveries is available at http://exoplanets.org/. More confirmatory information should be obtained by NASA’s upcoming 2017 Transiting Exoplanet Survey Satellite (TESS) which, for a two-year period, will monitor 500,000 bright nearby stars for Earth-to-Jupiter sized planets (NASA TESS 2015).

If there are 4 X 10^{11} stars in the Milky Way and the same number of exoplanets, this large number enforces the argument that there could be intelligent life in our galaxy. It begs the question about an apparent paradox: if technically advanced civilizations are out there, why don’t we see evidence of them? In 1950 the physicist Enrico Fermi asked, “Where are they?” (Zuckerman and Hart 1985; Webb 2002; Ferris 2003).

In this paper, a model to estimate the probability of extraterrestrial intelligent life in the Milky Way utilizes the product of four probabilities, a method similar to one set forth in 1961 by the American astronomer Frank Drake (Shklovskii and Sagan 1966; Webb 2002; Basalla 2006). Since the actual probabilities vary greatly and actual values are not known, the following discussion simply describes a method and uses assumed probability values. Numerous astrobiologists have discussed the possibility of extraterrestrial life, and estimates vary from Carl Sagan’s estimate of one million civilizations whose creatures are capable of interstellar communication existing in the Milky Way galaxy at the present time to Ward and Bronlees’ (2004) modification of the Drake equation leading to a probability approaching zero.

The model described below uses an equation in which the number of Extraterrestrial Civilizations (ETC) presently in the Milky Way Galaxy is the product of the number of exoplanets (R = 4 X 10^{11}) times the probability of four circumstances, assuming each of these four probabilities is an independent parameter:

1. Probability of a planet orbiting in the “habitable zone” (P_{hz})—Liquid water and an atmosphere are believed to be requisite conditions for the development of life. A planet has to be just the right distance from its parent star to be in the habitable zone (also referred to as the “Goldilocks Zone”). Consider our Solar System. The surface temperature of Venus is 470° C. Mars currently is a frozen waste, although it may have had surface water at one time. But Earth is just the right distance from the Sun where water can exist on the surface as a liquid. (Note: an exoplanet in the habitable zone must be big enough to support an atmosphere and liquid water. The concept of a habitable zone with water doesn’t
account for unusual conditions where water could exist such as in a geothermal area beneath the surface.)

The habitable zone is only a small percentage of the total range of planet orbits in our Solar System. Hart (1978) postulated that Earth would not have been habitable had its orbit been just 1% further from the Sun, or 5% closer to the Sun. Disregarding Pluto, the last planet from the Sun is Neptune which orbits at a distance of 4,497 X 10^6 km from the Sun. Earth orbits the Sun at 149.6 X 10^6 km. If Earth's orbit is 1% further from the Sun, it would orbit at 151.1 X 10^6 km. If its orbit is 5% closer to the Sun, it would orbit at 142.1 X 10^6 km. Therefore, using Hart’s postulation, the habitable zone is 9.0 X 10^6 km wide. Considering the total range of planetary orbits in the Solar System, the habitable zone represents 9.0/4,497.1 = 0.0020013 = 0.2% of this distance. Based on solar luminosity, Scelza (2015) estimates that the habitable zone in the Solar System is between 0.99 to 1.65 astronomical units from the Sun; thus the habitable zone would represent approximately 2% of the Solar System planetary orbit distances.

Assuming the Solar System has a typical range of planetary orbits, for the purpose of this paper an estimate of the probability that an exoplanet would be orbiting in the habitable zone is 1%; that is,

\[ P_{hz} = 10^{-2}. \]

It follows that if there are at least 4 X 10^{11} exoplanets in the Milky Way galaxy, there would be at least 4 X 10^9 exoplanets in the habitable zone. (Note: Some of these extraterrestrial objects may actually be satellites of an exoplanet.)

2. Probability of planet in the habitable zone developing life (P_{dl})—There is great uncertainty in any estimate of the probability that an exoplanet containing liquid water would actually develop life. In fact, creationists have argued that non-living chemicals can't turn into living things by pure happenstance, and that the hand of a divine Creator (God) is behind the creation of the Universe and, thus, the development of life. The origin of life on Earth seems to involve pre-biologic proteins and nucleic acids (Shklovskii and Sagan 1966; Webb 2002). Somehow non-self-replicating molecules became self-replicating entities that led to microbes and single-celled organisms such as protozoa.

Once an exoplanet has liquid water and suitable elements, the chance that life could develop involves many factors. There is only a rudimentary understanding of the variables involved, and few statistics. It has been hypothesized that there may have been a link-up of amino acids, primitive proteins, the DNA molecule, and eventually living cells. A few kilometers below the Earth’s surface, or at “black smoker” vents on the seafloor, temperatures are high and the necessary chemical reactions that form organic compounds may be present. Most of the basic ingredients of life (oxygen, organic compounds based on carbon, etc.) are formed and transformed in geothermal environments. The origin of life may well be inevitable if the conditions were right. Some exoplanets actually may have had much better conditions for originating life than Earth. On the other hand, abiogenesis, the development of life from non-living material, could be an exceedingly rare occurrence. We do not know what these probabilities really are.
Life was quite an achievement. In order to illustrate the model used in this paper, it is simply assumed that an exoplanet existing in the habitable zone would have one chance in a hundred that this could happen, thus

\[ P_{dl} = 10^{-2}. \]

It follows that if there are 4 × 10⁹ exoplanets in the habitable zone there would be 4 × 10⁷ exoplanets where life developed.

3. **Probability of life evolving into intelligent life \((P_{il})\)**—What is the chance that life, once formed on an exoplanet, would evolve to intelligent life? Ward and Brownlee (2004) argue that microbes may be common in the Universe, but animals and higher plants are quite rare. Intelligent life is defined in different ways. To some it implies civilization with some degree of communication. To others it implies technical proficiency such as arrowhead making. Others feel that advanced intelligence implies the capacity of interstellar communication.

On Earth, cave paintings have been around for about 30,000 years. Our species \((Homo sapiens)\) is about 175,000 years old. \(Homo erectus\) has walked on Earth over the past million years; this is roughly 0.02% of Earth’s 4.5 billion year history. For the purpose of this paper let us assume this is the probability that intelligent life evolves:

\[ P_{il} = 2 \times 10^{-4}. \]

It follows that if there are 4 × 10⁷ exoplanets where life developed, there would be 8 × 10³ exoplanets that developed intelligent life.

4. **Probability of intelligent life at the present time \((P_{pt})\)**—An important factor in trying to answer Fermi’s question is that intelligent life with some kind of technical development, once established, may not exist for a very long time. Just because intelligent life evolved on some exoplanet doesn’t mean it exists there forever.

Consider Earth: the fossil record contains many examples of mass extinctions, the latest (the “Anthropocene extinction”) occurring in the Holocene (Kolbert 2014). During the past 1,000 years, human beings have been threatened from disease (e.g., Bubonic Plague, Smallpox, Spanish Flu, Ebola) and wars including atomic warfare (e.g., Cuban missile crisis). For this paper it is assumed that intelligent life on Earth has a million-year lifetime. Since the Solar System has been around for 4.5 billion years, then intelligent life on some exoplanet, should it exist at all, would only be around for 0.02% of the time. Therefore:

\[ P_{pt} = 2 \times 10^{-4}. \]

It follows that that if there were 8 × 10³ exoplanets that developed intelligent life, only approximately two exoplanets would have intelligent life at the present time. (Note: of course, it is easy to come up with a larger number. Webb (2002) estimates up to 10⁶ extra-terrestrial possibilities in our galaxy; but using a very low abiogenesis probability there may be no extraterrestrial intelligent life at all.)
THE MILKY WAY IS VAST

This paper admittedly uses some crude probability values, but let us continue the story. If there are two exoplanets harboring intelligent life in the Milky Way, why haven’t we heard anything?

The answer to Fermi’s question involves the speed of light. If the two exoplanets with intelligent life were scattered somewhat randomly in the Milky Way (that consists of $4 \times 10^{11}$ exoplanets), how far would it be to this exoplanet? The closest star from Earth (Proxima Centauri) is 4.2 light-years away; the brightest star (Sirius) is 8.6 light years away, and so on. Essentially we need to keep reaching further out until we have encompassed perhaps half of the galaxy. The Milky Way (spiral) galaxy is 100,000 to 120,000 light years across, edge to edge, and the Sun is approximately 27,000 light years from the relatively densely-packed center (Williams 2014), as shown in Figure 1. These two exoplanets that presently have intelligent life could be approximately 30,000 light years away, and if these intelligent creatures presently look at Earth, they see the way Earth was 30,000 years ago. Do they see any intelligent life? Not really. Any radio signals? No. They would reason that Earth is just another planet going around its parent star with nothing special going on. Why should they bother trying to communicate to it?

![Figure 1. Artist’s conception of the Milky Way galaxy. Available at http://www.atlasoftheuniverse.com. [Cited 2 March 2015]. Included in this sketch are spiral arms (yellow color) and Messier objects (red color).](image-url)
SUMMARY

Recent astronomical observations showing numerous exoplanets in the Milky Way galaxy begs the question: what is the probability of extraterrestrial intelligent life? In this paper, probability values are assumed for a model that shows that two exoplanets may presently have intelligent life. The actual values for the parameters used in this model are not known with certainty. Due to this uncertainty, any resulting conclusions are speculative. The assignment of actual values, as shown in this paper, is included as an example of how this model can be utilized. An important, sometimes overlooked, consideration must be given to the fact that, although thousands of exoplanets may have developed intelligent life over geologic time, this life probably doesn't exist today. Further, these two exoplanets with present intelligent life most likely are so many light-years away that the extraterrestrials would not recognize Earth as harboring intelligent life. So we don't hear from them. This is the answer to Fermi's question.

Uncertainties exist in any attempt to quantitatively answer Fermi's question. But we can still ponder, as exemplified by these two quotes, one from a scientist and the other from a theologian:

_The important thing is not to stop questioning. Curiosity has its own reason for existing. One cannot help but be in awe when he contemplates the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of this mystery every day._

—Albert Einstein

_Scientists are well aware that the search for truth, even when it concerns a finite reality of the world or of man, is never-ending, but always points beyond to something higher than the immediate object of study, to the questions which give access to Mystery._

—Pope John Paul II

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One Hundred Years of Physics in
South Dakota: A Current Legacy
Symposium Abstracts of Papers
presented at the
100th Annual Meeting
of the
South Dakota Academy of Science
PHYSICS AND THE SOUTH DAKOTA ACADEMY OF SCIENCE

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ABSTRACT

In celebration of the 100th anniversary meeting of the South Dakota Academy of Science, the physics research community has organized a symposium for the annual academy of science meeting. This presentation provides an overview of the first 100 years of South Dakota physics that contributes historical background and an introduction for the Physics Symposium “One Hundred Years of Physics in South Dakota: A Current Legacy.”
DARK MATTER AND THE
DARKSIDE IN SOUTH DAKOTA

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ABSTRACT

About a quarter of the mass-energy density of the universe is known to be composed of dark matter. Dark matter is matter that doesn’t interact with the electromagnetic force. We will introduce some evidence for dark matter and Weakly Interacting Massive Particles (WIMPs). We will discuss the DarkSide detector which is searching for direct evidence of WIMPs in the halls of LNGS in Italy. We will present an introduction to the DarkSide experiment and recent results and discuss the efforts at Augustana College.
NOvA: THE GIANT WITH SQUARE SHOULders

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ABSTRACT

The NOvA experiment is a long-baseline accelerator-based neutrino oscillation experiment. It uses the upgraded NuMI beam from Fermilab and measures electron neutrino appearance and muon neutrino disappearance at its far detector in Ash River, Minnesota. Goals of the experiment include measurements of the neutrino mixing angles, mass hierarchy, and CP violating phase. Construction of the detectors was completed in August 2014. Both detectors are constructed of PVC extrusions filled with liquid scintillator. The experiment is operational and gathering data, and the NOvA collaboration is preparing its first report of the results.
PURIFICATION OF GERMANIUM CRYSTALS BY ZONE REFINEMENT: THEORETICAL AND EXPERIMENTAL APPROACHES

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ABSTRACT

The results of single germanium crystals grown from zone-refined germanium ingots and identified by photon thermal ionization spectroscopy (PTIS) show that there are three main impurities—Aluminum (Al), Phosphorus (P) and Gallium (Ga) in the crystals. Based on the PTIS results, we calculated theoretically the influences of zone speed, zone width and the number of passes on effective segregation coefficient of Al, P and Ga in the process of zone refinement. A further calculation of the distribution of Al, P and Ga along the zone refined ingots has been conducted. In terms of the trend of impurity distribution, the calculated results have a very good agreement with the experimental results.
RESEARCH EXPERIENCES FOR PHYSICS UNDERGRADUATES IN NOVEL MAGNETIC MATERIALS AT SOUTH DAKOTA STATE UNIVERSITY

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ABSTRACT

Undergraduate research experiences are a primary indicator of high quality physics and engineering degrees. The main challenge for many physics departments in the United States, including South Dakota State University (SDSU), is the recruitment and retention of students majoring in physics. Recruitment and retention are enhanced in departments that have robust research programs that provide opportunities for undergraduate research experiences. At SDSU, we are focused on providing undergraduate physics students with research opportunities in the areas of materials science. In this presentation, I will discuss the model we have adopted to involve undergraduate students in various cutting edge research projects in novel magnetic materials which have potential for magnetic and spintronic applications. In addition, I will also discuss some of the important results from one of the current projects. The main goal of this project is to develop and understand the structural, magnetic and electron transport properties of an interesting class of materials, namely the spin-gapless semiconductors (SGS), with electronic band properties similar to those of half-metallic magnets and zero-gap semiconductors.

This research is supported by Academic and Scholarly Excellence Funds, Office of Academic Affairs, South Dakota State University.
UNDERGRADUATE RESEARCH IN ATOMIC, MOLECULAR, AND OPTICAL PHYSICS AT AUGUSTANA COLLEGE†

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ABSTRACT


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MOTIVATION AND DEVELOPMENT OF THE MPC-EX DETECTOR AT RHIC-PHENIX

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ABSTRACT

The Relativistic Heavy Ion Collider (RHIC) provides beams of fully ionized nuclei for the study of the strong nuclear force. Experiments before RHIC indicated that the gluon portion of the nuclear wave function is suppressed at low \(x\), the gluon’s fractional momentum, compared to the gluon portion of a proton’s wave function. This suppression, known as nuclear shadowing, is incorporated into theoretical calculations as a modification to the nuclear parton distribution function with only a qualitative physical explanation. Experiments at RHIC revived the idea of gluon saturation as a physical mechanism to explain the suppression. In this talk, we review gluon saturation physics. We will also give details about the MPC-EX detector that is newly installed in the PHENIX experiment at RHIC to help make decisive measurements about the gluon portion of the nuclear wave function.
The work of the nuclear physics group at Augustana College is focused on understanding luminous hadronic matter through the collisions of relativistic nuclei. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory provides beams of heavy nuclei of many different species and many different energies. These collisions are the laboratory in which to study the strong nuclear force between quarks and gluons (the partons) and perform precision tests of Quantum Chromodynamics (QCD). In this talk I will focus on phases of nuclear and partonic matter as a way to understand the luminous matter all around us.
THE SANFORD UNDERGROUND RESEARCH FACILITY AT HOMESTAKE

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ABSTRACT

The former Homestake gold mine in Lead, South Dakota, has been transformed into a dedicated facility to pursue underground research in rare-process physics, as well as offering research opportunities in other disciplines such as biology, geology and engineering. A key component of the Sanford Underground Research Facility (SURF) is the Davis Campus, which is in operation at the 4850-foot level (4300 m.w.e.) and currently hosts two main physics projects: the LUX dark matter experiment and the MAJORANA DEMONSTRATOR neutrinoless double-beta decay experiment. In addition, two low-background counters currently operate at the Davis Campus in support of current and future experiments. Expansion of the underground laboratory space is underway at the 4850L Ross Campus in order to maintain and enhance low-background assay capabilities as well as to host a unique nuclear astrophysics accelerator facility. Plans to accommodate other future experiments at SURF are also underway and include the next generation of direct-search dark matter experiments and the Fermilab-led international long-baseline neutrino program. Planning to understand the infrastructure developments necessary to accommodate these future projects is well advanced and in some cases has already started. SURF is a dedicated research facility with significant expansion capability.
CHARACTERIZATION OF DISLOCATION AND DEFECTS FOR LARGE HIGH PURITY GE CRYSTALS

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ABSTRACT

Large diameter (~10 cm) high purity Germanium (HP-Ge) crystals have been growing via Czochralski method at University of South Dakota. We investigate the impacts of growth rate, time-temperature profile, and thermal gradient on the dislocation and defects distribution in HP-Ge crystals along <100> orientation. The dislocation density across the entire cross-section of a grown crystal is measured using a microscope. Utilizing X-Ray Diffraction method, we obtain the rocking curves from the same crystal samples. We analyze the correlation between the full width at half maximum (FWHM) of the rocking curves and the dislocation densities from the optical observations (etch pits distribution). A model that describes the correlation of dislocation density, along the HP-Ge crystal, with the FWHM of the rock curves for XRD is established. We report these analytic results.
AN UPDATE ON LUX RESEARCH PERFORMED AT SDSMT

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ABSTRACT

The Large Underground Xenon (LUX) detector operating at the Sanford Underground Research Facility (SURF) is the world's most sensitive dark matter experiment. The LUX detector consists of a liquid Xenon detector utilizing 350 kg of ultrapure xenon and a 300-ton water Cherenkov detector operating as both a background attenuator and muon veto system. The experiment is part way through a 300-day run (Run-4) attempting to test dark matter models at an even greater sensitivity. The work being done at SDSMT includes the simulation, operation, and calibration of the water Cherenkov detector. New data samples from the muon veto system are analyzed. This presentation describes our preliminary results and our research plan with the veto data.
A THEORETICAL MODEL FOR CALCULATING PLASMA EFFECTS IN GERMANIUM DETECTORS

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ABSTRACT

In the detection of WIMP-induced nuclear recoil with Ge detectors, the main background source is the electron recoil produced by natural radioactivity. The capability of discriminating nuclear recoil (n) from electron recoil (γ) is crucial to WIMP searches. Digital pulse shape analysis is an encouraging approach to the discrimination of nuclear recoil from electron recoil since the nucleus is much heavier than an electron, and heavier particles generate ionization more densely along their path, which forms a plasma-like cloud of charge that shields the interior from the influence of the electric field. The time needed for total disintegration of this plasma region is called plasma time. The plasma time depends on the initial density and radius of the plasma-like cloud, the diffusion constant for charge carriers, and the strength of the electric field. In this work, we developed a theoretical model for calculating the plasma time in Ge detectors. Using this model, we calculated the plasma time for both nuclear recoils and electron recoils to study the possibility of Ge detectors to realize n/γ discrimination and improve detector sensitivity in detecting low-mass WIMPs.
CRYSTAL GROWTH AND DETECTOR PERFORMANCE OF Ø12 CM HIGH-PURITY GE CRYSTALS

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ABSTRACT

High-purity germanium crystals with 12 cm diameter and of about 5 kg mass were grown in a hydrogen atmosphere using the Czochralski method. The crystalline quality of grown crystals was studied by dislocation counting and X-ray rocking curve measurements. The dislocation density of the crystals was determined to be in the range of 2000 - 7000 cm\(^{-2}\), which meets a requirement for use as a radiation detector. The net carrier concentration of impurities was reached at \(\sim 10^{10}\) cm\(^{-3}\), which is close to that for commercialized crystals. The axial and radial distributions of impurities in the crystals were measured by Hall effect and Photo-thermal ionization spectroscopy (PTIS). Three detectors were fabricated from grown crystals with different techniques and then evaluated for electrical and spectral performance. The results show that the detectors have excellent energy resolution.

This work is supported by DOE grant DE-FG02-10ER46709 and the state of South Dakota.
PIRE: A GLOBAL CONSORTIUM FOR ADVANCED GERMANIUM DETECTORS AND TECHNOLOGY

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ABSTRACT

This PIRE proposal will establish a global consortium for developing state-of-the-art germanium detectors, which advance experiments focused on Cosmic and Intensity Frontiers, including exploration of dark matter and the properties of neutrinos. The research and educational activities associated with this program will build upon the unique facilities that have been developed at multiple institutions in US, China, Germany, France, Italy, and Taiwan. The participants in this consortium include twenty-one researchers across four domestic institutions and five international institutions. The goals of this consortium are to: 1) develop a detector suitable for the next generation of germanium detectors at the ton-scale with low energy threshold and neutron/gamma (n/\gamma) discrimination; and 2) develop educational and curriculum experiences with a rich international perspective on the challenges facing the future in science, technology, engineering, and mathematics (STEM) careers. To accomplish these goals, we utilize the combination of talents, skills, and disciplines in the established global infrastructure to develop techniques which would guarantee the required cleanliness and purity of materials to enable new detectors to reach the necessary thresholds and identify backgrounds for understanding dark matter and neutrino properties, an excellent fit within NSF’s interest in the discovery of basic sciences. The proposed consortium aims to coordinate international research efforts in nine institutions across the world to build a strong and sustainable consortium by providing the established unique instruments and laboratory spaces that individual faculty research groups cannot afford or sustain, but which are critically needed for cutting edge frontier research. We will foster an international research consortium in which new knowledge and exciting new techniques emerge through crossing international boundaries between institutions. The goal is to apply these skills to the underground experiments for rare event physics, critical problems in cleanliness, growth of detector-grade crystals, and development of detectors and other devices.
LOW-ENERGY RECOILS AND ENERGY SCALE IN LIQUID XENON DETECTOR FOR DARK MATTER SEARCHES

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ABSTRACT

Liquid xenon has been proven to be a great detector medium for the direct search of dark matter. However, in the energy region of below 10 keV, the light yield and charge production are not fully understood due to the convolution of excitation, recombination and quenching. We have already studied a recombination model to explain the physics processes involved in liquid xenon. Work is continuing on the average energy expended per electron-ion pair as a function of the energy based on the cross sections for different type of scattering processes. In this paper, the results will be discussed in comparison with available experimental data using Birk’s Law to understand how scintillation quenching contributes to the non-linear light yield for electron recoils with energy below 10 keV in liquid xenon.
DEVELOPMENT OF A P-TYPE POINT-CONTACT GERMANIUM DETECTOR WITH AN AMORPHOUS SEMICONDUCTOR SURFACE FOR RARE-EVENT SEARCHES

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ABSTRACT

We investigated the possibility to develop a $p$-type point-contact, high-purity germanium detector with an amorphous semiconductor surface, and its potential in rare-event search experiments. There is an ~1 mm thick transient layer below the lithium-diffused n+ outer surface on a traditional $p$-type germanium detector, where only part of the charges created by an interaction can be collected. Background events located in this layer have their energies misidentified and may contaminate signal regions in rare-event search experiments. Surface contamination resulting from such a configuration can be significantly reduced by novel surface treatments. By covering the surface of a point-contact detector with ~0.1 µm thick amorphous semiconductor, we can eliminate the partial-charge-collection layer. Surface α and low energy γ events can be identified by their fully deposited energies together with the rise times of their electronic pulses. In addition, the thin surface has the following two advantages over the traditional lithium-diffused one. At first, it maximizes the sensitive volume of the detector. Secondly, it can be segmented easily, providing rich information regarding the interaction topology, which is crucial for background identification in rare-event searches.
THE PHYSICS MATERIALS AND NANO-SCIENCE (PMNS) LAB AT SOUTH DAKOTA STATE UNIVERSITY

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ABSTRACT

The goal of the Physics Materials and Nano-Science (PMNS) Lab serves as a hub of research in materials and nano-science in the Colleges of Arts and Sciences, Engineering, Agriculture and Biological Sciences, and Pharmacy at SDSU. Specific aims of the PMNS lab are to promote interdisciplinary research in materials and nano-science in South Dakota, to provide hands-on research opportunities to undergraduate and graduate students in the relevant scientific and engineering disciplines, and to contribute to advances in materials and nano-science. The facilities in the PMNS lab include: Materials Preparation - two RF/DC sputtering systems with three guns to fabricate multi-layered thin film structures; X-ray Diffractometer for structural characterization; Thermal treatment under controlled environment in ultra-high vacuum (< 10^-8 Torr); Magnetic, Thermal, and Electrical properties characterization in a wide temperature range between 50 K and 1000 K; UV-Vis Optical Spectrometer for Absorption, Transmission, and Reflection characterization. In addition to current research projects, recent research accomplishments of the Department of Physics at SDSU including publication and dissemination will be presented.
AN EXPERIMENTAL PROGRAM IN NEUTRINOS, NUCLEON DECAY AND ASTROPARTICLE PHYSICS ENABLED BY THE FERMILAB LONG-BASELINE NEUTRINO FACILITY

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ABSTRACT

Neutrinos are the most abundant particles in the universe. The scientific impact of these nearly massless, neutral and weekly-interacting-with-ordinary-matter particles of particle physics, astrophysics and cosmology is tremendous and could be a key to a better understanding of our universe. Several independent worldwide efforts, developed through years of detailed studies, converged around the opportunity provided by the megawatt neutrino beam facility planned at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, and by the new significant expansion with improved access at the Sanford Underground Research Facility (SURF) in Lead, South Dakota, 1,300 km from Fermilab. The planned Deep Underground Neutrino Experiment (DUNE) is an international accelerator-based, long-baseline, neutrino experiment that aims to determine the neutrino properties as well as the possibility of proton decay and the dynamics of the supernovae that produces the heavy elements. DUNE research will be conducted with the international Long-BaseLine Neutrino Facility (LBNF) at Fermilab and the Sanford Underground Research Facility in South Dakota. The proposed experiment will be the most powerful tool in the world for studying neutrinos, with an approximately 40-kt fiducial mass modular liquid argon time projection chamber (LAr-TPC) far detector located deep underground (4,850 ft) at the Sanford Underground Research Facility and a high-resolution near detector located at Fermilab. The principle goals of this experiment are: a comprehensive investigation of neutrino oscillations to test CP violation in the lepton sector, determine the ordering of the neutrino masses, and test the three-neutrino paradigm; to perform a broad set of neutrino scattering measurements with the near detector; and to exploit the large, high-resolution, underground far detector for non-accelerator physics topics including atmospheric neutrino measurements, searches for nucleon decay, and measurement of astrophysical neutrinos especially those from a core-collapse supernova.
Abstracts of
Senior Research Papers
presented at the
100th Annual Meeting
of the
South Dakota Academy of Science
SYNTHESIS AND CHARACTERIZATION OF Ti₂MnAl: A POTENTIAL SPIN GAPLESS SEMICONDUCTOR

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ABSTRACT

Materials with high spin polarization and zero net magnetization have huge potential for spintronic applications because of their ability to produce electrons of only one spin direction without producing stray magnetic fields. We are investigating the structural, magnetic and electrical transport properties of Ti₂MnAl alloy to find if these properties are consistent with the theoretical prediction that Ti₂MnAl is a half-metallic, fully-compensated ferrimagnet. Ti₂MnAl ribbons were synthesized using an arc-melter and a melt-spinner. The elemental composition of the resulting ribbons was analyzed using energy-dispersive X-ray spectroscopy (EDX) and the composition was found to be Ti₂.06Mn₁.01Al with an uncertainty of 0.1 atomic percent. Ribbon samples were annealed through a range of temperatures and time durations. Ribbons annealed at 400 °C for 6 hours and 450 °C for 4 hours yielded the desired highly ordered structure according to X-ray diffraction (XRD) analysis. The magnetic and electron transport properties of these samples were then investigated. The magnetization of the samples was negligible at both high and low temperatures, and the resistivity decreased with increasing temperature. These findings were consistent with the expectations for a half-metallic, fully-compensated ferrimagnet or spin gapless semiconductor with zero net moment. For further investigation, thin films of Ti₂MnAl were prepared via sputtering deposition on silicon substrates. These samples were annealed in the same manner as the ribbon samples, and their magnetic and structural properties are under investigation. The current findings indicate that Ti₂MnAl may have potential for spintronic devices.

This research is supported by Academic and Scholarly Excellence Funds, Office of Academic Affairs, South Dakota State University. We would like to thank Prof. David J Sellmyer at Nebraska Center for Materials and Nanoscience, University of Nebraska for materials synthesis.
MICROSTRUCTURE AND PHYSICAL PROPERTIES OF THE Al$_2$O$_3$-40WT.\%TiO$_2$ CERAMIC COATING

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ABSTRACT

We used plasma sprayed technology to prepare Al$_2$O$_3$-40wt.\%TiO$_2$ ceramic coating on carbon steel substrate. The surface morphology, element composition and crystal structure of the plasma-sprayed coating were analyzed using scanning electron microscopy (SEM), energy disperse spectroscopy (EDS) and X-ray diffraction (XRD). The thickness, micro-hardness and adhesion strength of the plasma sprayed coating were measured using a TT260 thickness tester, micro-hardness tester and electronic universal tensile testing machine. The experimental investigation showed that the plasma sprayed coating has a typical laminar structure consisting of $\alpha$-Al$_2$O$_3$, $\gamma$-Al$_2$O$_3$ and TiAl$_2$O$_5$. The thickness of the plasma sprayed coating was about 500\,\mu m and the micro-hardness ranged from 468.2 to 623.7 HV$_{0.2}$. Moreover, the value of adhesion strength between the plasma-sprayed coating and the substrate was 38.25MPa. The results showed that the plasma sprayed coating of Al$_2$O$_3$-40wt.\%TiO$_2$ has a homogeneous microstructure with high hardness, maintains good bonding to the substrate, and is ideally suited for surface engineering applications.
A NOVEL DESIGN FOR A HIGH-EFFICIENCY PHASED ARRAY FEED DIGITAL DOWN-LINK

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ABSTRACT

Using a firmware-based computing platform, I created a novel digital logic-based intermediate frequency down-link and frequency pre-processing engine for radio astronomy applications. Specifically, it is a complete L-band back-end module for a 19-feed phased array receiver that inherits raw, unformatted, time-domain data at 2.48832 Gigabits per second, and presents the end-user with packetized representations of the complex frequency-domain.
CHARACTERIZATION OF
DIAPORTHE SPECIES INFECTING
SOYBEANS (GLYCINE MAX L.) IN SOUTH DAKOTA

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ABSTRACT

Stem canker of soybean (Glycine max L.) is caused by fungi of the Diaporthe/Phomopsis complex. The disease is caused primarily by Diaporthe caulivora (Athow and Caldwell) Santos, Vrandecic and Phillips, which is related to Diaporthe sojae Lehman, the pod and stem blight pathogen. The prevalence of stem canker depends on the amount of rainfall received during the early reproductive stages of soybean growth. Recently, the disease has become an emerging problem in South Dakota and in the neighboring states of Iowa and Minnesota. The objective of this study was to characterize the Diaporthe species associated with stem canker of soybean in South Dakota. The internal transcribed spacer (ITS) regions of ribosomal DNA of 14 isolates were sequenced, analyzed, and compared with their morphological characteristics. The molecular analysis of ITS sequences by alignment with those of the type strains deposited in GenBank allowed the identification of Diaporthe longicolla (Hobbs) Santos, Vrandecic and Phillips and D. caulivora to be associated with stem canker in South Dakota. Pathogenicity tests conducted by inoculating a 2-week-old commercial soybean variety confirmed that these Diaporthe isolates were pathogenic. There were significant (P ≤ 0.05) differences among isolates based on lesion length. Future work will include screening soybean varieties belonging to maturity group-0 and maturity group-I for resistance to the Diaporthe species identified in South Dakota.
DETECTING AND QUANTIFYING SOYBEAN STEM CANKER PATHOGENS (DIAPORTHE SPP.) IN SOIL AND PLANT SAMPLES USING REAL-TIME PCR

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ABSTRACT

The *Diaporthe/Phomopsis* complex is known to cause yield losses in soybean (*Glycine max* L.). Traditionally, morphological characteristics of *Diaporthe* species can be highly variable, and therefore cannot be used as reliable criteria for identification. Moreover, symptoms associated with these pathogens can be easily confused with one another. Recently, molecular tools are being used to reliably differentiate *Diaporthe* species. The objective of this study was to validate specific primers and probe within the internal transcribed spacer (ITS) gene region to detect the *Diaporthe* species known to cause stem canker of soybean in South Dakota, namely *D. caulivora* and *D. longicolla*. Standard curves were obtained over a range of 5 serial dilutions, from 100 pg to 10 fg. In the soil samples from an infected field and healthy field, *D. caulivora* was detected in small amounts (1.67 fg to 436.55 fg, Ct values >38). In contrast, *D. longicolla* was detected more or less evenly between the soil samples from the infected and healthy soybean fields (≥22.86 fg). Future work will include validating qPCR assay for quantification of *D. caulivora* and *D. longicolla* in soybean plants sampled from commercial fields.
DIFFERENTIAL RESPONSE OF TEOSINTE AND FLINT, SWEET, AND DENT CORN VARIETIES TO WEED COMPETITION

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ABSTRACT

Weeds negatively impact crop growth and future yields. The literature suggests that sweet corn (Zea mays convar. saccharata var. rugosa) and some modern dent variants (field corn, Zea mays indentata) have varying degrees of weed tolerance (or weed suppressive ability). These variants were derived from teosinte, the ancestor to all corn varieties, which is a weedy plant that still grows wild in southern ranges. Understanding what genes and mechanisms are involved in weed tolerance and yield loss, and what untapped genetic resources may exist in teosinte, are keys to reaching the goal of increasing crop tolerance of weeds. Determining which early and mid-season growth parameters correlate with yield differential while under weed pressure is a first step in determining genetic mechanisms available for increasing or building upon pre-existing crop tolerance abilities in corn and other crops. Eleven corn varieties and five teosinte lines in a two-year study were evaluated to determine correlations between corn or teosinte variety, crop height, leaf area, stem diameter, and mid-season biomass differentials and yield differentials between weedy and non-weedy treatments. No single parameter measured in weedy plots correlated with yield loss or gain in weedy plots compared with controls. Further research is needed to determine which, if any, morphological traits in corn and teosinte are clearly related to weed tolerance and the ability to maintain yield under weedy conditions.
BELOWGROUND BUD BANK OF BROMUS INERMIS IN RESPONSE TO MOWING FREQUENCY OVER TWO GROWING SEASONS

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ABSTRACT

Smooth bromegrass (Bromus inermis) is a Eurasian C3 perennial grass. It was introduced to North America in 1884 to control soil erosion and for pasture improvement, but has been outcompeting the native grasses of the northern Great Plains, decreasing diversity and altering habitats. Control of smooth bromegrass is a key to improve degraded native dominated grasslands. However, current practices have minimal or only short term effects due to extensive rhizome and tiller production by bromegrass. Even though vegetative reproduction via the belowground bud bank is the primary means for its invasiveness and persistence, the effect of management on its bud production dynamics and fate has not been evaluated until recently. The objective of this study was to examine smooth bromegrass belowground bud viability and tiller and rhizome production under various mowing frequencies over two consecutive growing seasons. Plants were mowed back to 5-cm stubble each time when their elongated node reached beyond mowing height. Mowing treatment at the boot stage significantly reduced the number of total crown positions per tiller by 17 to 26%, total buds by 13 to 31%, and percentage of dormant buds by 5 to 48%. Total daughter tillers and rhizomes were significantly reduced by 26 to 52% as the mowing frequency increased. The results indicate that repeated moving at the optimal growth stage can effectively hinder bud formation and development, tiller recruitment and food reserves, and deplete existing bud bank by activating dormant buds. To achieve long-term effectiveness, the treatments need to be implemented for multiple years until food reserves and bud supply are completely depleted.
WEATHER AND TEMPORAL EFFECTS ON URBAN COMMON NIGHTHAWK (*CHordeiles Minor*) ACTIVITY DURING THE BREEDING SEASON

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ABSTRACT

Grassland habitat in the Northern Prairie region has been greatly reduced since historical times, and this decline has recently intensified due to conversion to agricultural row-crop production. Common Nighthawk nesting habitat includes grasslands and urban rooftops, but preliminary data indicate disproportionate use of urban sites as nesting habitat in southeastern South Dakota, suggesting that row-crop landscapes are ill-suited for nesting. Nighthawks are crepuscular insectivores and income breeders that reduce activity when weather is unfavorable for arthropod prey. Accordingly, we expect nighthawk occurrence on point counts to be influenced by weather (i.e., temperature, short-term temperature change, sky and wind conditions), temporal factors (i.e., moon phase, time before/since sunset, Julian Date), and other variables (i.e., site and noise level). Using urban point count data in generalized linear models with binomial distributions, I analyzed the interaction of nighthawk presence/absence (as a dependent variable) with all variables. The models yielded low interaction probability between presence/absence and all variables tested. These preliminary data suggest little impact of weather or temporal variables on urban nighthawk activity, which contrasts with other Caprimulgids. Reasons for a different response in nighthawks compared to other Caprimulgids might include urban habitats or the crepuscular, rather than nocturnal, habits of nighthawks, both of which are unusual among Caprimulgids. Future modeling with larger sample sizes and including natural ground nest sites is needed to test whether weather and temporal factors might differentially affect nighthawk activity in urban versus natural nesting areas.
PHYLOGENY OF ARMADILLOS

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ABSTRACT

North American Armadillos (Family Dasypodidae) originated north of the Rio Grande and have since spread throughout southern and midwestern North America. By examining the mitochondrial DNA (mtDNA) of the North American Armadillo, we can determine its origins and lineage. This project examines the differences between the varying regions occupied by armadillos to determine how the South Dakota North American Armadillo differs from those in other regions. By determining lineage we can track the movement of these animals and the possible spread of leprosy across North America. We found unexpected Armadillo lineages where there was a coastal lineage and a central lineage (which includes South Dakota).
EVALUATING CATTLE INTROGRESSION IN BISON ON THE PINE RIDGE RESERVATION

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ABSTRACT

Before the 1800s, millions of bison (Bison bison) roamed a majority of North America. Within a short 80 years, “The Great Slaughter” diminished the entire population to just a few hundred. In an attempt to save the species and restore a viable population, crossbreeding bison with cattle (Bos taurus) was aggressively promoted. Today, North American bison populations exhibit a range of genetic purity depending on the history and management of individual herds. Determining the purity of a population is vital because, at some point, the level of introgression will impact individual behavior and reproductive viability. The information obtained from this study would assist herd managers to reduce the presence of cattle genes. This large-scale study assesses the introgression of cattle genes present in the Oglala Sioux Tribe’s bison herd. Maternal introgression is inherited through mitochondrial DNA. Maternally inherited introgression was determined by screening 900 individuals using a polymerase chain reaction (PCR) based assay. No evidence of maternally inherited introgression was discovered. A subset of 336 individuals were further screened for paternal cattle introgression, using PCR amplification with a panel of 17 nuclear DNA markers. Paternal introgression is inherited through nuclear DNA. The nuclear based assay product is genotyped to detect the presence of introgression. This study emphasizes the significance of genetic analysis of interspecies introgression for wildlife population management and species conservation. Furthermore, detailed knowledge of cattle introgression can be used by herd managers to develop strategies that best meet their management goals of restoring purity within a population. This research is part of the “Defining Optimal Bison Herd Management Practices in the Oglala Sioux Tribe” project supported by USDA NIFA award # 2011-38424-30914 (PI: A. Higa).
EXPRESSION OF ADH GENE
IN POPULATIONS WITH A HIGH
FREQUENCY OF ALCOHOL DEPENDENCY

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ABSTRACT

Research on alcohol use disorders (e.g., alcohol dependency) has proven a genetic link between people who have these disorders and how such genetics can be transmitted in families. Such a link can occur via the expression of ADH4. Few studies have examined ways to alter this gene or its expression. Through trial and error, we used different methodologies to examine gene frequency and expression of ADH4 within populations as well as survival rates of individuals with and without another variant of ADH. More specifically, we examined the frequency of ADH4 in several ethnic populations (Korean, Caucasian, and Native American). We also tested a variant of ADH – and ADH+ of Drosophila melanogaster using various media, control and experimental groups (caffeine and potassium), to examine effects of behavior and survivability of these individuals. Results indicate that few people within the general population have the ADH4 gene, thereby reducing risks of alcohol use disorders due to genetics. In addition, ADH- flies have low survivability compared to ADH+ flies ($P < 0.05$), even with potassium and caffeine present, in the presence of alcohol. This indicates the importance of understanding ADH frequency in populations in addition to recognizing the role of ADH in the metabolism of alcohol.
PHYSICAL HABITAT CHARACTERIZATION OF PERENNIAL WADEABLE STREAMS IN THE NORTHWESTERN GREAT PLAINS OF SOUTH DAKOTA

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ABSTRACT

Physical habitat is a critical driver of aquatic ecosystem health and biological community structure. However, physical habitat is poorly described from wadeable streams of the northern prairie. Our objective was to evaluate the riparian attributes, channel morphology, and substrate habitat traits of perennial wadeable streams in the Northwestern Great Plains (NWGP) ecoregion of South Dakota. Sixty-one streams were sampled using modified REMAP protocols during the 2014 growing season; physical habitat measurements included substrate, discharge, channel morphology, and riparian characteristics at each of eleven transects along a sampling reach. These streams were highly variable, but some trends were apparent. The majority of streams were 5 meters or less in wetted width (range 1.1 to 15.7 m) with flood prone widths of 10 meters or less (range 2.9 to 69.9 m). Entrenchment ratios tended to be moderate (1.4 -2.2; range 1.2 to 7.4), while width to depth ratios were primarily low (< 12; range 2 to 28). Land use within the riparian zone was classified as pasture/rangeland or prairie for the majority of streams, and discharge for about 95% of streams was less than 1 cubic meter per second (range 0 to 2.6 cms). Substrate in 54% of streams was dominated by fine sediment (< 2 mm), while a further 37% were dominated by gravel (2 – 64 mm). This high degree of variability is characteristic of prairie streams, which exhibit variable hydrology and increasing modification by humans.
INFLUENCE OF PACTOLA RESERVOIR ON THE AQUATIC INSECT ASSEMBLAGE OF RAPID CREEK

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ABSTRACT

The impoundment of streams and rivers has well documented influences on the chemistry, physical habitat and biology of river systems. While the fish assemblage of Rapid Creek in and around the Pactola Reservoir has been thoroughly studied, the benthic macroinvertebrate assemblage, a key element of the aquatic food web, has not been closely monitored nor has the direct impact of the reservoir on invertebrates been closely studied. During the summer of 2013, benthic macroinvertebrate samples were taken at four sites along Rapid Creek (one above the reservoir and three below) using a 30 x 30 cm Surber sampler. At each site, five samples were taken at even intervals across the stream. On average, 92% of the macroinvertebrate assemblage was found to be insects. The impact of the reservoir within this community was clear, with an observed 20% decrease in Ephemeroptera, Plecoptera and Trichoptera and a 39% rise in Diptera proportional abundance from above the reservoir to below the impoundment. Similar changes were also observed in several other common assemblage metrics, including a decrease in family richness, evenness and diversity. Some signs of recovery from the influence of the reservoir were observed at the final site, 10 stream miles downstream from the reservoir, though this was small and for the most part insignificant. These findings demonstrate the clear impact impoundments can have on a stream invertebrate assemblage, a disturbance that can potentially have larger ecosystem consequences as changes in invertebrate assemblages can directly impact fish assemblage structure and productivity.
PHOSPHORUS CONCENTRATIONS IN TRIBUTARIES AND LAKES OF THE LAKE HERMAN AND LAKE MADISON WATERSHED

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ABSTRACT

Phosphorus is a limiting nutrient for phytoplankton growth in many aquatic systems and high concentrations greatly increase productivity which accelerates eutrophication of lakes. Lake Herman and Lake Madison located in Lake County, South Dakota, have both been classified as hypereutrophic for several decades due to the high phosphorus levels and large blooms of cyanobacteria. We measured phosphorus concentrations and other water quality measurements at seven stream and two lake sites within the combined watershed from 2006-2014. All sites had mean total phosphorus levels that exceeded 0.30 mg/L and several exceeded 0.40 mg/L. Values over 1.0 mg/L were routinely recorded during times of high surface run-off. Within-year measurements generally showed higher nutrient concentrations in the early spring followed by a second period of increased phosphorus during the late summer period. There was a small, but significant trend for increasing total phosphorus concentrations for all sites combined over the course of the nine years of the study. Transparency measurements demonstrated a significant inverse relationship between water transparency and total phosphorus concentration. These results establish baseline values for evaluation of water quality improvement projects. Despite increases in concern for environmental impacts of anthropogenic activities, our study indicated that the level of nutrient inputs to area lakes was considerably greater than target values.
TOXICITY OF AMMONIA TO RIO GRANDE SILVERY MINNOW UNDER VARIABLE EXPOSURE REGIMES

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ABSTRACT

A portion of the federally endangered Rio Grande silvery minnow’s (Hybognathus amarus) current range receives discharges from several wastewater treatment plants. These plants experience periodic upset events, whereby they discharge elevated concentrations of ammonia into the Middle Rio Grande, NM. Acute toxicity tests were conducted to determine the effects of short-term exposures to elevated ammonia concentrations on larvae and young juveniles. Two chronic toxicity tests were then conducted simultaneously in which larvae were exposed for 30 days to either constant ammonia concentrations or 12-hour pulses of ammonia in which the peak concentrations were about 1.0X and the daily average concentrations were about 0.5X those in the constant concentration exposure test. In the acute pulsed ammonia tests, exposures to high ammonia concentrations for only 1.5 hours were nearly as toxic as exposures to the same concentrations for 96 hours and the larvae were twice as sensitive to ammonia as the juveniles. The 96-h median lethal concentrations (LC50s), based on total ammonia as nitrogen (N), were 16–23 mg N/L for larvae and 39–70 mg N/L for juveniles. In both chronic tests, growth (body weight) was a more sensitive endpoint than survival. Intermittent exposures to daily pulses of ammonia for 30 days caused reduced growth of silvery minnow at the same 24-h mean concentration as was observed in the continuous exposure study. In both exposures, the estimated no observed effect concentrations and maximum acceptable toxicant concentrations of total ammonia based on 24-h mean values were 4.6–4.7 and 6.8 mg N/L, respectively.
ON-SITE TOXICOLOGICAL ASSESSMENTS OF POINT SOURCE DISCHARGES TO THE RIO GRANDE, NM, ON THE SILVERY MINNOW

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ABSTRACT

A portion of Rio Grande silvery minnow (Hybognathus amarus) critical habitat lies in a reach of the Rio Grande, NM, that receives effluents from several major point source dischargers. These effluents comprise a significant portion of river flow, and concern has been raised that these discharges may adversely affect silvery minnow. Chronic on-site toxicity tests were conducted with 2-day old silvery minnow larvae and effluents from four major point source dischargers to the Middle Rio Grande; the two largest municipal wastewater treatment plants (WWTP) and two major riverside drains. The fish were exposed for 21 or 28 days under static-renewal conditions to full-strength and dilutions of the effluents, river water (control), and a reference water. Samples of effluent and river water were collected daily for test solution renewals and water quality analysis. In all tests, there were no differences in survival, weight, or total length of fish exposed to any of the effluent treatments compared to those in river water and reference water, which indicated that these effluents were not toxic to larval silvery minnow. To simulate an upset event at the WWTPs, I exposed 2-3-day old silvery minnow larvae to effluents spiked with ammonia. The acute toxicity (96-h LC50) of total ammonia (as N) in both effluents (11.7 mg/L and 19.8 mg/L) was similar to that in reference water (13.9 mg/L) and river water (20.9 mg/L).
ABSTRACT

Native freshwater mussels (Unionidae) are among the most threatened freshwater groups in North America, with approximately 60% of species considered endangered, threatened, or species of special concern. The objective of this study was to assess the decline of unionid mussels relative to basin wide comparisons and seven historical unionid survey (1975-2003) revisit sites from the Big Sioux, James, Vermillion, Red, and Minnesota River basins of South Dakota. Our survey employed timed searches randomly and proportionately distributed throughout the five river basins. At the basin-wide spatial scale, our survey (n = 76) found an average 51.6% decline in mussel species richness compared to previous surveys. The James and Big Sioux River basins declined the most by 5.2% per year and 4.0% per year, respectively. The Minnesota basin had a 3.0% per year decline and the Vermillion basin a 1.1% per year decline. The Red River basin did not have enough historical data to calculate an accurate decline. Historically, the Big Sioux River basin had the highest species richness with 34 recorded species. Currently, the James River basin was found to have the highest species richness with ten species each. We also revisited historical survey sites (n = 7) and found an average decline of 3.2% per year. Historical surveys recorded evidence of 31 species, while our survey found evidence of 15 species. This survey concludes South Dakota species have declined 51.6% since historically surveyed, which is comparable to the 60% decline reported in other North American studies.
POTENTIAL USE OF LECTINS TO IDENTIFY INTACT AND RUPTURED TRICHOSTRONGYLE NEMATODE EGGS IN SHEEP FECAL SAMPLES

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ABSTRACT

Diagnosing trichostrongyle infections in sheep and goats is difficult because the diagnostic egg stage of most trichstrongyle genera is morphologically indistinguishable. The lectin, peanut agglutinin (PNA), has been shown to bind to the external surface of Haemonchus eggs but not to the eggs of 2 other trichostrongyle genera commonly found in sheep and goats (i.e. Trichstrongylus and Teladorsagia). The binding of 20 other lectins to the outer surface of Haemonchus and Trichstrongylus and/or Teladorsagia eggs has already been evaluated, but none have shown the type of specificity observed with PNA. The only egg component used in lectin studies thus far has been the outer egg surface. By freezing eggs at -40 °C for 2 hours prior to lectin staining, it is possible to rupture the egg shell, and thus simultaneous evaluate the binding of lectins to the outer and inner egg shell surfaces, and to the embryonic blastomeres. The present study evaluated the binding of 20 lectins in the 3 screening kits sold by ©Vector Laboratories, Inc. (i.e. ECL, GSL-I&II, AIL, PNA, RCA, SBA, DBA, VVA, ConA, LCA, PSA, WGA, SWGA, DSL, LEL, STL, UEA, PHA-L&E) to the ruptured fecal eggs isolated from a ewe naturally infected with Haemonchus contortus, Teladorsagia circumcinta, Ostertagia leptospicularis, Trichstrongylus colubriformis, T. vitrinus, T. rugatus and T. axei. Only ConA and STL (Solanum tuberosum lectin) bound to blastomeres from any of the eggs. PNA and STL bound intensely, and GSL-I, AIL, ConA, and SWGA bound moderately to shells from at least some of the eggs. These 6 lectins should be further evaluated to determine if their binding is specific for each genus or species of trichostrongyle.
ATTEMPT TO ELIMINATE AN ANTHELMINTIC-RESISTANT STRAIN OF *HAEMONCHUS CONTORTUS* FROM A SOUTH DAKOTA SHEEP HERD USING A COMBINATION TREATMENT INVOLVING THREE ANTHELMINTICS DRUG CLASSES

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ABSTRACT

*Haemonchus contortus* is an economically important gastrointestinal nematode that constrains the survival and productivity of sheep and goats. Eliminating *Haemonchus contortus* from herds is a primary objective in small ruminant health management programs because anthelmintic resistant *H. contortus* is a growing problem. This study involved the use of 3 anthelmintics (i.e. moxidectin, albendazole and levamisole according to the manufactures recommended dosage) in an attempt to eliminate egg shedding in a flock of ewes whose *H. contortus* population had some benzimidazole and avermectin resistance. Pre-treatment fecal egg counts (FECs) on 250 ewes that had grazed on pasture the previous season were performed by collecting rectal fecal samples and using the McMaster technique to quantify egg shedding. The mean pretreatment FEC was 3650 eggs per gram (EPG). A week later, the triple anthelmintic treatment was started with moxidectin (Cydectin) at a dosage of 0.2mg/kg, followed 3 days later with albendazole (Valbazen) at dosage of 7.5mg/kg. After another 3 days, levamisole was orally administered at dosage of 7.5mg/kg. Post-treatment FECs were performed 2 weeks after the levamisole treatment using 3g samples and a modified Wisconsin floatation technique. The results showed a 99.99% overall FEC reduction to 0.17 EPG. After treatments, 68% of the animals showed no eggs, 27.6% contained less than 1 EPG, and 4.4% contained between 1 and 2 EPG. These results indicate that while a triple treatment will significantly limit egg shedding, there is still a significant portion of the flock that continue releasing eggs from worms resistant to these 3 classes of anthelmintics.
FIRST REPORT OF ANTHELMINTIC RESISTANT TRICHOSTRONGYLE NEMATODES IN A GOAT HERD FROM EAST-CENTRAL SOUTH DAKOTA

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ABSTRACT

Benzimidazole anthelmintics have been used to control trichostrongyloge nematodes in small ruminants from South Dakota for the past 40-50 years. Due to their overuse, there is growing concern that these nematodes, especially Haemonchus contortus, are becoming resistant to the benzimidazoles. Unfortunately, there have been no studies in South Dakota to assess this potential problem. A fecal egg count reduction test was conducted on 2 goat herds (total of 40 animals) located in Brookings County, South Dakota. On September 25, pre-treatment fecal samples were collected from each animal while the ewes were treated with albendazole (Valbazen®) at the recommended dosage. Fecal samples were again collected for 9 animals 2 weeks post-treatment. Trichostrongyle fecal egg counts (FECs) of the pre and post-treatment samples were determined with the McMaster Method and Wisconsin Double Floatation Method respectively. Pre-treatment FECs ranged from 0 to 36777.8 eggs/gram (EPG). Egg DNA was isolated from several samples and tested with several trichostrongyle PCR primers. Haemonchus contortus, Teladorsagia circumcinta, Trichistrongylus (T. columbi-formis, T. vitrinus, and T. axei), and Cooperia onocophora were identified in at least 1 sample; Ostertagia leptospicularis, Oesophagostomum venulosum, and Chabertia ovina were not found. Treatment resulted in a 69.7% reduction in FECs, and reductions less than 95% are evidence for significant anthelmintic resistance in that worm population. This high level of resistance is surprising considering the historically low level of anthelmintic usage in this herd. While this herd has been primarily closed, with animals initially purchased locally or from Montana, a couple of animals were acquired from Oklahoma or Texas.
A HISTORICAL PERSPECTIVE OF MOSQUITO SURVEILLANCE IN SOUTH DAKOTA

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ABSTRACT

West Nile virus (WNv) was first identified in South Dakota in 2002, and since then the state often has the highest yearly incidence of West Nile Neuroinvasive Disease in the U.S.A. Starting in 2002, the South Dakota Department of Health has coordinated a state-wide mosquito/WNv surveillance program in multiple counties throughout the state. With this information, programs, policies, and community grants have been implemented in an attempt to reduce the risk of human infections. Light traps baited with CO₂ are used to trap mosquitoes so that they can be identified to species, and the vector species (primarily Culex tarsalis) tested for the presence of WNv. Mosquito species numbers are recorded in the MOSQCOUNT website according to date and location. A data base stores this information that currently contains over 41,000 lines of data. Thus far, 28 species (in 6 genera) have been recorded in this database. They include: Aedes campestris, Aedes canadensis, Aedes cinereus, Aedes dorsalis, Aedes excrucians, Aedes fitchii, Aedes flavescens, Aedes intrudens, Aedes sollicitans, Aedes triseriatus, Aedes trivittatus, Aedes vexans, Anopheles barberi, Anopheles punctipennis, Anopheles quadrimaculatus, Anopheles walkeri, Coquillettidia perturbans, Culex erraticus, Culex pipiens, Culex restuans, Culex salinarius, Culex tarsalis, Culex territans, Culiseta inornata, Psorophora ciliate, Psorophora cyanescens, Psorophora signipennis, and Uranotaenia sapphirina. Analysis of mosquito data for the past 10 years in Brookings County has shown variation in the percentage of species, with many present every year (e.g. Cx. tarsalis and Ae. vexans), and others (e.g. Cx. salinarius), only during some years. This information is publically available and used by communities to assist in targeting areas for insecticide applications and public service announcements.
A SURVEY OF MOSQUITO POPULATIONS IN BROWN COUNTY, SD IMPLICATIONS FOR WEST NILE VIRUS

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ABSTRACT

West Nile virus (WNV), a serious mosquito-borne zoonotic disease, has been reported in all contiguous states. The prevalence of WNV is particularly high in South Dakota, with the highest incidence in Brown County. In past years, monitoring of mosquito populations in Brown County was restricted to the Aberdeen city limits, the county’s largest city. We report results from 2013-2014 surveillance activities outside of Aberdeen, where control is limited. Seven locations were surveyed using carbon dioxide light traps. Traps were placed at Sand Lake National Wildlife Refuge, Richmond Lake State Park, private residences along the James River near Stratford, SD, and the border of a corn field 3 miles north of Aberdeen, a cemetery near Moccasin Creek (Warner, SD), and along the banks of the Elm River 5 miles north of Aberdeen. Mosquitoes were collected 4-5 days/week from June-September. Individuals were identified to species, and *Culex tarsalis* were tested for WNV; Minimum Infection Rates (MIR) were then calculated. All sites had MIRs >0.6, indicating the need for increased vigilance and testing, with two sites exhibiting an MIR >4.0, suggesting high viral activity and the need for prompt action. This indicates that the rural localities sampled provide ideal habitat for disease-carrying species and that increased efforts are needed to prevent WNV.
DAILY ACTIVITY PATTERN AND CIRCADIAN RHYTHM IN A Nicrophorine Burying Beetle (NICROPHORUS MARGINATUS)

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ABSTRACT

Circadian rhythms are endogenous mechanisms responsible for the onset and termination of many important physiological processes related to energy allocation and are thought to evolve to maximize fitness in a particular biotic and abiotic context. These rhythms and the related daily activity regime of an organism are often the phenotypical expression of interspecific niche competition, and this expression is particularly interesting in species that compete for a hyperephemeral resource such as carrion. Here we examine the daily activity and circadian patterns in a Nicrophorine burying beetle species, Nicrophorus marginatus, which is often found in sympathy with multiple congeners and is one of few in its clade that exhibits diurnality. We tested the hypothesis that this species would segregate activity to periods associated with lower risk of dessication and predation by avian predators, and that activity phenotype would be governed by circadian regulatory mechanisms rather than external cues. We recorded daily activity patterns in a 12:12 LD condition using a Trikinetics digital locomotion monitor, and found that N. marginatus exhibit a strongly crepuscular activity pattern. We then recorded activity in dark-only conditions, and show that the crepuscular activity patterns persisted in the absence of external light cues, suggesting an endogenous mechanism of activity regulation. Crepuscular activity in the species may have evolved as a compromise between intrinsic physiological constraints associated with desiccation and extrinsic predation and competition risks.
VERIFICATION OF DIRECT INGESTION OF FLAME RETARDANT-TREATED CONSUMER POLYURETHANE FOAM BY HOUSE CRICKETS (*ACHETA DOMESTICA*) USING LIGHT MICROSCOPY

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ABSTRACT

In response to increasingly stringent flame retardancy standards, high levels of toxic flame retardant (FR) additives have been incorporated into myriad consumer plastics for decades. Over time, FR additives escape therefrom becoming bioavailable to humans and other organisms. Though some studies have addressed human exposure risks, virtually nothing is known of the extent to which FR additives may be transferred from treated consumer polymers to cohabitant insects (e.g. crickets, silverfish, cockroaches etc.). Such insects browse on consumer materials and may bioaccumulate FR additives therein and transfer them into proximate terrestrial food webs. Despite the pervasiveness of insect infestations in human spaces and solid waste disposal sites, we are aware of only a single published study of product-associated FR additive uptake by a cohabitant insect (Gaylor, M.O., E. Harvey and R.C. Hale. 2012. Crickets can accumulate polybrominated diphenyl ethers (PBDEs) directly from polyurethane foam common in consumer products. Chemosphere 86:500-505.). There, crickets reared with FR-treated furniture foam incurred high burdens of FR additives in their tissues. However, direct ingestion was assumed as the uptake mechanism and the extent to which gut-retained foam may have contributed to measured tissue burdens was not investigated. To address these knowledge gaps, we exposed house crickets (*Acheta domestica*) to FR-treated furniture foam and food and water *ad libitum* for 14 days and then examined foam particulate accumulation in gut tissues and feces using light microscopy. Prodigious foam loadings were observed in both, providing compelling evidence for direct ingestion as the principal FR uptake pathway. Results also indicate that such insects can feed on treated in-use and discarded consumer polymers and bioaccumulate FR additives therein. Direct biota interactions with treated consumer materials may thus be an important but so far underappreciated source of FR additives to terrestrial food webs.
ELATEROID BEETLES OF THE BAHAMAS: PRESENT AND FUTURE DIVERSITY

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ABSTRACT

An elateroid beetle (Coleoptera: Elateridae, Throscidae & Eucnemidae) survey of the Lucayan Archipelago (The Bahamas and the Turks and Caicos Islands) is ongoing. About 5000 historical museum and recently collected specimens were examined to date. Published reports of regional species before 2008 were few and produced an unrepresentative, depauperate faunal list. Interim results demonstrate a minimum 12-fold increase in the diversity of Elateridae to 36 species in 18 genera. Thirty-four species are newly reported; 11 are new to science. The Throscidae are represented by four species in two genera, three of which are new to science. The Eucnemidae are represented by 10 species representing six genera. Elateroid species from the southeastern islands seem most closely related to Hispaniolan congeners and those from the northern Bahamas have Cuban affinities. Paleoclimate reconstructions indicate that an optimum Lucayan colonization period was the late Wisconsin Glacial and postglacial Holocene during low eustatic sea levels. Lowest sea levels gave a 15 km distance between Cuba and the Pleistocene island of Paleoprovidence. The native elateroid insular fauna is severely threatened after about 500 years of settlement, exploitation, and local extinction events. Future sea level rise is expected to increase societal relocations, natural resource extraction, salinization of ground water, inundation, and storm surge that are expected to result in a regional mass extinction event. Continued sea level rise over the next 150-200 years could result in only a relatively few widely distributed Antillean waif and anthropo-tolerant elateroid species on only a few small remnant islands.
A MINISCULE NEW SPIDER SPECIES IN THE GENUS *MERMESSUS* O. PICKARD-CAMBRIDGE (ARANEAE, LINYPHIIDAE)

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ABSTRACT

A new species in the genus *Mermessus* O. Pickard-Cambridge 1899 is described based on the embolic division and other characteristics of the male, and on the epigynum and other characteristics of the female. This new species is miniscule (0.9 mm total length) and resembles *Mermessus jona* (Bishop & Crosby 1938). The new species was collected in portions of the Fort Pierre National Grassland, South Dakota, USA.
THE EFFECTS OF AIRBORNE PARTICULATE MATTER ON RAT NEURONAL CELLS

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ABSTRACT

In a recent survey of epidemiological evidences, a panel of experts concluded that data suggest a lower incidence of age-related dementia in developing regions. Air pollution, especially particulate pollution, might be partially responsible for this disparity. Recent studies of dogs and humans living in the highly polluted megacity of Mexico City, Mexico, showed evidence of oxidative stress and amyloid b accumulation in brains in animals as young as 4 months. We investigated the cytotoxic impact of two defined types of airborne particulate matter on rat neuronal cells in culture. Our results showed definite neuronal cytotoxicity, primarily from lipid oxidation. A comparison with the soluble compounds found from both types of airborne particulate matter, studied via FTICR-MS, showed different oxidized aromatic compounds—which may be related to the observed differences in cytotoxicity. Results from this study may impact air pollution regulatory decisions.
ENHANCED PROTEASOME FUNCTION MEDIATES
THE PROTECTION OF PDE5 INHIBITION AGAINST
MYOCARDIAL ISCHEMIA-REPERFUSION INJURY

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ABSTRACT

Cardiac proteasome functional insufficiency (PFI) is a characteristic phenotype in the pathogenesis of a large subset of heart disease. Phosphodiesterase 5 (PDE5) inhibitors (e.g., FDA approved sildenafil) can stabilize cyclic GMP and thereby increase cyclic GMP-dependent protein kinase (PKG) activity. Recent studies have shown PDE5 inhibitors have a cardioprotective effect; however the pathway of drug action remains elusive. We used a cardiac specific proteasome inhibition transgenic mouse line (Tg) in an ischemia-reperfusion (I/R) model to elucidate the effect of sildenafil on a stressed heart. Results showed infract size due to I/R injury was significantly reduced in the sildenafil treated non-transgenic (Ntg) mice, compared to the Tg mice with the same treatment. Systolic heart function after I/R injury was recovered in sildenafil treated control mice, but not in the Tg mice with sildenafil treatment. Further, cardiac proteasome chymotrypsin-like activity was significantly enhanced in sildenafil treated Ntg mice, but the Tg line showed no change in proteasome activity level in response to the sildenafil treatment. Additionally, in vitro analysis showed that PKG interacts with the proteasome in isolated neonatal rat ventricular cardiomyocytes, and that this interaction is augmented by sildenafil treatment. Together our results suggest that the cardioprotective effect of sildenafil is, at least in part, mediated by mechanisms which alleviate PFI. This could ultimately facilitate the search for new measures to prevent or more effectively treat heart disease.
FORENSIC SCREENING OF HAZARDOUS CHEMICALS PRESENT IN THERMAL CASH REGISTER RECEIPTS COLLECTED FROM BUSINESSES IN THE VICINITY OF DAKOTA STATE UNIVERSITY

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ABSTRACT

A growing body of scientific research continues to show that toxic chemical additives, such as the headline-grabbing Bisphenol A (BPA) and phthalate plasticizers, occur at disconcerting levels in and are easily leached from consumer materials, posing known and unknown risks to human and environmental health. Such reports inspired us to hypothesize that these and other hazardous chemicals occur in high-volume/high-contact consumer materials, such as thermal cash register receipts, within this region as well. To test this hypothesis, as part of an undergraduate capstone research project, we randomly collected cash register receipts from a variety of businesses in the vicinity of the Dakota State University campus and screened them for hazardous chemical constituents using gas chromatography-mass spectrometry (GC-MS). All receipts contained a multitude of compounds with known toxicities, including BPA, phthalate (and non-phthalate) plasticizers and polychlorinated biphenyls (PCBs), as well as a plethora of other compounds with as yet unknown toxic potentials. Though our investigative efforts to date have focused primarily on qualitative fingerprinting of hazardous constituents, we have estimated several of these problematic compounds to be present in collected receipts in the range of 0.1 to 2% by weight.
ISOLATION, IDENTIFICATION AND CHARACTERIZATION OF BACTERIAL MICROFLORA EXHIBITING INSECTICIDAL ACTIVITY

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ABSTRACT

Natural products are widely used in human medicine to fight numerous diseases, including bacterial, viral and fungal infections, cancer, and immune system disorders. They also continue to be the source of new modes of action and chemistry surrounding crop protection (i.e., insecticides, fungicides). Mosquitoes are one of the many insects that are controlled with these products. Control of mosquito populations is not only significant at the global level since mosquitoes are primary vectors for numerous human and animal infectious diseases (e.g., West Nile virus, Western equine encephalitis, Chikungunya and malaria), it is also of importance to communities located throughout South Dakota and the Great Plains where West Nile is especially prevalent.

Several strains of facultative anaerobic bacteria were isolated from environmentally-collected samples from northeast South Dakota. Bacterial flora found within ticks and leeches as well as those collected from soil samples consisting of bird refuse, were characterized microscopically, biochemically and molecularly. Isolated cultures of bacteria were utilized in insect larvae bioassays to determine the presence of insecticidal/growth inhibitory effects with three bacteria consistently exhibiting degrees of insecticidal activity against larvae of Aedes aegypti, Trichoplusia ni (cabbage looper), and Manduca sexta (tobacco hornworm). These strains were identified as members of the genus Proteus, Enterobacter and Pseudomonas. In order to deconvolute the region of DNA conferring insecticidal activity, we describe heterologous expression in E. coli and reverse genetic approaches and anticipate that the successful identification of bioactives will provide new biotechnology opportunities for crop protection and fighting infectious diseases.
BIOELECTROCHEMICAL/ MEMBRANE TECHNOLOGIES FOR ENABLING ENERGY-EFFICIENT WASTEWATER REUSE IN POWER PLANTS

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ABSTRACT

An ever-increasing demand for both energy and water has resulted in an imbalanced energy-water nexus in modern society. A tremendous portion of energy (~4% of total energy in the US) is required to maintain our water infrastructure; we use energy-intensive wastewater treatment plants (WWTPs) that annually spend 4480 MW to treat our wastewater water. At the same time, the energy industry threatens our freshwater supplies. As an example, a 500 MW power plant with a cooling tower consumes 4 million gallon of freshwater to meet daily cooling needs. Overall, the power plants in the US consume ~40% of our total freshwater withdrawals. Here we propose a bioelectrochemical system (BES) that provides a new route for inexpensive WWTP, and recycles treated wastewater as cooling water in power plants, all with a net production of electric power. Residual (macromolecular) chemical oxygen demand and sloughed particulates (including microbes) in the effluent will be treated with membrane ultrafiltration (UF), yielding a high-quality effluent for subsequent reuse in power plants. The power density and COD removal efficiency was as high as 2500 mW/m2 and 90%, respectively. More importantly, the treated effluent meets the regulated limits for typical contaminants (e.g. BOD, TSS, Ca, Mg, Mn, Cu, Al, and S) of concern in power plants.
ENGINEERING N$_2$-FIXING CYANOBACTERIA TO PRODUCE ETHANOL FUEL FROM CO$_2$ AND H$_2$O

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ABSTRACT

Current use of fossil fuels is both expensive and detrimental to the environment. Renewable fuels produced from plant biomass are not currently efficient enough to meet national demands and compete with other crops for farmable land that is required for food. Current ethanol plants release one third of the carbohydrate carbon as CO$_2$ during fermentation, for example, a 100 MGY (million gallons per year) ethanol plant releases over 23 tons/hr of CO$_2$. Ideally, a photosynthetic organism could be engineered to convert the waste CO$_2$ back into fuel ethanol. The use of cyanobacteria provides such an opportunity and requires little nutrients and substantially less land. Cyanobacteria can be genetically engineered to directly convert CO$_2$ and H$_2$O into ethanol. Using cyanobacteria to produce ethanol bypasses the need to create extensive infrastructure to ferment and process plant biomass into a usable biofuel. In this report, two genes coding for pyruvate decarboxylase (pdc) and alcohol dehydrogenase II (adh), which are required for converting endogenous pyruvate to ethanol in cyanobacteria were genetically introduced into cyanobacteria. The transgenic cyanobacteria were confirmed to produce ethanol using only CO$_2$, mineralized H$_2$O and sunlight. Further increasing the production of ethanol to a commercial viable level is in progress. If successful, the CO$_2$ to ethanol model could allow for the replacement of fossil fuels with a renewable ethanol fuel.
CHARACTERIZATION OF THREE N₂-FIXING CYANOBACTERIAL MEMBERS OF CHROOCOCCALES ISOLATED FROM THE BAY OF BENGAL

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ABSTRACT

Marine cyanobacteria, the drifting “forests of the ocean”, are an unlimited resource that can be exploited for the use of mankind. N₂-fixing cyanobacteria are the most important life-forms on earth due to their unique capability for simultaneously carrying out both photosynthetic CO₂-fixation and photosynthetic N₂-fixation, the process on which all life forms rely. Nitrogen is one of the most important life elements in DNA and RNA, and in proteins, but most organisms have no way to use N₂ to make these bio-macromolecules. Fortunately, some marine cyanobacteria can photosynthetically fix atmospheric nitrogen gas (N₂) into a form that can be used by other organisms. Therefore, we are interested in isolating N₂-fixing cyanobacteria from unexplored marine environments such as the Bay of Bengal, Indian Ocean. We had isolated three marine coccoid members belonging to the order of Chroococcales. These three isolated Chroococcus spp. were confirmed to have the capability for an oxic diazotrophic growth. The microstructure of three Chroococcus spp. was characterized using a broad suite of microscopic techniques including phase contrast, fluorescent microscopy and confocal scanning laser microscopy. Cytomorphological characteristics, such as cell breadth, cell shape, thylakoid pattern and nucleoid morphology have been studied in cultures grown in diazotrophic growth conditions (BG110 medium) and non-diazotrophic growth conditions (BG11 medium). The cells were usually broad, oval to almost spherical in shape. Multicellular forms have cell shapes that vary from oval to trigonal, tetragonal and pentagonal with convex outer surfaces. These shapes result from multiplanar division. However, some strains exhibited binary fission too. As a whole these divisions resulted in regular to irregular shaped colonies with pleomorphic shapes. The thylakoids membranes are arranged through the whole cell and the nucleoid morphology is almost network-like. Verification of N₂-fixing activity and nif genes are in progress and will increase our understanding of the physiology of these little explored, oxic N₂-fixing Chroococcus spp. and lead into genetic studies of their oxic nitrogen fixation.
EXAMINATION OF ANTIBIOTIC RESISTANCE
IN E. COLI FROM LAKE HERMAN,
LAKE COUNTY, SD, AND LAB STRAIN B

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ABSTRACT

Resistance to antibiotics is an increasingly serious concern in the medical field. Resistance to antibiotics occurs with incorrect or over use of antibiotics, and when strains of bacteria become unaffected by the antibiotics used originally against them. This study examined E. coli collected from Lake Herman in Lake County, SD, and lab strain B against a series of eleven antibiotics that work in different ways to kill bacteria. E. coli was isolated from water samples utilizing Coliscan Easy Gel®. The Kirby-Bauer method was used to determine initial susceptibility and for subsequent sequential challenges by specific antibiotics. An isolate from Lake Herman was examined for an increased potential for resistance to eleven antibiotics, and was compared against E. coli B. Under our treatment conditions, we observed that for the antibiotic bacteria isolate combinations examined, 1) initially, the isolates of E. coli exhibited variable resistance; 2) for one E. coli isolate antibiotic combination, but not the other, under selection pressure, we were able to select for increased resistance to antibiotics, and 3) such resistance exhibited variable stability.
NITROGEN FIXING ENDOPHYTES OF A NON-NODULE FORMING LEGUME

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ABSTRACT

Prairie turnip (Pediomelum esculentum (Pursh) Rydb. [Fabaceae]), a legume not known to form nodules, is a traditional food for Native Americans of the Great Plains, and an excellent source of protein. We have investigated endophytic diazotrophs as a potential source of nitrogen for the large protein stores contained within the edible tuber. Plants were divided into three tissue types: herbaceous top, edible tuber, and inedible root. From these portions, bacterial cultures were isolated on nitrogen free media, and genomic DNA was obtained directly from the plant. PCR amplification of nifH, a gene coding for nitrogenase reductase, was performed to detect nitrogen fixers. Denaturing gradient gel electrophoresis (DGGE) of the nifH PCR product was used to detect the diversity and presence of unculturable diazotrophs within the plant. Multiple bacterial isolates were found to have the nifH gene, and DGGE analysis revealed variation in the diazotroph community in all plant tissues investigated. Our work suggests that this legume may form a unique symbiotic relationship with more than one species of nitrogen fixing bacteria.
CHARACTERIZATION OF LIQUID AND SOLID PHASES PRODUCED AFTER HYDROTHERMAL TREATMENT OF LIGNIN IN SUB- AND SUPERCRITICAL ENVIRONMENT

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ABSTRACT

The results of liquefaction of lignin in sub- and supercritical conditions in a temperature range of 200-500 °C at 3200 psi are reported. After hydrothermal treatment, the organic phase separated by liquid-liquid extraction was characterized by GC-MS and TOC (total organic carbon) approaches. The solid phase was analyzed by a GC-MS 2010 Schimadzu pyrolyzer. Among a number of phenolic products (e.g. o-guaiacol, p-guaiacol, methylguaiacol, and vanillin), o-guaiacol had the highest relative percentage yield of 39.69% and 37.91% in presence of CO₂ and N₂ at 400 °C. It was confirmed by the TOC test that the percentage of carbon evolved (40.3%) was highest at 300 °C when the lignin was treated with CO₂. The presence of phenolic products in the solid phase obtained after the hydrothermal treatment of lignin also has been confirmed by GC-MS pyrolysis.
PRODUCTION OF HIGH-VALUE ORGANIC PRODUCTS BY LIGNIN LACCASE-MEDIATOR SYSTEM

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ABSTRACT

Initiated enzyme-catalyzed and mediator-facilitated radical reactions of degradation lead to formation of both phenolic and non-phenolic aromatic structures. A laccase should have broad substrate compatibility and high redox potential and be tolerant to deactivation in the presence of a mediator. Unfortunately at present, there is no “universal” laccase that fulfills all the above criteria. The objective of this work is to characterize two specific systems for enzymatic degradation of lignin, including two types of commercially available lignin (Indulin AT and Alkali lignin) with Myceliophthora thermophila laccase enzyme and a mediator (Methyl syringate). Laccase (Novozymes, 22127) activity was determined by oxidation with diluted 2, 2’-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) in H₂O. The activity of the original laccase was 326 U/ml in aqueous solution. The lignin treatment was carried out by the laccase-mediator (1% -1%) system at 50 °C by using 2.23g lignin samples at 6% consistency (w:w) in 50 mM sodium dihydrogen phosphate (pH 6.5) under an O₂ atmosphere for 72 h. Electrochemical study of the LMS in buffer solution, Na₂HPO₄ -NaH₂PO₄ with pH = 6.5, was conducted to evaluate the role of laccase in promoting the mediator for selective oxidation of lignin. An SEM analysis revealed the changes in surface morphology associated with indulin and alkali lignin before and after the LMS treatment. A Brunauer–Emmett–Teller (BET) analysis of two types of lignin, specifically alkali lignin and indulin lignin, have been conducted before and after contact with the laccase mediator system (LMS). This work is supported by the National Science Foundation EPSCOR Cooperative Agreement #IIA-1330842 BIOCON project.
TESTING THE FEASIBILITY OF INEXPENSIVE, REAL TIME CARBON DIOXIDE MEASUREMENTS USING COMBUSTION SOURCES

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ABSTRACT

Real time measurements of the lower atmosphere have been limited in the past due to the cost prohibitive nature to buy and run the air quality monitors. Thanks to recent developments in technology however, it is possible to take readings of the atmosphere that can be viewed in real time at an inexpensive cost (< $1,000). This could hold important benefits in monitoring atmospheric releases of hazardous materials, in coordinating evacuation efforts on the ground and for verifying plume dispersion models. We tested one such device, a carbon dioxide data logger made by CO2Meter, Inc. to see if it could measure levels of carbon dioxide from a smoke plume downwind from a natural burning process (prescribed fire) and from an anthropogenic burning process (cement plant). Our results display some promise for the use of this device in future carbon dioxide air quality monitoring. The device recorded higher CO$_2$ concentrations compared to normal background levels when the prescribed fire smoke plume was over the device, including CO$_2$ concentrations 100 ppm above normal near the fire. However, sensitivity limitations were found when the device was farther away, as the device did not record any heightened CO$_2$ concentrations in the smoke plume from the cement plant.
A LONGITUDINAL STUDY OF TEACHING METHODOLOGY AND CONTENT LEARNING IN INTRODUCTORY BIOLOGY: DOES METHOD MATTER?

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ABSTRACT

National initiatives to bring innovative teaching into introductory undergraduate biology courses are grounded in well-established empirical studies of methodology. The goals of innovative teaching are to increase retention in courses, increase persistence in the biology major, increase student engagement with content material, increase learning of content material, and decrease student dissatisfaction and “boredom” in foundational courses. Innovative, empirically validated teaching practices can include cooperative group learning, classroom flipping, using primary literature during lecture sessions, and hybrid models of combinations of lecture and these other methods. Despite the overwhelming breadth of literature supporting hypotheses that these methods increase student engagement, studies of student learning increases as a result of these approaches show unconvincing results. In this longitudinal three-year study of a first-semester introductory biology course, we corrected for aptitude and learned from pre- and post-instruction exams that increases in learning correlated with ACT score in most content areas, and that teaching method did not result in significant increases in content knowledge compared to traditional lecture courses. Surprisingly, we also found that flipped classroom approaches in ecology and evolution content areas resulted in less learning gain than in lecture sections. In these content areas, use of primary literature resulted in the most increase in learning, but this result was insignificant.
THE LANGUAGE OF MODELS IN HYDROLOGY: A PARTICULAR CASE FOR SOUTH DAKOTA

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ABSTRACT

Science, especially natural science, is a late evolutionary development in human culture for obtaining communicable knowledge. Language has a unique function as a medium for communication and might be considered a natural phenomenon in studies of human culture. The ontology of research in hydrology as a natural science is presented in this paper.

A consideration of the function of modeling in a human language and also as a special language in a particular science (hydrology) allows one to formalize (to better understand) the way for formulating, communicating and distributing the knowledge obtained and the uncertainty involved in this process.

Results from the systemic analysis of stream flow, precipitation and air temperatures in the Missouri River basin completed over ten years are used herein to present the models. Topics in the presentation included: An Introduction: Models in the Title, Words in a Language, Models for South Dakota, Concept of Hydrologic Model: Knowledge and its Uncertainty, and Scientific Communication on the Move.

Content of the slides used in this presentation can be found at https://www.researchgate.net/publication/278019682_Models_as_a_Language_for_Communication_in_Hydrology_a_Particular_Case_for_South_Dakota and allows one to formulate conclusions for every topic and general conclusions for the entire presentation.

Models in the Title—Personal verbal communication is an initial and the most expressive (multi-dimensional) way to present content. Written communication is the model for verbal communication and the main way to operate with knowledge. A model serves as a replacement for an object and provides some kind of an advantage in comparison to the object. This presentation is a natural occurrence having existed at only one time and place. The slide show, which is used during the presentation, its title and abstract are parts and models of the presentation. The slide show, title and abstract are also natural objects and may be represented by models. The creation and operation of models allow one to gain some knowledge about the presentation.

Words in a Language—Words are natural objects; the meaning of a word exists in the context of a language and has a probabilistic nature (may be represented with a probabilistic approach). The context of language is represented by a dictionary (for some languages), and dictionaries reflect existing meanings of
a word and might be used to obtain sets for statistical analysis. The meanings of words obtained by statistical analysis may be represented as a multi-dimensional structure, the quantities of which reflect the variability of meanings of words in context of a particular language.

**Models for South Dakota**—Empirical data gathered and organized as databases reflect the time and spatial existence of natural hydrological objects (processes).

Statistical learning provides a methodology and a set of tools to analyze empirical data and presents the results as multi-dimensional models and maps. The natural variability of hydrological objects (processes) as structures is reflected and represented only within a set of multi-dimensional and multi-scaled models. While modeling provides quantitative results which may be useful for making decisions, there remain questions about how to formalize the understanding, use and communication (dissemination) of the results of modeling.

**Concept of Hydrologic Model: Knowledge and its Uncertainty**—A researcher in the systemic approach is the first and main component in analysis and interpretation of results for a natural object (process). A conceptual model, as prior formalized knowledge, presents a logical structure of interaction for natural hydrological objects and processes. Natural hydrological objects have coordinate systems which are different from mathematical and engineering ones, and have fuzzy boundaries in space and a fuzzy regime in time. Uncertainty inherent in the knowledge of hydrological objects (processes) may be reflected in multi-dimensional and multi-scaled models (structures) and characterized as the difference between the variability existing in data and the variability reflected by model. Modeling creates formalized and quantifiable content for the description and communication of the knowledge about natural hydrological objects (processes).

**Scientific Communication on a Move**—Human communication is evolutionary, informal, and personal in general; it includes all channels of sensory input and pattern recognitions. The science community has evolved as the most dynamic part of humanity, and is focused on analysis and the formalization of objects and processes in nature. Scientific communication requires a professional community and special scientific language; language reflecting the formal knowledge and residual uncertainty. Modeling, as the quantification of relations of words in the languages of the Internet, is based on the ability to extract a logical part and to characterize a stochastic part, both of which play a key role in scientific language. Words, texts and language might be modeled (coded, indexed and/or structured) in multi-dimensional and multi-scaled ways to reflect the variability of natural objects. The Internet with Google’s leadership reflects and represents changes in the meanings of words and intensifies the processes of language development.

**Hydrologic Conclusions**—Communication of knowledge about hydrologic objects and processes has to be based on modeling, and to be successful, requires a community of educated professionals having comparable field and modeling experiences as “language skills”. The education of students has to feature field and laboratory experiences and be focused on the attainment by students of subjective and personal experience in hydrology as a natural science (Geoscience). Models are tools for scientific communication. Knowledge and uncertainty
obtained with mathematical models help to determine: 1) the scope and kind of practical applications to be developed (e.g., water balance estimations for conservation and/or management of water resources on different scales), and 2) the topics of water resources/ environmental issues and tools to educate the public.

“Propositional” Conclusions—Communication is a condition for evolution. Language is the main tool for communication; verbal human interaction provides a rich, multimedia and multi-dimensional experience. Science is a part of human evolution; scientific language for every discipline is more formal and has fewer dimensions than the natural one. Development and the use of formal and non-formal parts (after V. V. Nalimov) in scientific languages improve communication within particular disciplines and between traditionally separated disciplines. The study of natural objects requires system analysis to provide a definition and quantification of obtained knowledge and its uncertainty.
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ABSTRACT

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