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TABLE OF CONTENTS

Complete Senior Research Papers presented at The 88th Annual Meeting of the South Dakota Academy of Science

Abstracts of Senior Research Papers presented at The 88th Annual Meeting of the South Dakota Academy of Science

A TRIBUTE TO
M. STEVEN MCDOWELL
1956-2003

When a colleague in the prime of life passes away abruptly, as Steve did last year, it is difficult for us, his surviving friends, to take stock in the life so unexpectedly ended. At any given moment in our lives, we all have many activities in which we are involved. Each activity includes many partially overlapping circles of friends and associates. As members of one of these circles, we find it fitting that all circles unite and tie together at an ending point the many threads woven by such a rich life.

Michael Steven (Steve) McDowell was born July 31, 1956, in Los Angeles, California, to Warner S. and Kathe (Bender) McDowell. He died unexpectedly on March 7, 2003, as a result of complications of a pulmonary aneurysm. In his early years, Steve was raised and educated in Los Angeles. He moved to Chicago, Illinois, in his teen years. He graduated from high school in Chicago in 1974. He continued his educational career at Miami University, Oxford, Ohio, earning a B.S. in Chemistry in 1978. His graduate studies were completed at Iowa State University in Ames, where he earned his Ph.D. in Inorganic Chemistry in 1983. Steve did postdoctoral research work at the University of California-Riverside, from 1983-1985, and then moved into a teaching career in chemistry at California State University-Long Beach, and Santa Monica College, Santa Monica, California. In 1990, Steve joined the faculty in the Department of Chemistry and Chemical Engineering at the South Dakota School of Mines and Technology, where he entered into a vigorous career of teaching, research, and service.

During his first decade at SDSMT, he advanced through the professional ranks from assistant to associate professor. He taught courses in general, analytical, physical, and predominately inorganic chemistry. He was known for having an open-door policy to his students and many stopped by to partake of his wisdom. Steve was heavily involved in his research, having as many as ten students, both undergraduate and graduate, working for him at a single time. A few of the projects he was involved in include Supramolecular Assemblies Containing Metal Ion Centers, Synthesis and Characterization of Novel Organocobalt(III) compounds, Synthesis and Characterization of Self-Assembling Surfactants, and Synthesis and Characterization of Metal Saccharinates. Steve and his research group often presented papers at regional and national American Chemical Society meetings, and Academy of Science meetings, in addition to publishing many journal articles.

On campus, he served a two-year term (1996-1998) as Chair of the Faculty during a fairly turbulent time for faculty governance at SDSMT. From 1998-2002, he served as Chair of the Department of Chemistry and Chemical Engineering. He was a member and leader in many professional organizations. He served a term as secretary of the South Dakota School of Mines Chapter of Sigma Xi, and worked his way up the leadership ladder of the South Dakota Academy of Sciences, which he was serving as president at the time of his passing. He was a member and long-time Chapter Advisor of Alpha Chi Sigma, a professional chemistry fraternity, and in July 2002 was elected to the position of District Counselor. In 1996, Steve received the Ronald T. Pflaum Award for Outstanding Chapter Advisor from Alpha Chi Sigma. He was a member of the American Chemical Society, and the Inorganic Division of the American Chemical Society, in whose journal he regularly published. He was also a member of the American Association for the Advancement of Science and the International Union of Pure & Applied Chemistry.

The Academy has been honored by Steve's many contributions to our organization, to higher education in South Dakota, and to the field of chemistry in general. He is truly missed.

Jaque Cranston, Dept. Chemistry and Chemical Engineering, and Andy Detwiler, Department of Atmospheric Sciences, South Dakota School of Mines and Technology

CONSOLIDATED MINUTES OF THE EIGHTY-EIGHTH ANNUAL MEETING OF THE SOUTH DAKOTA ACADEMY OF SCIENCE APRIL 4-5, 2003 SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY, RAPID CITY, SD

The Executive Council met at 12:00 p.m. Friday 4 April 2003 for a final check of plans for the day.

Past President Charles Lamb opened the executive committee meeting, noted that a quorum was present, and thanked Ken Higgins for timely presentation of the 2002 Proceedings.

The Council decided to include in the 2003 Proceedings a Memoriam honoring the memory of SDAS President Steven McDowell.

Treasurer Kristel Bakker distributed a copy of the budget. Neil noted that he has $350.00 in the account to be used toward updating the computer program for maintaining the on-line Proceedings to Cold Fusion. Currently on line are all Table of Contents from 1916 to the present and articles from 2000 to the present.

Krisma DeWitt reported that the Executive Board of the South Dakota Academy of Sciences has selected the following individuals for SDAS Fellows: Dr. Clyde Brashier, Dakota State University; Dr. Milton Hanson, Augustana College; Sr. (Dr.) Laeticia Kiltzer, Mount Marty College; Dr. Robert Looyenga, South Dakota School of Mines and Technology; Dr. Arlen Viste, Augustana College; and Dr. Everett White, South Dakota State University. Nominations for Fellows for 2004 will involve a letter of nomination and brief biography, and will be due 1 October 2004. Fellows will be invited to Chamberlain and the Academy will cover meals and lodging.

Bob Tatina reported that the membership committee will create and send out an electronic poster for membership and information about the 2004 meeting. He requested that members encourage colleagues to attend, renew, or participate as new members. Neil Reese suggested that he would like to place the agenda on the web. Charlie Lamb noted that having campus representatives appears to be working to get information to the campuses.

Consensus on the South Dakota regional science fairs was to request that awards be presented by a representative from the academy. This will involve setting up the process early in the year.

Ken Higgins reported that the 2002 Proceedings has been printed and distributed to members.

The 2004 annual meeting will be held on the Missouri River at Cedar Shore Resort, Chamberlain, SD, and will have an emphasis on The Missouri River and/or Lewis and Clark This meeting will not have a host institution, but instead will have an Organizing Committee consisting of Ken Higgins, Chair, Miles Koppang, and Donna Hazelwood. This meeting will consist of invited speakers Friday 2 April and paper sessions Saturday 3 April. Bob Tatina reported that Gary Moulton has accepted the invitation for keynote speaker for the 2004 meeting, and Dave Ode will give a presentation on South Dakota plants. Additional speakers will be contacted for the Friday Symposia centered around Lewis and Clark and the Missouri River. Consensus of the membership was to, where practical, invite individuals from the region. Andy Detweiler suggested that the statewide EPSCOR program on biocomplexity may tie in with the Symposia. Additional potential speakers and topics included Bruce Barton and the Missouri River Institute, State Fisheries and Wildlife, and Game Fish and Parks. The Speakers Committee includes Bob Tatina, Steve Chipps and Andy Detweiler. Jim Martin will arrange fieldtrips. In addition, Ken Higgins will be point person for the Program Committee.

Additional items discussed about the 2004 meeting included reservations for rooms at Cedar Shore will be due 1 March 2004. To enable participants time to plan, the Call for Papers will be moved ahead.

Neil Reese suggested that the Academy consider utilization of the Academy web site for payment of registration and membership by credit card. He will examine a company which will, for a fee, broker the credit card transactions. The addition of the pay by credit card service would make the website more visible. In addition a list serve for the society could be created, maintained, and utilized.

The Audit Committee will consist of Miles Koppang and Charles Lamb.

The 2005 meeting is scheduled to be held at the University of Sioux Falls.

Registration will be for the Annual Meeting began at 12:00 p.m. this afternoon Ken Higgins brought Terri Symens, and Andy Detweiller lined up Linda Embrock to assist with registration.

The Nominating committee will have the following positions to fill, Secretary, Treasurer, Second Vice President, and two members-at-large. Krisma DeWitt and James Lefferts will be going off as members-at-large.

Kristel Bakker provided the Treasurer's report. Miles and Charles served as Auditing Committee. The CD at Dakotah Bank will be allowed to rollover for another term.

The 2004 meeting of the Academy will be at Cedar Shore Resort Chamberlain SD and the 2005 meeting will be at The University of Sioux Falls. Because the Academy does not have a current member from USF, the membership voted to have Miles Koppang appoint a member from USF to the vacant slot for member-at-large. The Executive Council will meet at Cedar Shore in Chamberlain during September.

Ken Higgins provided the Proceedings report and had already passed out copies of the 2002 proceedings. Page costs are $25.00/page, and the presidential address and minutes are included at no charge to the Academy. Ken reported that he had received a request from a book author to include a portion of an article published in the 1963 Proceedings. The question of copyright issues were discussed. Andy moved and Charles seconded a motion that the proceedings editor would include a disclaimer granting permission fro reproduction of material from abstracts, articles, or posters transferring copyright to the Academy when published in the Proceedings of the South Dakota

Academy of Science. Motion carried by a voice vote. Ken reported that he had received a request for a 1972 Proceedings and noted that librarian Joe Edlund of USD is in charge of the repository of Proceedings, and he sends material to libraries. Ken handed out a copy of the Proceedings account. To date the 2002 issue is in debt, but the overall account is in the plus.

Ken suggested that the Academy provide honoraria for assistance in the following amounts to Terri Symens $300.00, Di Drake $100.00, and Linda Embrock $100.00. Neil moved and Donna seconded a motion to give the amounts requested. The motion carried by a voice vote.

Ken noted that normally the host institution for the annual meeting prints the program. For the 2004 meeting at Chamberlain, Ken will be in charge of printing the program.

Elections were held and officers for 2003-2004 are: members at large 2003-2005 Krisma DeWitt and to be filled, Second vice-President James Sorenson, Secretary Donna Hazelwood, Treasurer Kristel Bakker, and First Past President Charles Lamb. Charles Lamb moved and Bob Tatina seconded acceptance of the nominations. The motion carried by voice vote. Neil Reese moved, Krisma DeWitt seconded a motion, and the motion was carried to vest Miles Koppang with the power to contact USF to determine interest in and commitment to hosting the 2005 Academy meeting, appointing an individual from USF to the vacant Member-at Large position, and securing a date for the 2005 meeting at USF.

Committee positions for 2003-2004 include:

Membership	*Bob Tatina*
	to be filled
Bylaws	*Miles Koppang*
	Bob Stoner
Chuck Estee	
Resolutions	*to be filled*
Nominations	*to be filled*
Publicity for 2004 meeting	*to be filled*

Miles suggested that the Academy establish a date for the annual meeting consistent from year to year. Miles moved, Charles seconded and motion carried that annual meeting be held the first non-Easter full weekend in April.

Miles proposed that for future meetings the host institution consider hosting a symposium relating to their campus, the region, or a resource or activity relating to science in South Dakota. Miles will ask the University of Sioux Falls to organize and coordinate a symposium for the 2005 meeting.

Steve McDowell proposed the poster session held at the 2003 meeting South Dakota School of Mines and Technology. To honor Steve's vision, the membership decided to continue the tradition of poster sessions. The logistics of the poster sessions include a room large enough to hold the posters, location on or off campus, poster size. The membership decided to utilize the poster boards from USD and follow the poster session format established at USD. The poster numbers will be assigned by the Proceedings Editor from the number in the program.

For the format of oral paper presentations, at the 2004 meeting in Chamberlain, the membership decided to require PowerPoint presentations on CD.

Donna moved and Charles seconded the following resolutions: 1) thank President Richard J. Gowan and the South Dakota School of Mines and Technology for hosting the 2003 Academy meeting; 2) include a remembrance of Steve McDowell in the Proceedings; 3) a big thank you to Andy Detwiller for his efforts in organizing the 2003 meeting; 4) thank you to First past President Charles Lamb for assuming the role of President for the executive council meeting.; 5) thank you also to Miles Koppang, President-Elect, for his address on "Science in South Dakota: Two Steps Forward and One Step Back"; 6) thank the local arrangements committee the late Steve McDowell, Andy Detweiler, and Linda Embrock; 7) thank the program committee, Ken Higgins, Steve Chipps, the late Steve McDowell, Andy Detweiler, Terri Symens, and Linda Embrock; 8) thank to the secretaries Linda Embrock and Terri Symens for assisting with registration at the meeting; and 9) aspecial thanks goes to Editors Ken Higgins and Steve Chipps for their oversight of timely publication of the Proceedings.

Several items for consideration at the fall meeting of the Executive Committee were discussed. 1) Ken pointed out that the by-laws were last updated in 1989 and need to be updated. 2) The 2004 meeting including examination of proposed speakers for the general session Friday 2 April. 3) Nomination of individuals for Fellow. 4) Recruitment of new members. 5) A new operations manual to replace the one that apparently has been lost. 6) Assisting the five regional science fairs, providing prizes at the middle school level. Miles and Andy will brainstorm and bring a report to the meeting 6) the 2005 meeting scheduled for University of Sioux Falls.

Respectfully submitted,
Donna Hazelwood, DSU
SDAS Secretary

SOUTH DAKOTA ACADEMY OF SCIENCE
2002-2003 EXECUTIVE COMMITTEE

PRESIDENT	Steve McDowell, SDSM&T Chemistry. 394-1229 Steve.McDowell@sdsmt.edu; FAX 394-1232
PRESIDENT-ELECT	Miles Koppang, USD Chemistry, 677-5693 mkoppang@usd.edu
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SECOND PAST PRESIDENT	Lenore Koczon, NSU Chemistry, University College, 626-2633 koczonl@northern.edu; FAX 626-3317
MEMBERS-AT-LARGE	
2001-2003	Krisma DeWitt, Mount Marty College Chemistry 668-1530 kdewitt@mtmc.edu
2001-2003	James Lefferts, Dakota Wesleyan University Chemistry jileffer@dwu.edu
2002-2004	Gary W. Earl, Augustana, Chemistry Earl@inst.augie.edu; FAX 357-9772
2002-2004	R. Neil Reese, SDSU Biology/Microbiology, 688-4568 Neil_Reese@sdstate.edu

REPORT OF THE 2003 RESOLUTIONS COMMITTEE

The South Dakota Academy of Science wishes to thank the South Dakota School of Mines and Technology for hosting the 2003 meeting. In particular, we thank Richard J. Gowan, President of South Dakota School of Mines and Technology, and are grateful to the local arrangements committee the late Steve McDowell, Andy Detweiler, and Linda Embrock, to the program committee, Ken Higgins, Steve Chipps, the late Steve McDowell, Andy Detweiler, Terri Symens, and Linda Embrock, and for secretarial assistance and assisting with registration, Terri Symens, and Linda Embrock. A special thanks to several SDSM&T students for their assistance.

Thank you to the late Steve McDowell for his dedication as President of the Academy this past year. A special thank you to Andy Detweiler for an excellent job completing the program arrangements after the untimely passing of Steve McDowell. Thank you to First past President Charles Lamb for assuming the role of President for the executive council meeting. Thank you also to Miles Koppang, President-Elect, for his address on "Science in South Dakota: Two Steps Forward and One Step Back".

The Academy proposed to include in the 2003 Proceedings a Tribute to Steven McDowell, and to include in his honor a poster session at the 2004 meeting.

The Academy wishes to thank Donna Hazelwood and Kristel Bakker for their service as Secretary and Treasurer, respectively. A special thanks goes to Editors Ken Higgins and Steve Chipps for their oversight of timely publication of the Proceedings.

Respectfully submitted,
Donna Hazelwood, and Charles Lamb, Resolutions Committee

SDAS BUDGET SUMMARY 2002

Beginning Balance April 2002	**$10,288.07**
SDAS 2002 Meeting	
Augustana Miscellaneous (copying, etc.)	-150.00
Speaker	-750.00
Banquet	-870.07
Terri Symens	-200.00
Di Drake	-100.00
Cheryl Holzapfel	-100.00
Memberships, Registration, Banquet	+3,412.00
Sec. of State	-40.00
2002 Executive Board Meeting in Chamberlain	-119.06
SDAS Website Development	
SDSU Foundation	-500.00
Siva Prasad Massath	-500.00
Science Fairs (additional $400 yet to be disbursed)	-600.00
Miscellaneous costs	-33.34
Cash for 2003 SDAS	-300.00
Ending Balance April 2003	**$9437.60**

Respectfully submitted,
Kristel K. Bakker, Ph.D.
Treasurer, SDAS

EXECUTIVE SUMMARY – PROCEEDINGS EDITORS

Volume 81 for 2002 totaled 329 pages and the production cost for 310 copies was $7,313.59. Our overall Proceedings account balance to date is $5,445.07. Copies have been mailed to all current members, all life members, all the State libraries and to eight indexing services.

Respectfully Submitted by:
Kenneth F. Higgins and Steven R. Chipps, Co-Editors
For the SD Academy of Science Proceedings
August 31, 2003

PROCEEDINGS DISBURSEMENTS/RECEIVABLES

April 1, 2003—Prepared by Di Drake

	2002	2001	2000	1996-1999	Total
Lay Out Formatting	2,251.25	2,836.50	780.00	3,405.00	9,272.75
Publication	3,978.76	4,997.00	2,585.92	11,541.55	23,103.23
Reprints	839.21	1,178.98	320.99	3,538.47	5,877.65
Miscellaneous Printing	112.49	33.26	69.26	105.45	320.46
Supplies,Phone,Postage	131.88	450.29	126.55	303.14	1,011.86
TOTAL EXPENSES	7,313.59	9,496.03	3,882.72	18,893.61	39,585.95
TOTAL INVOICED	7,055.00	11,060.00	3,635.00	21,253.00	43,003.00
Profit / Loss to date	**(258.59)**	**1,563.97**	**(247.72)**	**2,359.39**	**3,417.05**

CASH BALANCE IN SDSU—SOUTH DAKOTA ACADEMY OF SCIENCE PROCEEDINGS ACCOUNT

April 1, 2003—Prepared by Di Drake

	2002	2001	2000	1996-1999	Total
Total Paid Expenses	(7,313.59)	(9,496.03)	(3,882.72)	(18,893.61)	(39,585.95)
Paid by SDAS-Treasurer				4,747.13	4,747.13
Payments Received	6,615.00	10,770.00	3,010.00	19,564.00	39,959.00
Corrections Est			525.00	525.00	1,050.00
Paid to SDAS-Treasurer				(240.00)	(240.00)
Balance of SDSU Account	**(698.59)**	**1,273.97**	**(347.72)**	**5,702.52**	**5,930.18**
Percent of Paid Invoices	0.94	0.97	0.83	0.92	0.93
Unpaid Invoices	440.00	290.00	100.00	1,164.00	2,234.00

PRESIDENTIAL ADDRESS

Science in South Dakota: Two Steps Forward and One Step Back

Address to the South Dakota Academy of Science
April 6, 2003

Presented by Miles Koppang
Department of Chemistry
University of South Dakota

When I first informed my colleagues of the title for my Presidential Address, they jokingly said, "Don't you have the title reversed?" I told them that my original title was actually, "Science in South Dakota: One Step Forward and Two Steps Back." I am confident that many of you often feel that such a phrase describes the advancement of science in South Dakota. Upon further reflection and after discussions with my colleague across "the aisle," I decided to change my title.

In recent weeks, our problems in South Dakota seem somewhat trivial and self centered given the ongoing war in Iraq. Many people in this room have family members, relatives, and/or friends presently serving in the armed forces who are in or will soon be in Harms Way. Numerous students from our home institutions who are members of the National Guard have been deployed to the Middle East. Are thoughts and prayers are with our troops and their family members in this tumultuous period. Also, our thoughts and prayers are with the Iraqi citizens who deal first hand with the war and still worry that they might be abandoned and face a tyrant's rage as was the case in the first war with Saddam Hussein.

Almost one year ago to this date, we gathered for our annual meeting in Sioux Falls on the Augustana College campus to hear Steve McDowell, Professor of Chemistry at South Dakota School of Mines and Technology, present the annual Presidential Address to the Academy. I trust all of you know Steve passed away unexpectedly on Friday, March 7, 2003. Steve McDowell joined the Chemistry Department at School of Mines in 1990. He received his BS degree from Miami University and his Ph.D. from Iowa State in 1983. He was a Post Doctoral Associate at the University of California Riverside and was a member of the Chemistry Departments at California State University and Santa Monica College before moving to Rapid City. He served as Chair of the Department of Chemistry and Chemical Engineering from 1998 - 2002. He also chaired the faculty senate at School of Mines. Last year in his Presidential Address, Steve talked about Science and Change in South Dakota and about his research interests in the inorganic vitamins; the Cobalamins. The admiration, respect and relationships that Steve enjoyed with his colleagues, students and former students are reflected in the comments that people posted at the Department's Web page I first met Steve at one of the earlier SD EPSCoR meetings. Through EPSCoR and South Dakota Academy of Science meetings, many of you had the opportunity to meet and interact with Steve. He will be missed and are thoughts are with his family, close friends and colleagues, many of whom are here in the audience. It seems that our problems in moving science forward in South Dakota seems rather unimportant with respect to losing a friend and colleague like Steve McDowell and with the war raging in Iraq.

I would like to use this time to review the changes in science in South Dakota that I have experienced since arriving at the University of South Dakota. I know that my comments are heavily influenced by my experiences with public higher education in South Dakota and I apologize if those from private institutions and other scientific entities here feel somewhat removed from my experiences.

First, I would like to tell you a little about myself. I was born and raised in the upper Midwest growing up on a farm in northwestern Minnesota. My father told us that we needed an education because the farm was too small for any of us to operate. Although farm life provides a wonderful setting for developing an interest in science, I was much more interested in sports and would have preferred growing up in town so that I could play ball more frequently. However, my love of baseball was definitely nurtured on the farm. While sitting in the truck during grain harvest, I would listen to the Minnesota Twins and have followed their progress religiously since the fall of 1965. It wasn't until my final year in high school that my interest in science was kindled. I took chemistry from an "ex-hippie" my senior year. When he was going through the elements of the Periodic Table, he came to radon and proceeded to fall into song, "a radon love", (which I am not going to sing) a tune made popular at the time by the group Golden Earring. I received my bachelors majoring in chemistry and math from Mayville State College and earned my Ph.D. in Analytical Chemistry from the University of North Dakota. My research was in organic electrochemistry and we studied reductive cleavage of ethers. After postdoctoral work at Kansas University in Bioanalytical, I accepted a faculty position in the Chemistry Department at the University of South Dakota in September 1986 and am now in my seventeenth year at USD.

In the summer of 1988, I was asked to contribute a research component to the NSF EPSCoR proposal. EPSCoR, for those who might be unfamiliar with the acronym, stands for Experimental Program to Stimulate Competitive Research, a program designed to make those states that were typically unsuccessful in obtaining federal research dollars, more competitive in securing federal grants and contracts. This proposal was actually the third round or attempt for South Dakota, having "failed" in two previous attempts to participate in EPSCoR. I say fail, not because the proposed science or the quality of investigator was lacking, but the EPSCoR program required a commitment by states to change the way or manner in which basic research was supported. In the first two submissions, the state did not demonstrate a sufficient commitment or level of support for the participating investigators. By the late 80's, the level of commitment by the state and industry had changed and South Dakota's proposal was funded. The first proposal was limited to participants from USD, SD-

SU and SDSM&T, and the National Science Foundation was the initial federal agency to have such a program. Today the South Dakota EPSCoR program includes EROS Lab and has involved students and faculty from the other public and private Higher Ed institutions through collaborative arrangements. EPSCoR or EPSCoR-like programs have been created in other federal agencies including DOD, EPA and the NIH. I would like to present some data that comes from the South Dakota EPSCoR UPDATE, the newsletter of SD EPSCoR.[1] Since 1989 when the first proposal was funded, total grants and contracts awarded to the state have increased almost 5-fold. Some recent highlights include:

1) South Dakota was successful in receiving funding from the United States Department of Agriculture EPSCoR,
2) NSF awarded South Dakota an EPSCoR grant in the amount of $13.5 million for FY01 to FY04,
3) The National Institutes of Health Center for Biomedical Research Excellence (COBRE) was awarded to the USD Medical School in the amount of $8 million over 5 years to establish a center for neuroscience research and a second COBRE grant for 9.5 million for 5 years for the cardiovascular research center and
4) The Basic Biomedical Sciences faculty at USD were awarded a $6 million BRIN grant for three years in the area of cellular growth and development of bioinformatics.

When I first arrived at USD, only one medical school faculty member had continuous NIH funding. That has changed dramatically today, due in large part, to the science infrastructure development made possible largely through the EPSCoR program. Also, in FY02, for the first time in its history, South Dakota had 100 active NSF grants.

We have greatly increased research opportunities for students as well as opportunities to present their results. My own undergraduate research students were able to attend the following meetings to present their results this past year:

1) The ACS Midwest Regional Meeting at Kansas University
2) NCUR at the University of Utah
3) Pierre Poster Session
4) The National ACS Meeting in New Orleans
5) Posters on the Hill sponsored by CUR in Washington DC.

I doubt that anyone in this room would dispute the contention that South Dakota Science is much more visible at the national level today than in 1986.

With all of these positive changes, why do I say that with every two steps forward we take one step back? In 1988, two instrument grants were submitted by USD Chemistry to NSF. The first, a proposal for a medium field NMR spectrometer, was funded but required local matching funds. The second grant requested a Gas Chromatograph-Mass Spectrometer through the NSF ILI program. Instead of finding the matching funds locally, the Governor's Office provided the matching monies through the newly established Future Fund. The

Future Fund, using unspent workman's compensation, was established by the late Governor Mickelson to build the intellectual capacity of the state for economic development. Furthermore, the matching requirements for the EPSCoR proposal were provided through the Future Fund. When Bill Janklow was elected Governor in 1996 for his third term, the use of Future Funds as matching funds for instrumentation grants was discontinued. I would like to point out that the statue on the USD campus honoring William "Doc" Farber, Professor Emeritus, was paid with funds ($60,000) from the Future Fund. This valuable source of matching funds is no longer…two steps forward, one step back.

In the early 90's the public institutions were encouraged to increase enrollment to their capacity. Since funding is enrollment driven, this resulted in significant increases in funding for the public institutions. Record or near record enrollments were seen at the institutions. Students were coming from out of state and with them, their tuition dollars and their disposable income which was being spent in South Dakota. Approximately six years ago, the Board of Regents adopted various policy changes for the institutions including the 7/10 rule, increased tuition for out of state students, reinvestment priorities and a funding framework in which 5 % of the budget dollars were withheld and distributed to the institutions based on regental goals and whether or not the institutions achieved those goals. One goal required increasing the number of majors in disciplines considered to be of critical importance with respect to economic development. Initially, chemistry at USD was targeted as a department that needed to grow. Despite a rather robust enrollment of ~ 70 majors and an average of graduating 15 majors per year (slightly below the number of majors at Iowa State and University of Iowa and larger than numbers at University of Nebraska), we were expected to increase majors by 5 to 10 % annually over a 5 year period in order for the University to recoup a portion of the 5 % of their budget that was withheld. The 7/10 rule was especially problematic. While it was implemented to discourage the practice of offering classes to small numbers of students because of inefficiencies, the rule created chaos. This rule effectively eliminated the departments at the USD Medical School and was the driving force behind the naming of the Division of Basic Biomedical Sciences and its subdivisions of research areas. (This seems to have been one of the few outcomes that has been positive).

Remember last year's (2001-2002) legislative session. The Governor proposed a scholarship program for South Dakota students. South Dakota was the only state in the nation without a state sponsored scholarship or financial aid program for its higher education students. The problem with the proposal was exclusion of the private institutions from the program. Obviously, those institutions voiced strong opposition and the proposal was modified to include private as well as public institutions. These modifications caused the Governor to veto his own bill. A scholarship bill was passed this session without funding but does include private and public institutions.

The creation of the discipline councils by the Board of Regents was to provide a means of better communication within disciplines throughout the regental system. Unfortunately, the discipline councils have been spent a large amount of time and effort on a common course numbering system which implies that all institutions, despite clear and distinctive missions, are the same. Ironically, as the cookie-cutter stadiums become obsolete throughout the country, a cookie cutter approach to higher education is embraced within the state.

I must applaud and salute our former governor for his efforts to make the mobile science lab a reality. The first lab is outfitted with instruments and curriculum has been developed. It has been on the road this past month visiting schools as test sites to work out the all the bugs and will be fully operational this upcoming fall. Please visit the web site for the mobile lab and/or attend my presentation this afternoon on outreach initiatives.

What about the South Dakota Academy? Have we been able to make any progress? Our current mission statement calls for the South Dakota Academy of Science to:

- develop interest in science
- strengthen the bonds of fellowship between scientists,
- preserve information of scientific value and
- stimulate research in areas that relate to the natural resources of the state.

First, are we developing interest in science? Unfortunately, the Junior Academy, very active and vibrant when I first started attending academy meetings, is no longer active. Instead, the Academy encourages precollege students to participate in regional and the South Dakota State science fairs and the South Dakota Science Olympiad. Academy members play critical roles as judges of the fairs and the Academy is supporting regional fairs and encouraging participants through the sponsorship of modest prizes. The South Dakota Academy co-sponsors along with South Dakota EPSCoR the Pierre Poster session for undergraduate research students.

Second, are we strengthening the bonds of fellowship between scientists? With all of the discipline specific and sub-discipline specific meetings, it is becoming increasingly difficult to encourage colleagues to support the Academy. Institutions such as USD are sponsoring their own meetings for student presentations. At USD these include our Ideafest for undergraduate presentations and our Graduate Science Research Forum. Personally, despite their logistic nightmares, I have truly enjoyed our joint meetings with academies of other states. In the late 80's the SD and ND Academies had a joint meeting in Bismarck. In the late 90's, MN, SD and ND Academies met for a tri state meeting in Moorhead. Professionally, both meetings were especially beneficially for me as the joint meetings provided a critical mass of scientists with similar research interests. The tri-state meeting included an outstanding symposium on electrochemistry. Our meeting next year will hopefully be well attended as we plan on meeting in Chamberlain on Friday and Saturday, April 2 and 3. The focus of the meeting will be the Missouri River and the 200th anniversary of the Lewis and Clark expedition and I encourage all to mark the meeting on your calendars. I can say that the Academy does a great job in strengthening the bonds of fellowship, provided that we can convince more of our colleagues to attend the meetings.

The Proceedings serves as our tool to achieve the third component, preservation of information of scientific value. The hard work of our Proceedings Editor and their support personnel is critical in this area and is too frequently underappreciated. In the fourth area, to stimulate research in areas that relate to the natural resources of the state, the 2004 Meeting in Chamberlain will play an important role in achieving this fourth component or goal. I can personally say participation in the Academy has been worthwhile, helpful and rewarding. Solving today's scientific problems requires crossing discipline boundaries. Participation in the Academy is worth your time and effort and what better setting exists to discuss science with your colleagues from other disciplines than through the academy's annual meeting.

Have we made progress in the past 17 years? My answer is yes but continued progress or two steps forward will likely be accompanied by one step backward. Maybe in the coming years we can change the backward steps from one to one half.

[1] From the South Dakota EPSCoR 2003 Newsletters which can be found at http://www.sdepscor.org/newsletter.htm

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SCREENING ELITE SOUTH DAKOTA WINTER WHEAT FOR SSR MARKERS LINKED TO *FUSARIUM* HEAD BLIGHT RESISTANCE

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ABSTRACT

Resistance to wheat (*Triticum aestivum* L.) *Fusarium* head blight (FHB) - caused by *Fusarium graminearum* Schwabe - is a very complicated quantitative trait. Marker assisted selection (MAS) could be a useful tool to enhance the efficiency of FHB resistance breeding. A major FHB resistance QTL, *Qfhs.ndsu-3BS*, has been identified in Spring wheat cultivar Sumai 3, and SSR markers *Xgwm389-135*, *Xgwm493-190*, *Xgwm533-98* and *Xgwm533-145* were found to be linked to this QTL. In this study, we screened 61 elite winter wheat lines for these four markers. The results indicated that 22 wheat lines had either *Xgwm533-98* or *Xgwm389-135* marker. However, none of the 61 winter lines had either *Xgwm493-190* or *Xgwm533-145*, the two SSR markers that are tightly linked to the *Qfhs.ndsu-3BS* FHB-resistance QTL. Of the four markers, *Xgwm389-135* was the most polymorphic. An *Xgwm533-120* allele, which was a diagnostic marker for stem rust resistance gene Sr_2, was observed in 35 wheat lines.

Keywords

Scab, marker assisted selection, *Triticum aestivum* L., *Fusarium graminearum*

INTRODUCTION

Fusarium head blight (FHB), or scab, is a destructive wheat disease frequently occurring in the eastern South Dakota. In the past, FHB used to be a problem only in spring wheat. However, due to changes in winter wheat cultural practices and because more acreage is planted to it in traditional soybean [*Glycine* max (L.) Merr.] and maize (*Zea mays* L.) rotations in the eastern part of the state, precaution needs to be taken to prevent this disease by breeding FHB resistant winter wheat cultivars.

Wheat's resistance to FHB is a complicated quantitative trait (Bai and Shaner 1994). In our field trials and evaluation nurseries it is often difficult to distinguish genetic variance from the environmental effects, resulting in difficulties in screening for the presence of FHB resistance genes. Marker assisted selection (MAS) could be a useful tool to help resolve this problem.

Efforts have been made to identify DNA markers linked to FHB resistance in wheat. A major FHB resistance QTL, *Qfhs.ndsu-3BS*, has been identified in spring wheat cultivar Sumai 3, the Sumai 3-derivatives, or other germplasm that are resistant to FHB (Anderson et al. 2001; Angerer et al. 2002; Bourdoncle and Ohm 2002; Bowen et al. 2002; Buerstmayr et al. 2002; Chen et al. 2002; Gonzalez-Hernandez et al. 2002; Waldron et al. 1999; Xu et al. 2002; Zhou et al. 2002). Consistent results from various research groups have clearly verified this major QTL on chromosome arm 3BS. Since FHB resistance is scarce in winter wheat germplasm, this QTL should be the first candidate to be introduced for breeding FHB-resistance in winter wheat.

Simple sequence repeats (SSRs) or microsatellites are desirable markers in MAS because SSRs are abundant, codominant, highly polymorphic, and widely dispersed in diverse genomes as well as easy to assay by PCR based mapping techniques. Researchers have found several SSR markers linked to the *Qfhs.ndsu-3BS* QTL (Anderson et al. 2001; Angerer et al. 2002; Buerstmayr et al. 2002; Chen et al. 2002; Gonzalez-Hernandez et al. 2002; Zhou et al. 2002; Xu et al. 2002). Among these are *Xgwm389-135*, *Xgwm493-190*, *Xgwm533-98* and *Xgwm533-145* (Anderson et al. 2001). *Xgwm389-135* is located in the distal region of chromosome arm 3BS (Röder et al. 1998). Anderson et al. (2001) flanked the QTL *Qfhs.ndsu-3BS* with *Xgwm493-190* and *Xgwm533-145*, and indicated that *Xgwm493-190* was most-significantly associated with the QTL.

In our previous studies (Zhu et al. 2001, Weng et al. 2001), 78 elite breeding materials from South Dakota spring wheat breeding program and 87 elite selections from USWBSI spring wheat germplasm program were screened with SSR primer sets gwm533, gwm493, and gwm389. Thirty-eight of the 78 elite breeding lines were found to have *Xgwm493-190*, while only five also had *Xgwm533-145*. Of the 87 elite germplasm selections, 27 had *Xgwm493-190*, 31 have the Xgwm533 markers, and 26 had *Xgwm389-135*. It seems that the four SSR markers linked to the Sumai 3 FHB-resistance QTL *Qfhs.ndsu-3BS* were also frequently distributed among other spring wheat lines.

The objective of this study was to screen elite winter wheat lines from South Dakota winter wheat breeding program for the existence of the SSR markers revealed by SSR primer sets gwm389, gwm493 and gwm533. We tried to estimate the potential of using these four markers in MAS for FHB resistance in our winter wheat breeding program.

MATERIALS AND METHODS

Sixty-one hard winter wheat lines selected from South Dakota Crop Performance Testing (CPT) and Advanced Yield Trial (AYT) in the year of 2003 were assayed (Table 1). Spring wheat cultivars Sumai 3 (resistant to FHB) and Wheaton (susceptible to FHB) were used as the controls.

Table 1. Results of SSR fingerprinting of winter wheat (bold print indicates the band with same size as that of Sumai 3).

No.	Lines	xgwm533 (Size in bp)	xgwm493 (Size in bp)	xgwm389 (Size in bp)
W1	Alliance	98, 120	140	110
W2	Arapahoe	175	140	112
W3	CDC Falcon	175	140	112
W4	Jagalene	**98,** 120, 175	140	138
W5	AP502 CL	**98,** 120, 175	140	112
W6	Nekota	120	140, 230	112
W7	Jerry	120, 175	140	**135**
W8	Ransom	120, 175	140	115
W9	Tandem	**98,** 120	160	112
W10	Wesley	175	140	140
W11	Millennium	175	140	112
W12	Wahoo	175	140	112
W13	Crimson	120	160	**135**
W14	Expedition	**98,** 120, 175	140, 230	112
W15	Harding	175	140	112
W16	SD92107-3	175	140	112
W17	SD92107-5	120, 175	140, 230	138
W18	SD97049	175	160	112
W19	SD97250	120,175	140	112
W20	SD97088	175	140	112
W21	SD98102	120	140, 230	110
W22	SD97538	**98,** 120, 175	140, 230	110
W23	SD97059-2	120, 175	140, 230	145
W24	SD97380-2	120,175	160	110
W25	Nuplains	120	140	**135**
W26	Trego	120	140	**135**
W30	SD97W671-1	120	130	133
W31	SD97089-1	175	140	112, 140
W32	SD97250-2	175	140	112
W33	SD97394-1	**98,** 120	140	112
W34	SD99073	**98,** 120	140	112, 140
W35	SD99075	**98,** 175	140	112
W36	SD99096	175	140	112
W37	SD00032	**98,** 120	160	**135**
W38	SD00042	120	140, 230	**135**
W39	SD00235	175	140	138
W40	SD00111	175	140	112
W41	SD00258	120, 175	140	115
W42	SD00127	**98,** 120	140	112
W43	SD00189	175	140	112
W44	SD00261	175	140	112
W45	SD00330	**98,** 120	160	112
W46	SD00311	120, 140	140	**135**
W47	SD00386	120	140	**135**
W48	SD00305	**98,** 120, 175	140	112
W49	SD00260	120, 175	140	112
W50	SD97W609	120	140	**135**
W51	SD97W604	120	130	**135**
W52	SD97W604-1	120	130	133
W53	SD99W015	120	140	**135**
W54	96L9643-3	**98,** 120	140	110
W55	SD00W024	**98,** 130	130	110
W56	SD00W083	140	140	**135**
W57	SD00W028	**98,** 130	130	110
W58	SD00W021	140	140	**135**
W59	SD00W019	**98,** 130	130	110
W60	SD00W087	120, 140	140	**135**
W61	SD00W041	118	140	138
W62	SD00W022	118	140	133
W63	SD00W004	**98,** 118	140	133
W64	SD00W005	118, 140	140	133
	Sumai 3	**98,145**	**190**	**135**
	Wheaton	**120**	**140**	**110**

DNA was extracted from 0.25g young leaf from each line using DNAzol ES solution (Molecular Research Center, Inc). The protocol provided by the manufacture was followed. SSR primers gwm389, gwm493 and gwm533 were synthesized on the basis of the sequence information published by Röder et al. (1998). PCR amplification was done according to Röder et al. (1998) and Anderson et al. (2001) with minor modification. Silver staining was used to detect the PCR products after their separation on 6% sequence gels following a protocol described by Xing et al. (2000).

RESULTS AND DISCUSSION

All the four SSR primer sets amplified the correct DNA fragments in both Sumai 3 and Wheaton (Fig. 1, Table 1). Theses primer sets were used to elucidate the corresponding alleles in the 61 elite winter wheat lines. The primer set gwm389 revealed eight SSR alleles (from 110 bp to 145 bp) among the 61 lines, indicating a higher polymorphism than gwm493 (4 alleles) or gwm533 (6 alleles) did (Table 1). The higher polymorphism could be related to the distal location of *Xgwm389* on chromosome arm 3BS where exchange happens more frequently (Röder et al. 1998). Fourteen lines (23.0%), including 'Jerry', 'Crimson', 'Nuplains', 'Trego', SD97W604, SD97W609, SD99W015, SD00032, SD00042, SD00311, SD00386, SD00W083, SD00W021 and SD00W087 had the same allele as did Sumai 3, while eight lines (13.1%) had the same allele as did Wheaton. New alleles were observed in the remainder of the lines. For example, a 112 bp allele was found in 26 lines (42.6%), an allele of 115 bp in 2 lines (3.3%), an allele of133 bp in five lines (8.2%), an allele of138 bp in four lines (6.6%), an allele of 140 bp in three lines (4.9%), and an allele of 145 bp in one line (1.6%).

Anderson et al. (2001) flanked the Sumai 3's FHB resistance QTL *Qfhs.ndsu-3BS* with SSR markers *Xgwm493-190* and *Xgwm533-145*, and indicated that *Xgwm493-190* was the most-strongly associated with the QTL. Chen

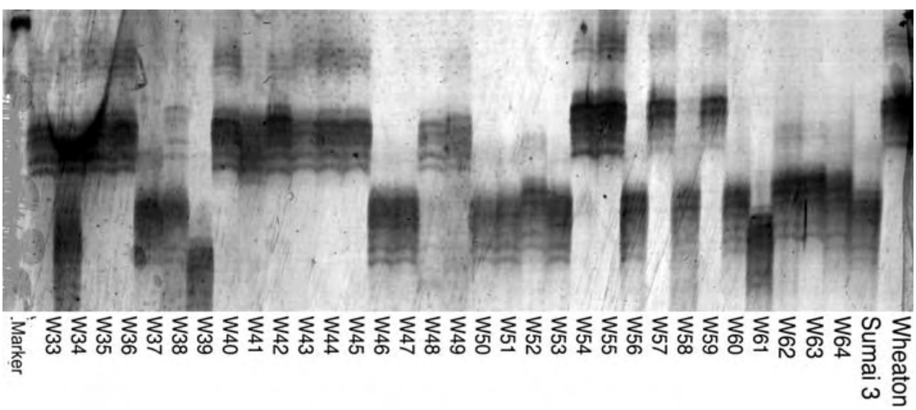

Figure 1. SSR fingerprinting with primer Xqwm389.

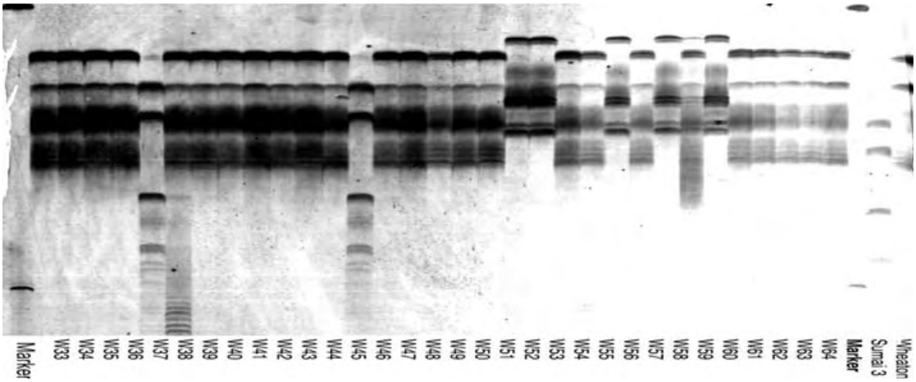

Figure 2. SSR fingerprinting with primer Xqwm493.

et al. (2002) found that, *Xgwm493-190* was one of the most commonly detected loci in 27 FHB resistant soft red winter wheat lines. However, none of the 61 hard red winter wheat lines we assayed contained *Xgwm493-190* (Table 1, Fig. 2). Most of the lines (49/61=80.3%) we assayed had the same allele *Xgwm493-140* as did Wheaton. None of the 61 lines we assayed has spring wheat in its pedigree. Therefore, *Xgwm493-190* can be used as a desirable diagnostic marker in our MAS for FHB resistance introduced from spring wheat. Other gwm493 alleles observed were *Xgwm493-130* (in six lines), *Xgwm493-160* (in six lines), and Xgwm493-230 (in seven line).

Primer set gwm533 revealed the *Xgwm-98* allele in 18 winter wheat lines (29.5%). None of the 61 lines was found to have the *Xgwm533-145* allele (Table 1, Fig. 3). Only three lines (4.9%) had the Xgwm533-130 allele as did Wheaton. Of the remainder, four lines (6.6%) had an allele 118 bp; 35 (57.4%) had an allele of 120 bp; 5 (8.2%) had an allele of 140 bp; and 30 (49.2%) had an allele of 175bp.

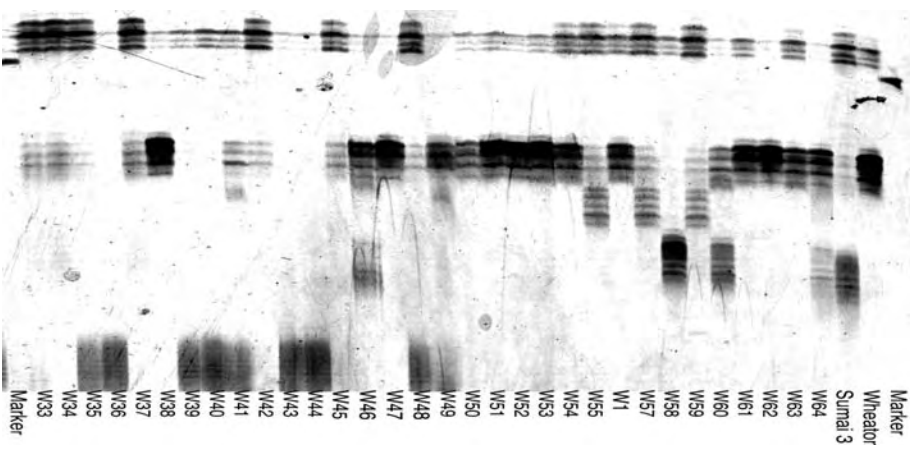

Figure 3. SSR fingerprinting with primer Xqwm533.

As shown in Table 1, 57.4% of the lines we assayed have an *Xgwm533-120* allele. This allele was found by Spielmeyer et al. (2003) as a diagnostic marker for the presence of a stem rust (caused by *Puccinia graminis* Pers.:Pers. F. sp. *tritici* Eriks. & E. Henn.) resistance gene *Sr2*. The stem rust resistance gene *Sr2* was transferred into bread wheat from a durum wheat (*Triticum turgidum* L., 2n=4x=28) by McFadden (1930) here in Brookings, SD. It has been recognized as one of the most important disease resistance genes used in wheat breeding and has provided durable, broad-spectrum stem-rust resistance effective against all isolates of *P. graminis* worldwide for more than 50 years. This SSR marker is definitely useful for MAS in our breeding for stem rust resistance.

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MICROBIAL POPULATIONS DURING LANDLOCKED FALL CHINOOK SALMON EGG INCUBATION AT McNENNY STATE FISH HATCHERY, SPEARFISH, SOUTH DAKOTA

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ABSTRACT

Microbial sampling was conducted during incubation of landlocked fall chinook salmon *Oncorhynchus tshawytscha* eyed eggs in vertically-stacked tray incubators at McNenny State Fish Hatchery, Spearfish, South Dakota. *Saprolegnia* spp. were identified from water obtained directly from the hatchery well, and also from the aeration tower and incubation headbox. Attempts to develop a fungal population census method were unsuccessful. Mean bacteria levels in the incubation tray water when the trays contained either eyed eggs or sac fry were significantly less than during hatching. Bacterial populations were also significantly elevated after removal of dead eggs and fry by hand-picking. Daily 15 minute formalin treatments of 1,667 mg/L from eye-up to hatch significantly improved embryo survival. However, there was no difference in bacterial levels in the incubation water between trays that did or did not receive formalin treatments, and bacterial levels were not reduced in the incubation water after formalin treatments.

Keywords

Saprolegnia, chinook salmon, salmonid eggs, vertical-flow incubator, formalin, hand-picking, bacteria

INTRODUCTION

Saprolegnia spp. fungal infections on incubating salmonid eggs are common at most hatcheries. Controlling such infections usually requires fungicidal chemical treatments such as formalin (Piper et al. 1982; Post 1987) until at least the eyed stage of egg development. After eye-up, physical removal of the dead eggs at regular intervals can be safely performed for fungal control or chemical treatments can continue. Manual removal of dead eggs and fry is a laborious procedure (Leitritz and Lewis 1976), whereas formalin treatments are relatively easy and effective (Bailey and Jeffery 1989).

McNenny State Fish Hatchery, Spearfish, South Dakota, has utilized both methods of control during incubation of landlocked fall chinook salmon *Oncorhynchus tshawytscha* eggs obtained from feral broodstock in Lake Oahe, South Dakota. These eggs typically exhibit poor survival to eye-up, with mortality rates often in excess of 50% (Barnes et al. 2000b). An additional 15% mortality occurs from the eyed egg stage to fry swim-up (Barnes and Cordes 1992). Traditionally, these eggs have been treated daily with formalin during initial incubation. Prior to 1993, formalin treatments were discontinued at the eyed stage of development and dead eggs and fry were then manually removed until fry swim-up (Barnes and Cordes 1992). Since 1994, formalin treatments have been continued daily from eye-up until just prior to hatch, and have consistently produced a 3 to 5 % increase in embryo survival (Barnes et al. 1997). The reasons for this increase are not understood and may be due to formalin decreasing either microbial (fungal or bacterial) populations or life-cycle stages (e.g. spores) that manual egg picking is unable to remove (Barnes et al. 1997; 2000a; 2001).

The objectives of this preliminary study were to determine the impacts of daily formalin treatments on the microbial populations associated with incubating fall chinook salmon eggs and identify the presence of Saprolegnia spp. in the incubation source water at McNenny Hatchery.

METHODS

General Egg Culture

All eggs used for this study were obtained from fall chinook salmon spawned at Whitlocks Spawning and Imprint Station, Lake Oahe, South Dakota. Eggs were collected on October 21, 1996.

After spawning at Whitlocks, the eggs were transported to McNenny Hatchery (4h). Temperature of the eggs upon arrival at the hatchery was 12°C. The eggs were disinfected in a 100 mg/L buffered free-iodine solution for 10 minutes, inventoried by water displacement (Piper et al. 1982), and placed in Heath (Flex-a-lite Consolidated, Tacoma, Washington) incubator trays. Well water (11°C, total hardness as $CaCO_3$ - 360 mg/L, alkalinity as $CaCO_3$ - 210 mg/L, pH - 7.6, total dissolved solids - 390 mg/L) at a flow of 12 L/min was used for egg incubation. Formalin treatments using Parasite-S (37% formaldehyde, 6 to 14% methanol, Western Chemical Inc., Ferndale, Washington) at 1,667 mg/L for 15 minutes were administered daily until the eyed stage of egg development with a Masterflex model 7524-00 microprocessor peristaltic pump (Cole-Parmer Instrument Company, Chicago, Illinois). Formalin concentrations were not analytically verified (Rach et al. 1997).

Experimental Design

At the eyed stage of egg development (incubation day 28), all trays were pooled and dead eggs were mechanically removed using a Van Gaalen Fish Egg Sorter (VMG Industries, Grand Junction, Colorado). This machine uses modulated infrared light to detect opaque (dead) eggs and air pressure to sort the eggs after detection. Eyed eggs were pooled, reinventoried, and retrayed at 900 mL (approximately 5,100 eyed eggs) per tray. Survival to the eyed stage was 71%.

Six trays from three incubator stacks were used during the study. The top tray of each stack served as a mixing tray and did not hold any eggs. The next two trays down the stack were included in the experiment. Each stack received a different treatment until hatch. One stack (2 trays) continued receiving daily formalin treatments (1,667 mg/L for 15 minutes) for an additional 10 days after auto-picking. A second stack (2 trays) did not receive any additional formalin treatments; fungal control was entirely due to hand-picking removing dead eggs. The third stack (2 trays) acted as a procedural control. It received daily formalin treatments and the trays were also hand-picked at the same time as the non-formalin treated trays (4, 7, and 9 days after auto-picking - incubation days 32, 35, and 37). After formalin treatments ceased (day 39), all trays were hand-picked on incubation days 42, 44, 46, 49, 52, 56, 59, 63, and 70. All mortality was recorded and percent mortality to hatch, swim-up, and total mortality was determined.

Hand-picking was performed by removing the trays from the incubation stack, floating them in a 274 x 66-cm fiberglass picking trough, and sucking out the dead eggs and fry using a pipette fitted with a hand-held rubber squeeze bulb (Leitritz and Lewis 1976). Water levels in the picking trough were maintained at 18 cm (total operating volume = 322 L) with flows set at 10 L/min.

Microbial Sampling

Both fungal and bacterial samples were taken immediately after re-traying following auto-picking at the eyed egg stage. Samples were taken the next day from all trays in the morning 07:30 both before and after formalin treatments, and at 15:30. This sampling regime (pre- and post-formalin treatments, late afternoon sample) was repeated on the last day formalin was administered (incubation day 39). Additionally on this date, samples were also taken both before and after manual picking (11:00 to 14:00). During hatch eight days later (day 47), samples were taken at 7:30, before and after hand picking, and at 15:30. Samples were also collected on this date from one of the hatchery wells, the aeration tower, and the incubator headbox (water supply channel to all incubator stacks). Samples from pre- and post-hand picking, the incubator headbox, and the picking trough were collected on incubation day 53. Well, headbox, and 7:30 tray samples were also collected on day 57.

Both fungal and bacterial samples were taken from each of the six incubator trays in the experiment. Fungal sampling occurred by pipetting 20 mL of water from a tray into a sterile glass petri dish. Ten non-viable hemp seeds

(Carolina Biological Supply, Burlington, North Carolina) were then added to the water sample with sterile forceps to provide a substrate for fungal growth. Prior to placement in the petri dishes, the seeds were boiled for a minimum of 20 minutes for sterilization and to break their seed coat. Each seed was checked daily for any signs of fungal growth using a 10X dissecting microscope. Bacteria were sampled using the Spread Plate Method (APHA et al. 1989) by pipetting 0.1 mL of water from each tray onto a nutrient agar plate. The water sample was spread over the entire agar surface using a sterile spreader.

All microbial samples were incubated at ambient temperatures in the incubation room (10 to 13°C) in an attempt to mimic incubation water temperature at the hatchery (11°C). The number of bacterial colonies in each plate was recorded after 7 days incubation at ambient temperatures of 11°C and reported as CFU (colony forming units) per 0.1 mL of water. When ambient temperatures increased to 13°C, plates were read after only 5 days.

Statistical Analysis

Data were analyzed by analysis of variance. Significance was predetermined at $P < 0.05$ and pairwise mean comparisons were performed using Fisher's Protected Least Signficant Difference. All embryo survival percentage data were arcsine transformed prior to analysis to stabilize the variances (Ott 1984).

RESULTS AND DISCUSSION

Daily formalin treatments at 1,667 mg/L for 15 minutes from eye-up to just prior to swim-up produced a 5 % increase in embryo survival (Table 1). Most of the mortality in the non-formalin treated trays occurred prior to hatch. These results are nearly identical to those seen in similar experiments from 1993, 1994, and 1995 (Barnes et al. 1997).

Saprolegnia spp. were identified as the prevalent fungus in the hatchery water system. The fungus is ubiquitous throughout the hatchery water supply. Water samples taken from the well next to the hatchery contained *Saprolegnia* spp., as did samples from the aeration tower and incubation headbox.

Table 1. Mean (+ SE) percent mortality from inland chinook salmon eyed eggs either treated with formalin and no manual removal of dead eggs, treated with formalin in addition to dead egg removal, or just receiving manual picking (no formalin treatments) (N = 2). Means in the same column followed by different letters are significantly different (P < 0.05).

Treatment	Hatch Mortality	Swim-up Mortality	Total Mortality
Formalin	6.9 ± 0.4 z	2.6 ± 0.4	9.5 ± 0.7 z
Formalin ± Manual Picking	6.0 ± 0.5 z	3.4 ± 0.1	9.4 ± 0.1 z
No Formalin (Picking Only)	10.5 ± 0.3 y	3.9 ± 0.7	14.4 ± 0.9 y

Our attempt at developing a fungal population census method failed. *Saprolegnia* spp. first appeared in the petri dishes after 6 days of incubation at 11°C. While the first observations of infection indicated that 60 to 90% of the hemp seeds harbored fungal growth, by the next day 100% of the seeds were infected. No possibility existed to develop a population index based on the number of seeds infected.

Bacterial populations were highly variable. The four water samples taken from the well next to the hatchery averaged 10 ± 8 CFU/0.1 mL and two samples taken from the aeration tower averaged 12 ± 8 CFU/0.1 mL. Mean readings from five incubation headbox samples were 21 CFU/0.1 mL.

No significant differences were detected in bacterial populations between pre-formalin and post-formalin treatments (P = 0.2907). A significant interaction (P = 0.0186) between sampling time (pre- or post-treatment) and sampling date was observed however. This interaction is evident in Table 2, with mean CFU/0.1 mL generally increasing after the 15 minute formalin treatments on the first sampling date, but decreasing on the second sampling date.

Bacterial population levels did not appear to fluctuate diurnally during normal incubation. Samples taken at 7:30 averaged 54 + 9 CFU, while samples taken at 15:30 averaged 69 + 33 CFU. Significant differences were detected however, when the trays were removed from the incubator for hand-picking and then re-inserted in the incubator stack (P = 0.0001). Table 3 illustrates the increase in CFU/0.1 mL observed during the second and third sampling periods, incubation days 47 and 53. These two days correlate with the initiation and near-end of hatching. Picking trough bacterial levels averaged 34 (+ 14) CFU prior to egg picking, and 400 (+ 71) after egg picking. No differences were observed between any of the formalin treatments (formalin only, formalin plus picking, no formalin) before or after hand-picking (P = 0.485).

Elevated bacterial levels during hatching were also observed by comparing first of the morning samples from incubation day 29 (next day after auto-picking) through day 53 (only fry present in the trays). A peak of 84 (+ 14) CFU/0.1 mL occurred during the peak of hatching activity (Table 4). The two samples taken during hatching were significantly different than the samples taken dur-

Table 2. Mean ± SE) number of bacterial CFU per 0.1 mL of water collected from incubator trays containing chinook salmon eggs either treated with formalin and no manual removal of dead eggs, treated with formalin in addition to dead egg removal, or just receiving manual picking (no formalin treatments). Sampling occurred both before and after any formalin treatments on two separate dates (N = 2).

Incubation day	Sampling time	Formalin only	Formalin + picking	No formalin (picking only)
29	Before	10 ± 8	11 ± 8	18 ± 11
29	After	7 ± 4	49 ± 46	58 ± 53
39	Before	70 ± 12	64 ± 12	64 ± 14
39	After	21 ± 5	9 ± 12	18 ± 13

Table 3. Mean (± SE) number of bacterial CFU per 0.1 mL of water collected from incubator trays containing chinook salmon eggs sampled before and after manual egg removal (N = 6). Means followed by different letters are significantly different ($P < 0.05$).

Incubation day	Sampling time (before/after hand picking)	CFU
39	Before	30 ± 5 z
39	After	29 ± 5 z
47	Before	67 ± 22 z
47	After	133 ± 27 y
53	Before	21 ± 8 z
53	After	313 ± 42 x

Table 4. Mean (± SE) number of bacterial CFU per 0.1 mL of water collected from incubator trays containing chinook salmon eggs sampled from auto-picking (eye-up) through hatching (N = 6). Means followed by different letters are significantly different ($P < 0.05$).

Incubation Date	Embryo Development	Colony Forming Units
29	Eyed Egg	13 ± 4 z
39	Hatching	66 ± 5 y
47	Hatching	84 ± 15 y
53	Sac Fry	21 ± 8 z
57	Sac Fry	6 ± 2 z

ing the eyed-egg and fry stages (P = 0.0001). The increase in bacterial numbers during this time is probably because of the nutrients liberated during rupture of the external egg membrane at hatching (Bell et al. 1971; Smith et al. 1985; Barker et al. 1989).

Despite our inability to determine fungal population levels, important information was obtained during this initial investigation. Fungal populations were identified as *Saprolegnia* spp., and these organisms were found to be present even in the hatchery wells. This is not surprising, since these water molds are known to survive in all types of aquatic environments and moist soils (APHA et al. 1989).

The mechanism by which formalin is producing an increase in egg survival is still unclear. Until a suitable fungal population estimation technique is developed, the impact of formalin on *Saprolegnia* spp. zoospores and microscopic hyphae will be difficult to determine. Our hypothesis that formalin is decreasing fungal levels is likely wrong however. The presence of *Saprolegnia* spp. in the incubation water supply ensures that the incubating eggs must deal with possible infection continually, except during the 10 minute formalin treatments. Even if formalin reduced incubation water fungal populations during treatment, the incoming water would quickly provide additional *Saprolegnia* spp. zoospores for possible re-infection (Rand and Munden 1993). Therefore, it is much more likely that formalin is either preventing zoospore germination or somehow removing any microscopic hyphae that may have attached to the external egg membrane (Smith et al. 1985), or possibly changing the structure of the external egg membrane.

Results from this year of the study seem to indicate that bacteria populations were unaffected by formalin treatments. However, just as with water molds, the source water just reintroduced bacteria into the incubation trays immediately after the formalin treatments ended. If bacteria are responsible for the elevated mortality associated with non-formalin treatments, then formalin could again possibly be working by possibly removing attached bacteria from the external egg membrane (Barnes et al. 2000b).

Additional information was gained beyond just the possible influence of formalin on microbial populations. Hatching, with the release of the embryo from the chorion, produced an elevated level of bacteria. This population spike was not the result of a large number of prematurely hatching embryos, since the formalin treated trays, with their minimal premature hatch, also experienced the same spike as the non-formalin trays. The large increase in CFU/0.1 mL noted during hand-picking is something that could likely be controlled by changes in culture technique. Frequent removal of the organic material (eggs/fry/shells) from the picking trough during a day of picking may be one mechanism to decrease the bacterial loads that the trays carry back into the incubators.

The results from this initial study indicate the need for additional research into fungal and bacterial levels during salmonid egg incubation, as well as investigation into the anti-microbial action of formalin.

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INFLUENCE OF HATCH TIMING AND DAILY GROWTH RATE ON SIZE STRUCTURE OF AGE-0 LARGEMOUTH BASS COHORTS IN ENEMY SWIM LAKE, SOUTH DAKOTA

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ABSTRACT

Hatch timing can influence growth and survival of age-0 largemouth bass *Micropterus salmoides* populations and has not frequently been analyzed for largemouth bass in northern natural lakes. This study describes hatching events of age-0 largemouth bass in Enemy Swim Lake, a glacial lake in north-eastern South Dakota during 2000-2002, and determined the potential effects of hatch timing and daily growth rates (mm/d) on size of age-0 largemouth bass collected in late summer seine hauls. Hatching occurred between May 20 and July 7; mean hatch date ranged from May 30 to June 11, indicating that peak hatching generally occurred between late May and mid June. Mean hatch dates were significantly different among all years; differences ranged from 5 to 11 d. On average, largemouth bass grew 0.76 mm/d (N = 93; SE = 0.01) and daily growth rates did not significantly differ among years. A significant negative correlation (r = -0.50, df = 25, P = 0.01) existed between hatching date and daily growth rate for age-0 largemouth bass in 2002, indicating that earlier-hatched bass exhibited faster growth than later-hatched individuals. Significant relations between hatch date and daily growth were not apparent in 2000 and 2001. Multiple regression modeling indicated that hatch date and daily growth explained nearly all of the variability in total length (TL) of age-0 largemouth bass captured in August seine hauls (R^2 > 0.97); the amount of variation explained by each independent variable varied across years. Hatch timing did influence TL of age-0 largemouth bass as reported in other studies; however, variation in daily growth played an important role in regulating TL attained by age-0 largemouth bass and was not always related to hatch timing. Among-year variability in daily growth of age-0 individuals should be considered in future studies of population dynamics and recruitment patterns in largemouth bass populations.

INTRODUCTION

First year survival of age-0 largemouth bass *Micropterus salmoides* may regulate relative abundance of young of the year bass populations (Goodgame and Miranda 1993; Ludsin and DeVries 1997; Post et al. 1998). Previous research has investigated the influence of hatching date on size dependent mortality of age-0 largemouth bass (Goodgame and Miranda 1993; Kohler et al. 1993; Ludsin and DeVries 1997; Post et al. 1998; Sammons et al. 1999). Sammons et al. (1999) found that earlier hatched largemouth bass had increased survival during the first year of life in one Tennessee reservoir. Conversely, Kohler et al. (1993) found that survival of age-0 largemouth bass was not related to peak hatching date in an Illinois reservoir. Additionally, Fuhr et al. (2002) determined that abundance of age-1 largemouth bass was related to the density of age-0 bass prior to their first winter, regardless of their size. Ludsin and DeVries (1997) found four factors that were critical to age-0 largemouth bass survival: hatching date, the shift to a piscivorous diet, autumn lipid accumulation, and first winter mortality. Goodgame and Miranda (1993) suggested that length advantages exhibited by earlier-hatched individuals persisted throughout the growing season. Earlier-hatched largemouth bass may become piscivorous at a younger age and sustain higher levels of piscivory throughout the growing season than their later hatched counterparts (Phillips et al. 1995), resulting in improved lipid accumulation and increased winter survival (Ludsin and DeVries 1997). Differences in survival probabilities between faster and slower growing fish of the same cohort become more pronounced by factors influencing competition and predation (Coutant and DeAngelis 1983). Hence, daily growth rate may also affect age-0 largemouth bass survival because fish that grow faster may achieve greater total lengths than slower growing members of the same cohort.

The purpose of our study was to estimate the hatching date and calculate daily growth rates for largemouth bass from Enemy Swim Lake, South Dakota. Additionally, we evaluated the effects of hatch date and daily growth on size structure of age-0 largemouth bass prior to their first winter.

STUDY AREA

Enemy Swim Lake is an 884-ha (mean depth = 4.8 m, maximum depth = 10.0 m) natural lake of glacial origin located in the prairie pothole region of northeastern South Dakota in Day County. Enemy Swim Lake has been described as mesotrophic to eutrophic (Stueven and Stewart 1996). Submergent and emergent vegetation coverage in late summer is near 30% with silt composing the majority (55%) of the substrate (Blackwell 2001). The fish community of Enemy Swim Lake includes black crappie *Pomoxis nigromaculatus,* largemouth bass, smallmouth bass *Micropterus dolomieu,* yellow perch *Perca flavescens,* bluegill *Lepomis macrochirus,* pumpkinseed *Lepomis gibbosus,* common carp *Cyprinus carpio,* white bass *Morone chrysops,* northern pike *Esox lucius,* walleye *Sander vitreus,* white sucker *Catostomus commersoni,* johnny darter *Etheostoma nigrum,* black bullhead *Ameiurus melas,* rock bass *Ambloplites rupestris,* and spottail shiners *Notropis hudsonius.*

METHODS

Collection

Age-0 largemouth bass were collected in seine hauls (15.3-m long, 6.4-mm bar mesh) from Enemy Swim Lake during the first week of August from 2000 to 2002. Twenty-four sites were sampled annually to capture age-0 largemouth bass. Sample sites were chosen randomly and remained fixed throughout the study. All bass captured within each seine haul were identified to species and age-0 largemouth bass were measured (total length; TL) to the nearest mm.

Laboratory Analysis

Sagittal otoliths were removed, using techniques described by Schmidt and Fabrizio (1980), from randomly selected age-0 largemouth bass for hatch date estimation. After removal, sagittal otoliths were wiped clean and allowed to air dry in numbered vials for 2 weeks prior to enumeration of daily rings. One whole otolith from each age-0 largemouth bass was secured to a microscope slide using a small amount of cyanoacrylic cement (Miller and Storck 1982). Otoliths were viewed using a compound microscope (400x magnification) that projected images to a television monitor to aid in the enumeration of daily rings. Three separate counts (per otolith) were made by one individual reader and average daily ring counts were used in estimating hatch date. Some otoliths were lightly polished with wetted 1000-grit sand paper and immersion oil was used to improve clarity.

Hatching Date

Miller and Storck (1982) determined from laboratory analysis that age-0 largemouth bass were 7- to 8-d old at swim-up. Thus, hatch date estimations were calculated using the following equation:

hatch date = day of capture – (average daily ring count + 7 d).

Daily growth

Prior research indicated that total length of age-0 largemouth bass at swim-up was approximately 5 mm (Miller and Storck 1982). Therefore, the following equation was used to determine daily growth rates (mm / d) over the period from swim-up until time of capture in August seine hauls:

daily growth = (TL at capture – 5 mm) / average daily ring count.

Statistical Analyses

Relative abundance of age-0 largemouth bass among years was described using mean catch per unit effort (CPUE; catch per seine haul). Mean hatch dates, mean TL, and mean daily growth rates were compared among years using analysis of variance (ANOVA) and multiple comparisons were made using

Bonferroni procedures (α = 0.05). The relationship between daily growth and hatching date was evaluated for each year using Pearson correlations. For individual years, stepwise multiple regression was used to determine the relative importance of hatch date and daily growth in explaining variation in TL of age-0 largemouth bass collected in August.

RESULTS AND DISCUSSION

The mean CPUE of age-0 largemouth bass ranged from 1.18 (SE = 0.3) to 3.4 (SE = 2.7) among years, and August seining length-frequency distributions were unimodal in nature (Fig. 1). Mean TL of age-0 largemouth bass ranged from 45 to 55 mm across years (Fig. 1); mean TL in 2002 (45 mm) was significantly lower than in 2000 and 2001 (55 mm; $P < 0.05$). Similarly, Toneys and Coble (1979) reported mean total lengths of 52.7 mm ± 9.7 mm for age-0 largemouth bass captured during the fall in Thomas Lake, Wisconsin. Keast and Eadie (1985) recorded comparable total lengths (37 mm – 63 mm) for age-0 largemouth bass in Lake Opinicon, Ontario collected in September.

Hatching dates of age-0 largemouth bass occurred from May 20 (day 140) until July 7 (day 187) with mean hatching date ranging from May 31 (day 151) to June 11 (day 162; Figure 2). Over the course of the evaluation, hatching duration in Enemy Swim Lake ranged from 24 to 44 d. Sammons et al. (1999) found that largemouth bass in Normandy Reservoir had hatch durations of 35 to 68 d, while Phillips et al. (1995) reported that bass captured in a 64-ha embayment of B. Everett Jordan Lake, North Carolina hatched over a 70-d period. Extended hatching windows could be caused by protracted spawning periods for largemouth bass that may be attributed to local weather, changes in water temperature, or interspecific competition (Schmidt and Fabrizio 1980). Additionally, hatch date distributions of age-0 largemouth bass in Enemy Swim Lake were generally unimodal (Fig. 2); however a 15-d gap occurred in hatch date distribution dur-

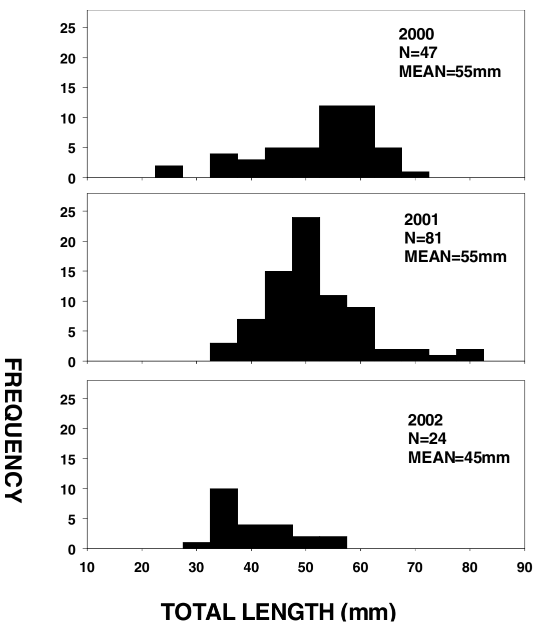

Figure 1. Length-frequency distribution for age-0 largemouth bass captured during August seine hauls in Enemy Swim Lake, South Dakota from 2000 to 2002.

ing 2000, where a small proportion of fish (14%, 5 of 30) hatched between June 10 (day 162) and June 15 (day 177). Mean hatching dates were significantly different among years (F = 17.67; df = 2, 90; P = 0.0001). Multiple comparisons revealed that mean hatch date occurred significantly later in 2000 and 2002 than in 2001 (7-12 d later; $P < 0.05$); mean hatch date did not significantly differ between 2000 and 2002.

Mean daily growth rate of age-0 largemouth bass in Enemy Swim Lake over the 3-year period was 0.76 mm/d (SE = 0.01). Phillips et al. (1995) found similar daily growth rates, ranging from 0.51 to 1.04 mm/d for age-0 largemouth bass captured in North Carolina. Mean daily growth rate did not significantly differ among years and ranged annually from 0.74 (SE = 0.03) to 0.80 (SE = 0.03) mm/d. Daily growth rate was negatively related to hatch date in 2002 (r = -0.50, df = 25, P = 0.01; Fig. 3), indicating that earlier hatched age-0 largemouth bass tended to experience faster growth than later hatched fish from that cohort. Similarly, Goodgame and Miranda (1993) found that earlier hatched age-0 largemouth bass experienced faster growth rates and attained greater total lengths by

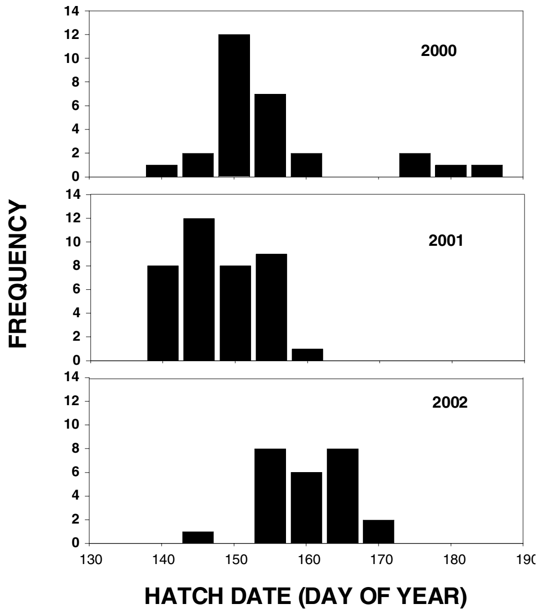

Figure 2. Hatch date distributions for age-0 largemouth bass collected during August seine hauls in Enemy Swim Lake, South Dakota from 2000 to 2002.

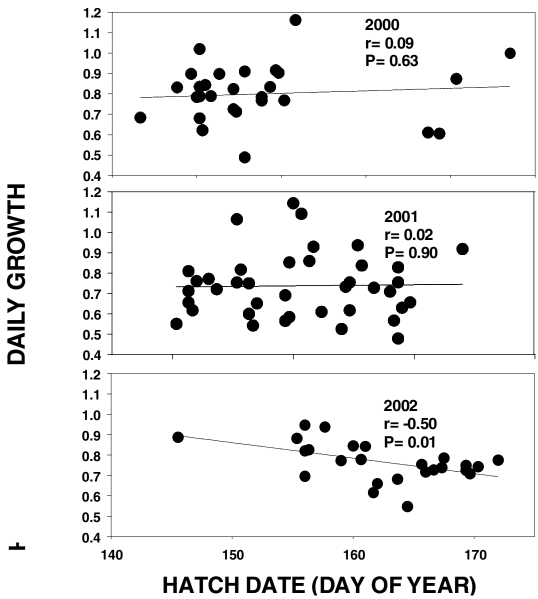

Figure 3. Daily growth rate as a function of hatching date for age-0 largemouth bass that were sampled during August seine hauls in Enemy Swim Lake, South Dakota from 2000 to 2002.

time of collection than later hatched bass of the same cohort. However, no significant relations between daily growth and hatch date for age-0 largemouth bass were detected in 2000 or 2001 (Figure 3).

Hatch date and daily growth rate explained > 97% of the variation in TL of age-0 largemouth bass collected in August seine hauls ($R^2 > 0.97$; P = 0.0001) in all three years. Based on partial coefficients of determination (r^2), hatch date explained the majority of the variation in TL (r^2 = 0.50-0.76; P = 0.0001) in regression models for 2000 and 2002, with daily growth rate explaining the remaining variation in the model (r^2 = 0.24-0.48; P = 0.0001). However, in 2001 daily growth rate explained over 80% of the variability in TL of age-0 largemouth bass collected in August (r^2 = 0.81; P = 0.001) with hatch date explaining the remaining variability (r^2 = 0.19; P = 0.0001). Multicollinearity may have existed between hatch date and daily growth in 2002 based on the significant correlation between these two variables that year.

Our study indicated that hatch date and daily growth determined total length attained by age-0 largemouth bass by time of capture in August. Because age-0 largemouth bass survival can be length dependent, bass that have faster growth rates and hatch earlier may achieve a larger total length during their first growing season and could be less vulnerable to predation (Goodgame and Miranda 1994), have lower overwinter mortality (Miranda and Hubbard 1994; Post et al. 1998), and have greater ability to shift to a piscivorous diet sooner than others of the same cohort (Phillips et al. 1995). Therefore, hatching date and daily growth rate could influence the relative abundance of age-1 largemouth bass.

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IDENTIFICATION OF GROUND AND SURFACE WATER INTERFACE PARAMETERS IN A FAULT-CONTROLLED ALLUVIAL VALLEY

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ABSTRACT

A perennial spring forming a tributary to Battle Creek in the Black Hills was studied to determine controls on both shallow and deep water sources. Characteristics defining the interface between these sources are poorly understood but are integral to development of a tenable water supply. Seismic reflection has indicated a large fault extending to the basement, potentially cutting the Mississippian Madison Group aquifer. Alluvial deposits consist of interbedded gravel and silt and overlie the Triassic Spearfish formation. Gypsum beds in the upper Spearfish formation dissolve forming conduits for surface runoff to infiltrate into coarse-grained alluvial beds that are in hydraulic connection with the stream channel. Thus, a mixed spring source seems likely. Six piezometers were installed up- and downstream of the spring and monthly water table measurements have been made. Observed water levels have remained steady at each location and are unaffected by precipitation. Shallowing of the water table proceeds southward from five to zero meters at the spring representing the decrease in surface elevation in the down valley direction. The subsurface water table gradient is low, much less than the land surface, and the intersection of these 2 features results in the spring. Analysis of these data have suggested that deep-sourced water rises through the brecciated rock along the fault to the surface due to artesian pressure within the underlying aquifers. This deep source provides a continuous supply that is enhanced by flow through the dissolution features and shallow gravels in wet precipitation years.

Keywords

Shallow aquifers, water table, faulted aquifers

INTRODUCTION AND GEOLOGIC SETTING

Availability of tenable water supplies are a major concern for livestock owners/managers throughout the arid west. Changing climate and seasonal variability result in the uncertainty of maintaining traditional water supplies such as surface stock dams and shallow wells in alluvial aquifers. Current options are hauling water to stock tanks or constructing pipelines to convey water from source to the point of use.

Research described below was conducted ~5 miles west of Hermosa, South Dakota on a tributary stream to Battle Creek (Fig. 1) and was in the Hayward, SD 7.5 minute quadrangle. The immediate study area was located within a north-south trending alluvial valley bounded on the west and east by pine-forested uplands having a maximum relief of approximately 400 feet on the east. The western edge of the area consisted of outcrops of the upper section of the Permian-Triassic Spearfish formation dipping ~10° SE. The Spearfish consists of clay with scattered interbedded sandy lenses and characteristically contains a gypsum-rich member near the top. To the east, the upper Spearfish formation outcropped at the base of a hogback ridge consisting of Jurassic and Lower Cretaceous rocks (primarily sandstone, shale, and interbedded thin calcareous units). The ridge top was formed by the Inyan Kara Group sandstone and interbedded clays. Locally, dips in the Inyan Kara Group ranged between 7° and 28° SE. The central floor of the valley was capped by recent alluvial deposits derived both from fluvial (stream) and alluvial (landslides and debris flows) processes.

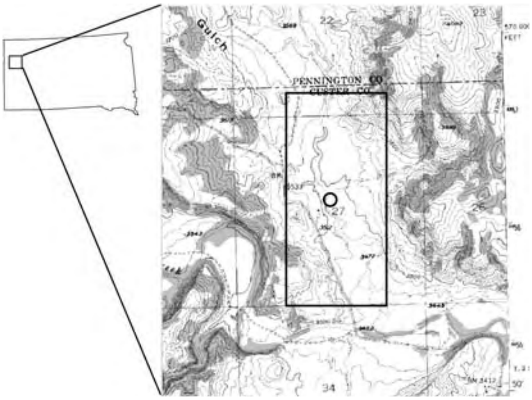

Figure 1. Site location map for the present study. Figure is a portion of the Hayward, SD 7.5 minute topographic quadrangle map. The area enclosed by the box is the approximate region of the study focusing on water resources development and the circle is the approximate location of the spring. The forested western and eastern sides of the map are inclusive of the geologic description given in the text.

Observed geologic structures in the immediate area are limited to several NW-SE trending faults. These faults are most prominent on the Inyan Kara hogback ridge to the east and can be tentatively traced to the western side of the valley. No visible expression of faulting was observed within the alluvial valley.

Of potential importance to regional water-flow patterns within the area was the presence of the Gypsum Springs member of the Spearfish formation. Gypsum deposits, common in the upper part of the Spearfish formation, outcrop on the east and west side of the alluvial valley. The presence of gypsum in this valley, as in other parts of the Black Hills, indicate potential for preferential dissolution and redirection of surface runoff and shallow ground water flow and may have immediate importance to water flow within this valley. Dissolution may occur under 2 formats: 1) within the Gypsum Springs member proper and from dissolution of blocks of gypsum that were moved down slope incorporated within alluvial debris. Several small dissolution basins (10's of feet in diameter) were observed in the valley alluvium suggesting dissolution occurred below the gravel layers.

A perennial spring having a flow rate of approximately 30 gallons per minute was located in the center of the alluvial valley (circle shown in Fig. 1). According to the spring classification system of Meinzer (1923), this spring is a fifth-order spring, defined from having a discharge between 0.3 and 3 gallons per second. The spring was bounded on both the west and the east by the Spearfish formation. The presence of a spring in an open valley consisting of Spearfish formation bedrock was somewhat anomalous. Satellite images suggest a perennial water course has remained in place below the spring source even in low precipitation years. Anecdotal evidence indicates that live water has, in past years, moved in an up valley direction but live water has not moved below the spring. A well-developed surface channel system extended for at least 1 mile upstream, suggesting flowing water has occurred at least sporadically throughout the past.

STUDY METHODS AND RESULTS

Seismic refraction and reflection methods were used to determine depth to the water table and the tops of underlying formations. It was also determined from geophysical analysis that several faults cross the main valley floor below the surface alluvial materials and are hidden from direct observation. One of these faults cuts through all rock units overlying the Precambrian basement rocks, including the Madison, Minnelusa, and Minnekahta aquifers.

Depth to water table was confirmed by installation of 7 piezometers (shallow observation wells) above and below the spring. Four wells (numbers 1-4) were located in or near to the dry channel above the spring. These locations were selected to provide optimum water table monitoring. Three additional wells (numbers 5-7) were located downstream of the spring. Well 5 was located east of the stream in the center an abandoned oxbow and about 9 feet higher in elevation than the active channel. Well 7 was located at the south end of the oxbow on the edge of an alluvial fan. Well 6 was installed immediately west of the stream about _ mile from well 5.

These wells were all installed using a hand-operated auger drilling rig housed in the Department of Geology & Geological Engineering at SDSM&T. This drill has the ability to penetrate up to 30 feet of alluvium with a 3" auger. The wells were completed using 1.5" PVC where the bottom 3 to 8 feet was slotted. Sand was placed around the slotted section and the hole was topped with bentonite clay. A 4" diameter riser and cap was placed over the end of the well pipe and sealed with bentonite.

Monthly water table measurements are being made from each piezometers. The observed water table history is shown in Table 1. In general, water levels have remained steady at each location and the shallowing of water depth between wells 1 and 4 represent the decrease in surface elevation in the down valley direction. The subsurface water table gradient is low, much less than the land surface, and the intersection of these 2 features results in the spring.

Table 1. Water levels measured in piezometers in feet below the surface.

Well #	Mar-03	Jeb-03	Jan-03	Nov-02	Oct-02	Sep-02	Sep-02	Aug-02
1	16.13	16.27	16.13	15.94	14.82	15.74	15.71	15.61
2	11.57	11.57	10.65	10.68	11.24	10.52	10.42	10.29
3	8.31	8.31	8.08	7.89	8.51	7.82	7.89	7.66
4	5.65	5.62	5.45	5.29	5.85	5.16	5.26	10.52
5	4.24	4.70	4.99	5.03	-	5.29	4.17	-
6	7.43	7.78	7.49	7.46	7.72	7.43	7.33	-
7	7.89							

Well bailers were constructed and used to bail out water from the wells allowing the water recovery to be measured. These results provide the hydrologic connectivity of the materials immediately surrounding the well bore. Hydraulic conductivity is the ability of a unit of aquifer material to transmit a unit of water; the higher the hydraulic conductivity value, the greater the water yield (Fetter, 1988). Initial bail tests showed very poor to no recovery after being bailed dry suggesting plugging of aquifer materials. Well stimulation was used to clear the aquifer interface using hydraulic flushing. After this process, each well showed extremely high aquifer connectivity that would be expected from coarse gravel material. Equipment is currently being designed to enable collection of data from the rapid recovery rates and, thus, the determination of hydraulic aquifer properties.

INFILTRATION AND SINKHOLES

Figure 2. Large sinkhole in the alluvium. The opening is 5 feet in diameter and is 6 feet deep.

Gypsum has apparently dissolved at numerous locations within the valley forming low depressions to open sinkholes (Fig. 2). These areas are able to collect and store runoff water and allow time for it to infiltrate into the alluvium below. Once there, the water flows toward the stream providing an increased discharge from other than a spring. Mapping of sinkholes and characterization of the dissolution processes are ongoing.

SUMMARY

From the data analyzed thus far, it appears that the spring has mixed source waters. The majority of the water is upwelling from bedrock aquifers through fracture systems such as that identified using geophysical methods and described above. This upwelling water is most likely augmented by shallow alluvial aquifers that are climatically dependent. The shallow alluvial aquifer(s) could feasibly have several sources such as: through-flow from runoff on the hogback ridge through numerous alluvial fans located along the slope margin; gypsum sinkholes (at or near the surface) that are in hydrologic connection with subsurface gravel layers and alluvium; and flow (both surface and subsurface) through the watershed surface drainage system (Fig. 3). Based on observations within the cut bank of the stream bed and from monitor well drilling logs, the stream gravels appear to be thin, 3-15 inch lens of coarse material that fines upward. Several gravel layers may be present in any location and are separated by variable thickness clay layers. The shallow aquifer(s) store, and act as conduits for, meteoric and artesian water.

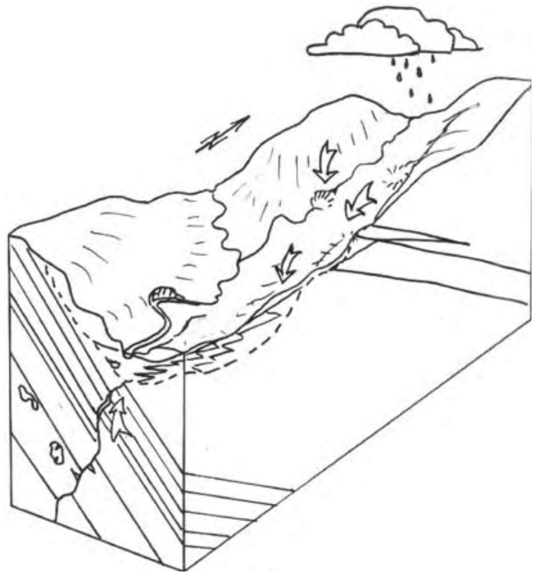

Figure 3. Conceptual diagram for the summary of processes leading to the spring or direct increases in streamflow. Upwelling from deep sources occurs along fault lines (arrow on from panel) while surface runoff and infiltration through sinkholes during precipitation periods (arrows on upper slope).

ACKNOWLEDGEMENTS

We would like to acknowledge Dr. Paul Wright for allowing us access to his land to perform these studies. Financial support has been in the form of a grant from the SD Department of Game, Fish, and Parks and a financial gift from Dr. Paul Wright.

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REAL-TIME FUZZY LOGIC COMPUTATIONS

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ABSTRACT

Traditionally digital systems and electronics have been based on Boolean algebra and binary numbers. It is, however, possible to utilize fuzzy set theory in digital applications, especially for control applications in consumer electronics and other real-time systems. Fuzzy logic has been used effectively to handle nonlinear systems. In order to accelerate the operation of fuzzy logic systems we have developed hardware chips that allow direct computation and manipulation of fuzzy set membership functions, fuzzy set operators, fuzzification, fuzzy associative matrices, and center of area defuzzification. Unlike software implementations of fuzzy set theory, the computational architecture we have designed allows all fuzzy logic computations to be performed completely in parallel and in real-time.

Keywords

Fuzzy Logic, Fuzzy Set Theory, Control Systems

INTRODUCTION

Traditional electrical and mechanical control systems are based primarily on systems of differential equations. Nonlinearities in the systems have always been a problem. One solution is to make linear approximations for a specific operating point. However, the complexity and performance demands of today's systems are making this increasingly difficult to accomplish. Another approach has been to digitize the systems and use various digital signal processing techniques. These tend to be computationally intensive solutions and performance depends on the sampling frequency of the system as well as the computational abilities of the processors used to perform the Fast Fourier Transform calculations that often involve floating-point calculations of complex numbers.

A separate train of thought for control systems has been developing for a number of years based on fuzzy logic and fuzzy set theory developed by Zadeh

(Zadeh, et. al. 1992). The fuzzy approach to linear and nonlinear control systems eliminates the use of differential equations and transforms the problem into a largely algebraic problem. Most fuzzy controllers developed up to this point have all been implemented as software programs on standard computing or embedded systems platforms. Instead of using typical linear programming methods, we have developed a custom processor architecture that performs the fuzzy computations and control in a parallelized method.

One of the key concepts in fuzzy systems is to determine the degree of membership a variable has to various elements of a fuzzy set. In a traditional Boolean set the membership or nonmembership of a variable to a particular portion of the set is described by a characteristic function $\mu_A(x)$, where

$$\mu_A(x) = 1, \text{ if } x \in A, \text{ and}$$
$$\mu_A(x) = 0, \text{ if } x \notin A.$$

In a fuzzy set, however, partial memberships are possible, and the value of membership is a real valued number between 0 and 1 inclusive, i.e.

$$\mu_A(x) = [0.0,\ 1.0].$$

The distinction between Boolean and fuzzy sets can be more easily understood with Figures 1 through 3. Figure 1 illustrates that all values of height which are less than 182.5 cm have a degree of membership of 1.0 to the category "Short" and no membership to the category "Tall". Heights greater than 182.5 cm have no membership to category Short and full membership to category Tall. Thus, a person with a height of 182 cm is classified as 100% Short and 0% Tall. Similarly, a person with a height of 183 cm is 100% Tall and 0% Short. However, in the fuzzy system of Figure 2 a person with height 183 cm is both Short and Tall. Figure 3 shows more specifically that such a person would be classified as 0.4 Short and 0.6 Tall. The triangular membership functions shown are rather arbitrary. Other types of fuzzy membership functions such as trapezoids can be used. The particular shapes, slopes, and ranges of the fuzzy membership functions have to be determined by an expert which is why fuzzy logic is generally considered to be part of the field of artificial intelligence.

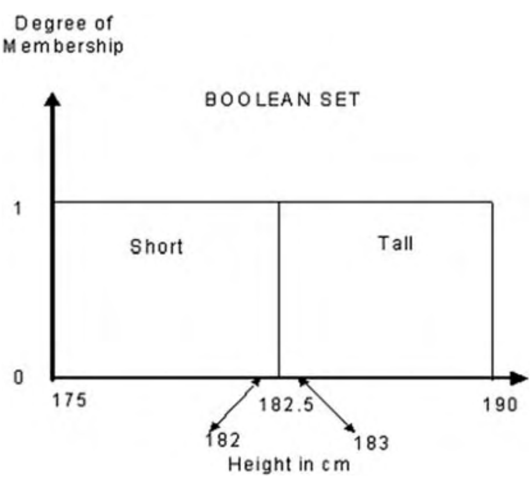

Figure 1. Graphical representation of the membership functions of a Boolean set.

METHODS

The fuzzy control approach generally has three stages: fuzzification, rule evaluation, and defuzzification. For fuzzification, one or more "crisp" inputs are sampled by the system and then categorized or fuzzified using the various fuzzy membership functions to describe how much the input belongs to each element of the system's fuzzy set. An example application would be a greenhouse humidity control system. In this case, the actual relative humidity could be measured as well as the current difference between actual and desired humidity. Figure 4 shows the five membership functions that apply to the fuzzification of relative humidity. The sample data point illustrates that 64% relative humidity gets fuzzified as 0.5 Humid and 0.7 Normal (it should be noted that it is not necessary for the sum of memberships to be 1.0). Figure 5 shows the five membership functions for error in relative humidity and that a humidity error of –4% is fuzzified as 0.4 Negative Low and 0.6 None.

Based on the current inputs' degrees of membership in each of the fuzzy set members, a series of rules is evaluated to determine what the fuzzy output should be. Sometimes the

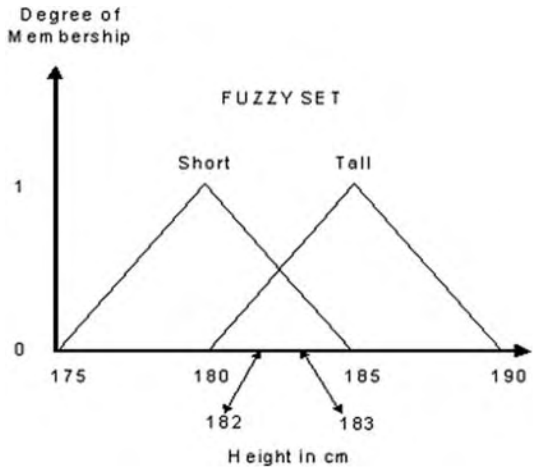

Figure 2. Graphical representation of the membership functions of a fuzzy set.

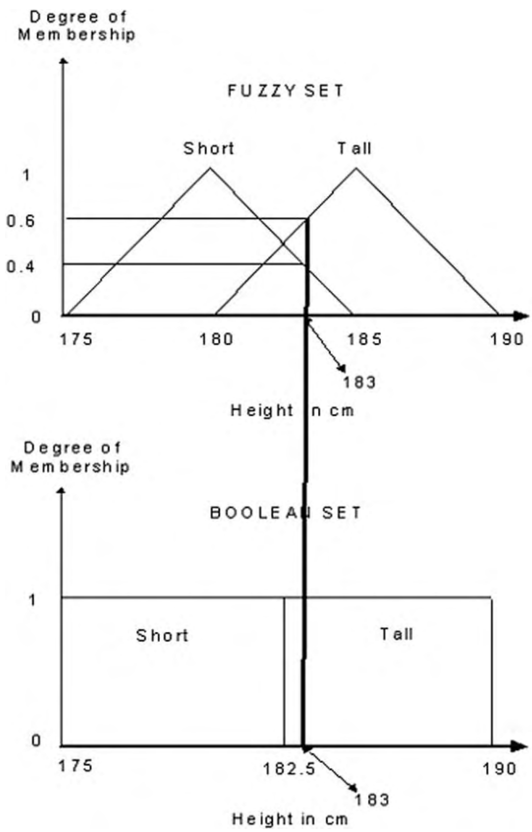

Figure 3. Graphical comparison of the classification of height in a Boolean set to the fuzzification of height in a fuzzy set.

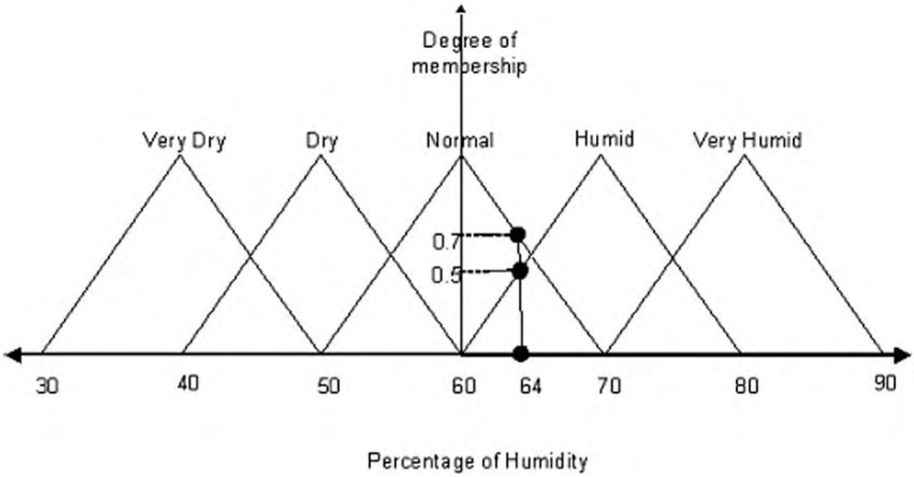

Figure 4. Graphical representation of the five membership functions for the crisp input of relative humidity. Shown is the fuzzification of a sample input value of 64% relative humidity into the two membership functions Normal and Humid. Here, the value of relative humidity fuzzifies into 0.7 Normal and 0.5 Humid.

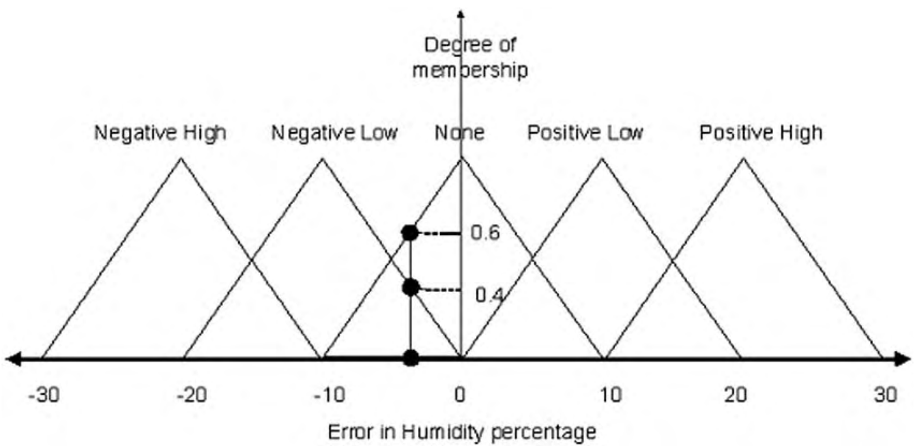

Figure 5. Graphical representation of the five membership functions for the crisp input of error in relative humidity. Shown is the fuzzification of a sample input value of –4% error in relative humidity into the two membership functions Negative Low and None. Here, the value of error in relative humidity fuzzifies into 0.4 Negative Low and 0.6 None.

rule evaluation is viewed as a series of IF-THEN statements similar to what are used in expert systems. However, it is more common to summarize the rules in a fuzzy associative matrix as seen in Figure 6. The evaluation of a rule in the fuzzy associative matrix leads to the generation of a fuzzy output. A rule evaluation can occur at every intersection of row and column. Looking at Figure 6, if the humidity is Dry and the error in humidity is Negative Low then there should be a Highly Positive output (the output being the injection of water mist into the greenhouse). Or for example, if the humidity is Normal and the error in humidity is None then the output should be Zero. We arbitrarily choose the numerical value of fuzzy output membership to be the minimum of the degree of memberships of the fuzzified inputs as illustrated in Figure 7. Since the input(s) can belong to one or more membership functions, usually several rules in the fuzzy associative matrix are triggered and have to be evaluated and thus lead to several simultaneous fuzzy outputs. In this example the humidity is both Humid and Normal and the error in humidity is both Negative Low and None so four rules in the

	Neg. High	Neg. Low	None	Pos. Low	Pos. High
Very Dry	PH	PH	PH	PL	ZE
Dry	PH	PH	PL	ZE	NL
Normal	PH	PL	ZE	NL	NH
Humid	PL	ZE	NL	NL	NH
Very Humid	ZE	NL	NH	NH	NH

Figure 6. The fuzzy associative matrix for rule evaluation in the humidity control example. The rows of the matrix correspond to the membership functions for fuzzified relative humidity. The columns of the matrix correspond the membership functions for fuzzified error in relative humidity. The elements of the matrix are the fuzzy outputs. The various fuzzy outputs are: PH – Positive High, PL – Positive Low, ZE – Zero, NL – Negative Low, and NH – Negative High.

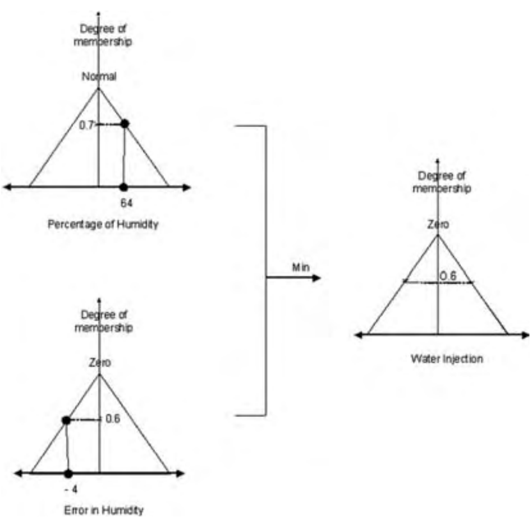

Figure 7. Graphical representation of how the rule evaluation for two fuzzified inputs maps to the corresponding value of fuzzy output. Here, the combination of Normal relative humidity and None error in relative humidity evaluates to a value of 0.6 in the fuzzy output membership function of Zero.

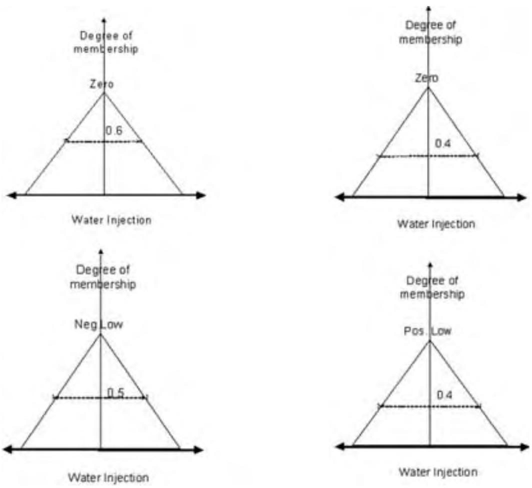

Figure 8. Graphical representation of the four fuzzy output memberships obtained after rule evaluation for sample inputs of 64% relative humidity and –4% error in relative humidity.

fuzzy associative matrix are triggered and result in the four fuzzy output memberships shown in Figure 8.

The various fuzzy outputs have to be combined into a single "crisp" output (occasionally, multiple crisp outputs are created for certain systems using the same crisp inputs). This conversion is called the defuzzification process. Several techniques have been developed to calculate the defuzzified output. We have chosen to use the Center of Area method where the defuzzified output is found by

$$Output = \frac{\sum_{i=1}^{N} A_i * C_i}{\sum_{i=1}^{N} A_i} \quad \text{(Equation 1)}$$

where N is the number of fuzzy output membership functions, A_i is the active area of each output membership function triggered by the rule evaluation, and C_i is the center of the output membership function. The application of Equa-

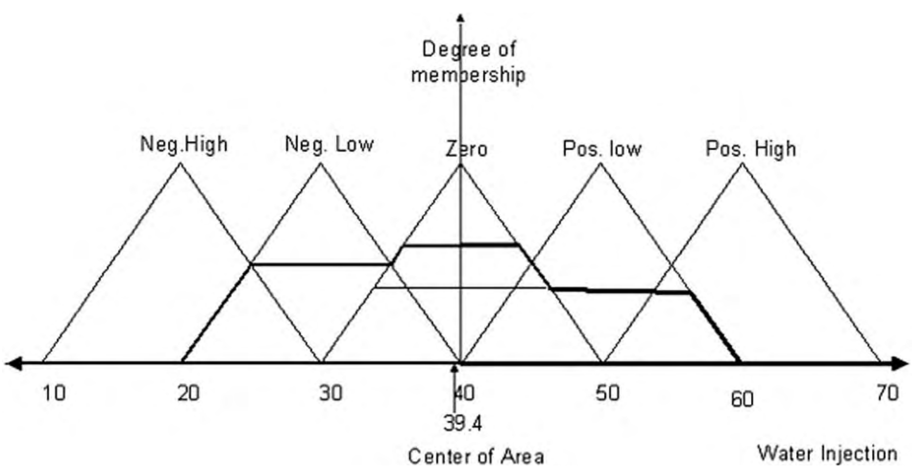

Figure 9. Graphical representation of defuzzifying the four fuzzy output memberships in the humidity control example. The center of area for the four fuzzy outputs from Figure 8 is a crisp output value of 39.4 for the water injection level.

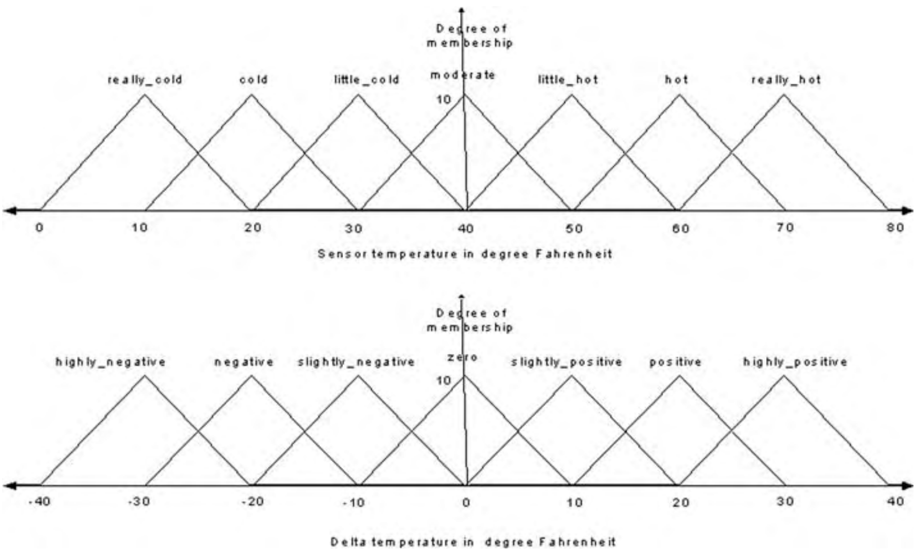

Figure 10. Graphical representation of the seven membership functions for each of the crisp inputs of temperature and error in temperature.

tion 1 to the humidity example results in a water injection output with a crisp value of 39.4 as illustrated graphically in Figure 9.

To demonstrate the ability to parallelize the fuzzy operations in hardware we have implemented a temperature control system using the membership functions shown in Figure 10 for fuzzification, the fuzzy associative matrix shown in Figure 11 for rule evaluation, and the Center of Area method for defuzzification. The actual defuzzified output goes to a separate motor interface circuit to regulate the fan speed on a ventilation system. The details of the arithmetic circuitry and the motor interface will be dis-

	HN	N	SN	ZE	SP	P	HP
Real Cold	VC	VC	VC	NO	LH	H	VH
Cold	VC	VC	C	NO	LH	H	VH
Little Cold	VC	VC	C	NO	LH	H	VH
Mod erate	VC	C	C	NO	H	H	VH
Little Hot	VC	C	LC	NO	H	VH	VH
Hot	VC	C	LC	NO	H	VH	VH
Real Hot	VC	C	LC	NO	VH	VH	VH

Figure 11. The fuzzy associative matrix for rule evaluation in the temperatuve control system. The rows of the matrix correspond to the membership functions for fuzzified temperature. The columns of the matrix correspond the membership functions for fuzzified error in temperature. These values are: HN – Highly Negative, N – Negative, SN – Slightly Negative, ZE – Zero, SP – Slightly Positive, P – Positive, and HP – Highly Positive. The elements of the matrix are the fuzzy outputs. The various fuzzy outputs are: VC – Very Cold Air, C – Cold Air, LC – Little Cold Air, NO – No operation, LH – Little Hot Air, H – Hot Air, VH – Very Hot Air.

Figure 12. Experimental setup of prototype temperature controller with test equipment.

cussed elsewhere (Hemmelman, et. al., 2003). The prototype circuit is shown in Figure 12.

RESULTS

A custom fuzzy processor designed specifically for parallelizing the calculations required for fuzzification, rule evaluation, and defuzzification has been designed and implemented in a Field Programmable Gate Array (FPGA). The fuzzy set membership functions, the fuzzy associative matrix, and the Center of Area formula for the temperature control system were all successful hardwired into the processor. Testing of the chip on various inputs has demonstrated that the proper motor interface output signal is generated by the processor. The delay time for the fuzzy computations is strictly a matter of combinational logic propagation delay so real-time control is readily achievable.

CONCLUSIONS

Fuzzy logic and fuzzy set operations have been successfully hardwired into a custom processor that parallelizes the calculations allowing for real-time operation of a control system. This has been demonstrated in a temperature control application. However, the fuzzy processor design is suitable for any fuzzy control application.

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ERROR CORRECTION OF CORRUPTED DATA USING A REDUNDANT RESIDUE NUMBER SYSTEM

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ABSTRACT

Data communicated by wired or wireless methods is subject to being corrupted from a variety of sources. When data is corrupted the errors not only need to be detected, but also they also need to be corrected so the data returns to its original and useful form. We have developed a technique that uses redundant residue number systems and the maximum likelihood principle to create an error detection and correction scheme that has the ability to detect up to R errors and correct up to R-1 errors if R redundant residues are used. The error correcting abilities of this approach have been demonstrated in hardware communication systems.

Keywords

Number Theory, Residue Number Systems, Information Theory, Communication Systems

INTRODUCTION

All electronic systems can be affected by various sources of noise and interference. This noise and interference can corrupt the signals and information that the electronic circuitry is manipulating. In digital electronic systems, the information is in the form of bits with the familiar values of '0' and '1'. Collections of bits are organized and used for various control, communication, and computational purposes. When the bits become corrupted by noise, the system may fail to correctly perform its assigned task. We have developed a technique based on the number theory of redundant residue number systems and the Maximum Likelihood Principle to allow for the detection and correction of corrupted digital data. For data encoded using R redundant residues, this method can detect up to R errors and correct up to R-1 errors. This error correction technique has been demonstrated in hardware communication systems.

METHODS

Unlike a fixed-radix system where a number is completely specified by stating the single fixed radix or base, in the residue number system the base does not consist of a single radix but instead consists of a number of integer moduli, m1, m2, m3, …, mN. The range of numbers that can be represented using this moduli set is then given by $\prod_{i=1}^{N} m_i$. Any given number to be represented then is defined by the residue set obtained after applying each of the moduli to the number. For example, consider a moduli set {m1, m2, m3}. Then a fixed radix number X would be represented by the residue set {r1, r2, r3} where r1 = X mod m1, r2 = X mod m2, and r3 = X mod m3.

For error detection and correction it is necessary that the moduli set is a set of relatively prime numbers. Here, relatively prime means that each modulus does not have to be a prime number itself but that amongst the moduli in the set the only common factor is one. The entire moduli set will now contain nonredundant and redundant moduli for the purposes of error detection and correction. The actual number can be represented by just the residues obtained using the nonredundant moduli. The product of just the nonredundant moduli now defines what is called the legitimate range, and the product of the entire moduli set now defines the illegitimate range.

As an example, the moduli set {5, 7, 8, 9, 11, 13} can be used where the subset {5, 7, 8} contains the nonredundant moduli and the subset {9, 11, 13} contains the redundant moduli. The legitimate range is thus 280, and the illegitimate range is 360360. For instance, the decimal number 220 then would be represented as the residue set {0, 3, 4, 4, 0, 12}. The subset {0, 3, 4} contains the nonredundant residues, and the subset {4, 0, 12} contains the redundant residues. This residue representation is what can then be used in a control or computational system or transmitted in a communication system.

When it is time to check if a computation was performed correctly or transmitted data was received properly, a reverse conversion of the residue set is made using the Chinese Remainder Theorem (Szabo, et. al. 1967). To reconstruct the original number from the residue set, first compute

$$M_i = \frac{M}{m_i} = \frac{\prod_{i=1}^{N} m_i}{m_i}. \quad \text{(Equation 1)}$$

So, using just the nonredundant moduli {5, 7, 8} from the above example yields

$M_1 = m_2 * m_3 = 7 * 8 = 56$,
$M_2 = m_1 * m_3 = 5 * 8 = 40$, and
$M_3 = m_1 * m_2 = 5 * 7 = 35$.

Next K_i is computed where K_i is the smallest positive integer multiple of M_i such that $(K_i * M_i) \bmod m_i = 1$. For the nonredundant moduli {5, 7, 8}, $K_i = 1$, $K_2 = 3$, $K_3 = 3$. Note that the values of M_i and K_i are independent of the specific residues for any given encoded number. They depend only on the moduli set and thus are fixed values once the moduli set is chosen. Finally, the original data can be computed as

$$X = \left(\sum_{i=1}^{N} M_i * \left[(K_i * r_i) \bmod m_i \right] \right) \bmod M , \qquad \text{(Equation 2)}$$

where r_i are the residues for the specific data being converted.

For the decimal number 220 which has nonredundant residues {0, 3, 4} corresponding to the nonredundant moduli {5, 7, 8} the conversion is calculated as

$$X = \{(56 * [(1 * 0) \bmod 5]) + (40 * [(3 * 3) \bmod 7]) + (35 * [(3 * 4) \bmod 8])\} \bmod 280$$

$$X = [(56 * 0) + (40 * 2) + (35 * 4)] \bmod 280 = (80 + 140) \bmod 280 = 220 .$$

A mixture of nonredundant and redundant residues will also produce the original data. As an example, if the residue subset of {0, 3, 4, 4} corresponding to the moduli subset of {5, 7, 8, 9} for the decimal number 220 is used, the new values of M_i and K_i are found to be $M_1 = 504$, $M_2 = 260$, $M_3 = 315$, $M_4 = 280$, $K_1 = 4$, $K_2 = 5$, $K_3 = 3$, $K_4 = 1$. The Chinese Remainder Theorem then yields

$$X = \left\{ \begin{matrix} (504 * [(4 * 0) \bmod 5]) + (360 * [(5 * 3) \bmod 7]) + \\ (315 * [(3 * 4) \bmod 8]) + (280 * [(1 * 4) \bmod 9]) \end{matrix} \right\} \bmod 2520$$

$$X = 2740 \bmod 2520 = 220$$

If one of the residues is corrupted by noise or an electrical fault, the redundant residue number system proposed has the ability to detect the error and correct it. In the previous example, perhaps the residue subset of {0, 3, 4, 4} has been corrupted into the values {3, 3, 4, 4} (i.e. r1 has been changed from the correct value of 0 to the erroneous value of 3). The conversion process then yields

$$X = \left\{ \begin{matrix} (504 * [(4 * 3) \bmod 5]) + (360 * [(5 * 3) \bmod 7]) + \\ (315 * [(3 * 4) \bmod 8]) + (280 * [(1 * 4) \bmod 9]) \end{matrix} \right\} \bmod 2520$$

$$X = 3748 \bmod 2520 = 1228 .$$

However, the value 1228 is outside the legitimate range of 280 so the presence of the error has been detected.

The Maximum Likelihood Principle can now be applied to actually correct the error and obtain the original data (Premkumar, et. al. 2002). Additional combinations of nonredundant and redundant residues are formed. Each combination can then be converted using the Chinese Remainder Theorem. The value within the legitimate range that appears the most often will be the correct value of the original data. Continuing with the previous example where residue r1 for the decimal number 220 was corrupted into the erroneous value of 3, the additional residue combinations of $\{r_1, r_5, r_6\} = \{3, 0, 12\}$, $\{r_2, r_5, r_6\} = \{3, 0, 12\}$, $\{r_3, r_5, r_6\} = \{4, 0, 12\}$ can be created. Conversion using the Chinese Remainder Theorem yields the values X = 363, X = 220, X = 220 for the residue sets $\{r_1, r_5, r_6\}$, $\{r_2, r_5, r_6\}$, $\{r_3, r_5, r_6\}$ respectively. As 220 appears the greatest number of times it is known to be the correct original data.

RESULTS

A custom processor architecture designed specifically for pipelining and parallelizing the calculations required for this error detection and correction technique has been designed and implemented in a Field Programmable Gate Array (FPGA). The specific moduli set implemented was the set {5, 7, 8, 9, 11, 13} that was used in this paper's discussion. Testing of the chip on various data sets with and without errors has demonstrated that it does indeed detect and correct errors that exist in received residue sets. Only four clock cycles are needed by the chip to detect and correct an error.

CONCLUSIONS

A pipelined and parallelized computer chip has been developed that allows for the automatic detection and correction of corrupted data using redundant residue number systems and the Maximum Likelihood Principle. All testing of the design indicates that the chip's computations match the theoretically predicted results. Moreover, if data has been corrupted, the error can be corrected in only four clock cycles helping to increase the transmission rate of a communication system that uses this design.

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AN OREODONT OF MIOCENE AGE FROM SLIM BUTTES, HARDING COUNTY, SOUTH DAKOTA

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ABSTRACT:

The later Tertiary deposits of the Slim Buttes area have yielded relatively few fossils compared to the Oligocene and earlier strata. The lithostratigraphic unit that predominates the upper levels has generally been mapped as Arikaree (?) Formation and presumed to be of Miocene age, but evidence that could give a more detailed correlation is sparse. Presumably a detailed investigation of this unit could lead to a proposal of a local lithostratigraphic name, and associated paleontologic work could yield biostratigraphic and chronostratigraphic correlations.

One well-preserved mammalian fossil from this unit has recently been identified. It is a left dentary with essentially all premolars and molars, referable to *Merychyus* cf. *arenarum* Cope. This oreodont species is indicative of Hemingfordian (approximate Miocene) age.

Keywords

Oreodont, South Dakota, Miocene

INTRODUCTION

Many geologic investigations took place in the Slim Buttes area of northwestern South Dakota during the Twentieth Century. Economic evaluations, notably for coal, resulted in detailed mapping of Harding County and vicinity (Winchester et al.,1916; Denson et al., 1955; Moore and Gill,1955). Later studies focused on the wealth of vertebrate fossils that were found in the strata of Eocene and Oligocene ages (Bjork, 1967, Lillegraven, 1970). Overlying formations, generally mapped as Arikaree (?)Formation and presumably of later Tertiary age (Fig. 1), received little attention, inpart because prospecting in the upper levels had been relatively unproductive. Bjork (1967) noted only two fossils, both presumably Miocene, from the Arikaree (?) Formation in the entire region. There have been relatively few investigations in recent years, and it is to be hoped that the discovery of at least one significant specimen from these strata at Slim Buttes will revive interest in the area.

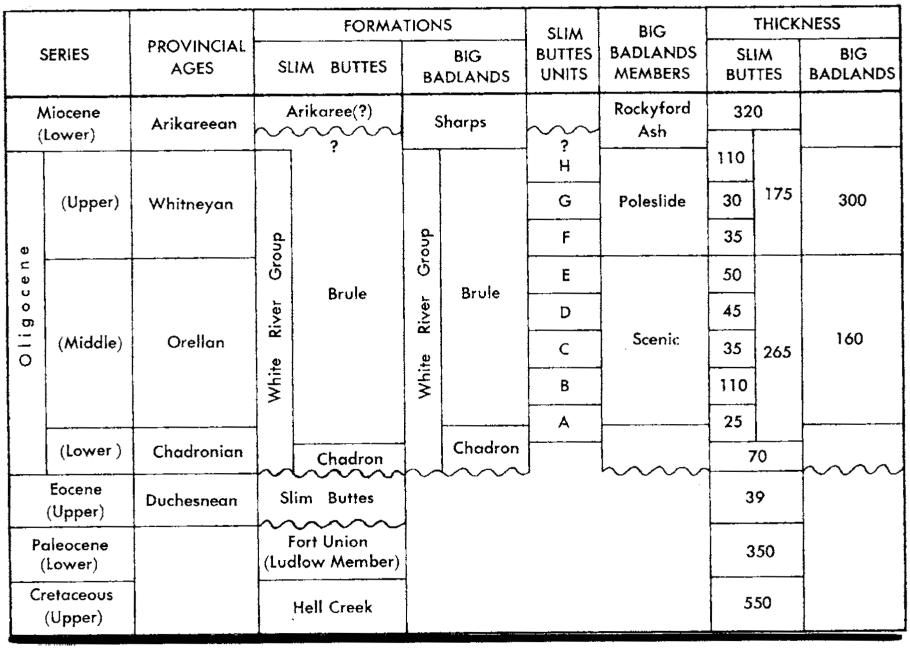

Figure 1. Stratigraphy of Slim Buttes and correlatives as established by Lillegraven (1970), with thicknesses in feet, standard usage then prevailing.

STUDY AREA AND METHODS

The readily accessible Summit Pass area was prospected during a brief expedition in 1988. This is within Township 16 North, Range 8 East, in the Irish Butte 7½ minute Quadrangle. (More specific locality data are on file with the South Dakota School of Mines and Technology and the New Jersey State Museum.) The Arikaree (?) Formation in this area consists of spectacular outcrops of white strata with substantial volcanic ash content. Fossils were collected by surface prospecting; no matrix was collected for microfaunal analysis, such as screening or washing. Fair numbers of bone fragments were found, although such identifiable items as teeth were relatively uncommon. It was hoped that prospecting would at least establish that the strata are bone-bearing, thus encouraging further investigations. Specimens found were prepared by simple physical removal of matrix and impregnation with preservatives. Identifications were made by comparison to museum collections and published literature.

RESULTS

The small collection obtained was sufficient to establish the formation as fossiliferous for permineralized bone. One mammalian specimen was sufficiently well-preserved and had enough diagnostic features to justify a more formal description. It cannot be considered sufficient to establish the age of the formation, but it is somewhat indicative. We describe it herein, anticipating further evidence in collections to be made in the near future.

SYSTEMATIC PALEONTOLOGY

Order Artiodactyla
Family Merycoidodontidae
Subfamily Merychyinae Simpson 1945
Genus *Merychyus* Leidy 1858
Merychyus cf. *arenarum* Cope 1884

Referred specimen: SDSM 62682, major portion of left dentary with all four premolars and all three molars, excepting the posterior portion of the third molar (Figs. 2 and 3).Provenience: Arikaree (?) Formation near Summit Pass, Slim Buttes, Harding County, South Dakota. (Note previous discussion of study area.)

Description/Identification: Shultz and Falkenbach (1947) state that the dentary of *Merychyus* is characterized by "inferior border of ramus more or less straight, slight curve posterior of m3." and "dentition advanced brachyodont to subhypsodont" and by "symphysis prominent, posterior point below region of p3-p4".. These characters are not all observable in the specimen, in which the inferior border is broken away, but comparison of the dentition to previously referred specimens in various museum collections shows consistency with *Merychyus* material generally and the prominent symphysis is exactly as described.

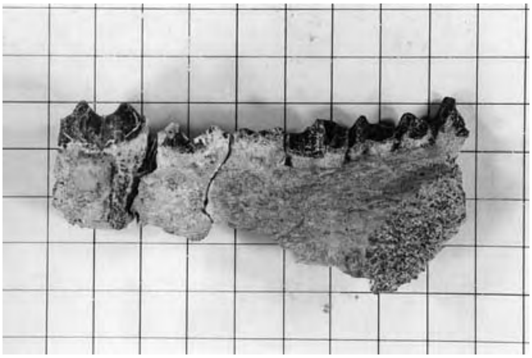

Figure 2. SDSM 62682. *Merychyus* cf. *arenarum* Cope. Left dentary, lingual aspect.

Figure 3. SDSM 62682. *Merychyus* cf. *arenarum* Cope. Left dentary, occlusal view.

We compared this specimen to type material of the type species of the genus, *Merychyus elegans* Leidy, at the United States

National Museum, with results as follows: Comparison to USNM 120 Cotype: Slim Buttes specimen very similar, but larger, the dentition differing mainly by size. The degree of hypsodonty is essentially the same. The third premolar is proportionately more elongate in the Slim Buttes specimen. The anterior crests are straight in both the second and third premolars; They curve lingually in USNM 120. There is also a small postero-lingual accessory crest in the third premolar of the Slim Buttes specimen, a feature absent from both left and right dentitions of USNM 120. The orientation of the premolars compares very closely, having an overlapping "shingled" appearance in occlusal view. The general similarity of the dentition is supplemented by overall similarity of the dentaries with the nutrient foramen beneath the third premolar in each case, and the symphysis very prominent (considered to be a diagnostic feature of the genus). The posterior margin of the symphysis is beneath the anterior edge of the fourth premolar in the Slim Buttes specimen, and slightly more posterior in USNM 120.

Comparison to USNM 121 Type: General similarity in overall shape of dentary and in degree of hypsodonty, however, the Slim Buttes specimen is slightly larger. The premolars are similarly overlapping in occlusal view. The third premolar is again proportionately shorter, with a slightly incurved anterior crest in USNM 121. There is an incipient auxiliary crest in USNM 121 which is more well-developed in the Slim Buttes specimen, but which was lacking in USNM 120, except for a tubercle. Measurements of the dentition in SDSM 62682 are: length p1-p4=37mm ;length p1-m3=85-90mm.

DISCUSSION AND CONCLUSIONS

Comparison of the Slim Buttes specimen SDSM 62682 to specimens of *Merychyus* leaves no doubt that the specimen belongs to that genus. Not only does the specimen conform to all diagnostic features of the genus, but the specimen differs very little from the type material of *Merychyus elegans* Leidy. However, it may be significantly larger than that species. The size range that we interpolate to be true of the dental measurements would fall within the range of *Merychyus arenarum* Cope. That species, originally described from Platte County, Wyoming, has been reported from various localities in the region. As we have not yet compared the specimen to the type material of that species, we refer it to *Merychyus* cf. *arenarum* Cope.

Regardless of what species may be represented, the genus is closely associated with the Hemingfordian Land Mammal Age, and suggests tentative correlation to that time. We recommend further prospecting and collecting in these later Tertiary strata in the Slim Buttes area in order to better establish age correlation and enable regional faunal comparisons. A local lithostratigraphic name may well be justified.

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AN EFFICIENT LOWER JAW REMOVAL TECHNIQUE FOR LARGE MAMMALS

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INTRODUCTION

Knowledge of age-structure of wildlife populations is invaluable to management. State agencies estimate ages of harvested deer at registration stations for use in population modeling (Rupp et al. 2000, Grund 2001). Methods have been developed to age white-tailed deer *(Odocoileus virginianus)* by tooth wear and replacement (Severinghaus 1949) and examining the cementum annuli of front incisors (Sergeant and Pimlot 1959, McEwan 1963, Low and Cowan 1963) or molars (Ransom 1965, Gilbert 1966). Although many studies have examined aging techniques, an efficient technique for removing the lower jaw of a deer has not been described.

By removing the lower jaw of a white-tailed deer, tooth wear (Severinghaus 1949) can be examined and an incisor can easily be removed to determine age using cementum annuli. These two estimates can then be compared and increase the ability to accurately estimate age. We describe an efficient lower jaw removal technique for large mammals.

METHODS

During a radio telemetry study of white-tailed deer in southeast Minnesota, we developed a technique to efficiently remove the lower jaw, while minimizing care and cleaning of the jaw. A scalpel is required to complete the procedure.

The removal technique begins by narrowly spreading the upper and lower jaws enough to slide a scalpel into the mouth. The skin is then cut (Fig. 1) between the upper and lower jaw towards the posterior portion of the head until the blade reaches the posterior portion of the mandible. Once the posterior portion of the mandible is reached, the blade should angle and cut toward the ear (Fig. 2). The skin and muscle tissue should then be cut along both sections of the jawbone to completely expose the bone. At this point, most of the mandible on both sides should be exposed.

The jaw is now spread by placing one hand over the incisors and anterior portion of the lower jaw and placing the other hand over the nose and anterior portion of the upper jaw. The upper and lower jaws should be spread until the coronoid process separates from the temporal fossa and the mandibular condyle separates at the mandibular fossa (Fig. 3). The mandible can now be held by the coronoid process and pulled forward away from the skull (Fig. 4). To prevent cracking the jaw, it is important to not squeeze together the two sides of the lower jaw while pulling the jaw away from the head. The skin will pull away from the bone to where it connects with the jaw just below the base of the lower incisors. The skin can then be cut and the lower jaw removed from the head (Fig. 5). Using this method, the jaw will be relatively clean of tissue once removed (Fig. 6). Some minor trimming may be necessary if muscle tissue remains on the jaw. Alternative methods of removing excessive tissue such as cleaning by beetles (Hall and Russel 1933, Borell 1938, Russell 1947), chemicals (e.g. Alconox, Aloconox, Inc.), or boiling is not required.

DISCUSSION

This method is simple and efficient. Once the jaw is removed little or no work is required to prepare the jaw for aging or as a lab specimen. This technique worked well for our study because it could be accomplished in the field at the site of the carcass, thus the entire deer carcass or head does not need to be collected. Our study area contained rugged terrain and removing the whole carcass was not practical.

Also, having known-age jaw specimens can have great value in an academic or management setting. Students can learn to estimate age of big game by looking at the teeth of known-age specimens. Managers can use known age jaws to review characteristics prior to hunting season. Universites are still instructing undergraduate and graduate students on the Severinghaus (1949) method, although tooth wear may not be the most reliable aging method (Gee et al. 2002).

ACKNOWLEDGEMENTS

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Figure 1. Cutting skin between the upper and lower jaw of a white-tailed deer to prepare the jaw for aging or lab specimen.

Figure 2. Continuing to cut along lower jaw to the temporal fossa of a white-tailed deer to prepare the jaw for aging or lab specimen.

Figure 3. Spreading upper and lower jaws exposing the coronoid process of a white-tailed deer to prepare jaw for aging or lab specimen.

Figure 4. Removing lower jaw of a white-tailed deer by pulling from back to front to use jaw for aging or lab specimen.

Figure 5. Cutting skin at base of lower incisors of a white tailed deer for aging or lab specimen.

Figure 6. Completely removed lower jaw of a white-tailed deer.

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FOOD HABITS OF BIG BROWN BATS *(EPTESICUS FUSCUS)* IN SIOUX FALLS, SOUTH DAKOTA

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ABSTRACT

Food habits of *Eptesicus fuscus* in Sioux Falls, South Dakota were described. Six hundred and twenty bats were collected from the South Dakota Department of Health in 2000 and 2001. Of these 620, only 56 bats had identifiable contents in the stomach. The stomach contents were examined with a dissecting microscope and insect parts were identified by comparing the contents to a reference collection of insects collected in South Dakota (Borror and White, 1970). Four orders of insects were identified: Coleoptera (beetles), Hemiptera (true bugs), Diptera (flies) and Lepidoptera (moths). Carabidae (ground beetles) occurred at an occurrence frequency of 29.1%, followed by unidentifiable insects (18.2%), Lepidoptera (12.2 %), unidentified Coleoptera (7.3%), Pentatomidae (stinkbugs) (7.3%), Diptera (1.8%), and hairballs (5.3%).

Keywords

Big brown bats, food habits, South Dakota, Department of Health, Coleoptera, Lepidoptera, Pentatomidae, Diptera, stomach contents

INTRODUCTION

All bats that reside in eastern South Dakota are insectivorous (Nowak, 1994). Knowing what insects these bats prey upon is an important step towards bat conservation. Dietary studies of bats are important because these animals devour agricultural pests such as corn root worm beetles *(Diabrotica* spp.) (Whitaker, 1995), which are one of the most serious crop pests in the United States (Krysan and Miller, 1986). If studies can show that bats consume enough of these agricultural pests to make a significant impact, then bats can possibly be considered as a biological control agent, deserving further conservation efforts.

In particular, ground beetle (Carabidae) parts were found in greater frequency than other families of insects (Whitaker, 1972). *Eptesicus fuscus* have large powerful jaws that allow them to feed more effectively on the hard bodies of beetles (Freeman, 1981). In northeastern Kansas, Scarabaeidae (scarab beetles), Carabidae (ground beetles), and Pentatomidae (stink bugs) were found in the stomachs of E. fuscus (Phillips, 1966). In Indiana, Scarabaeidae, Carabidae, and Pentatomidae were found in the stomachs of E. fuscus, along with Formicidae (ants), Ichneumonidae (ichneumon wasps) and Lepidoptera (moths) (Whitaker, 1972).

In 2000 and 2001, over 600 bats were collected throughout the state for rabies testing (South Dakota Animal Disease Research and Diagnostic Laboratory Report, 2000). A majority (98%) of the submitted bats were E. fuscus collected from Sioux Falls, Minnehaha County. After testing, the carcasses are usually destroyed. However, during 2000 and 2001, all bats that tested negative for rabies were saved and stomach contents of these E. fuscus were documented to formulate a baseline for the diet of E. fuscus in South Dakota.

MATERIALS AND METHODS

In 2000 and 2001, 620 bat carcasses were received by the Animal Disease Research and Diagnostic Laboratory at South Dakota State University for rabies testing. After testing, the rabies negative carcasses were transferred to our lab. Measurements such as forearm length, total length, ear length, tail length, total body length, mass, and sex and reproductive condition were taken on each carcass. Then, if any insect remains appeared in any of the stomachs, the stomachs were removed and the contents were identified.

Of the 620 bats, only 56 proved to have any stomach contents. These stomachs were preserved in plastic vials with 75% ethanol until analysis could be performed. Analysis consisted of identifying the stomach contents with a dissecting microscope. Each stomach was removed from its storage container and weighed on an assay scale (± 0.01 g). Then, the stomach was carefully cut open and placed inside a petri dish. The contents were bathed with 75% ethanol until all were removed from the lining of the stomach.

Once all the contents were contained with the petri dish, it was placed underneath a dissecting microscope and any identifiable insect parts were removed. Each petri dish of stomach contents was examined twice, a first sweep to remove any identifiable parts and a second sweep to verify that all applicable parts were removed. These sweeps were performed at different times so as to decrease the amount of human error from eyestrain. All insect parts were compared to a reference collection I made of insects collected in South Dakota. Individual insects from the collection were dissected into smaller parts in order to identify the stomach contents to order, and if possible to family.

RESULTS

Of the 56 stomachs, the contents of 20 stomachs were so mechanically broken down that nothing could be identified. Ten of these were taken from bats in April-September (Table 3.1) and were completely empty. These bats may have been captured after they had already completed the digestive processes, leading to an empty stomach or during the hibernation period when bats are not eating. Stomachs with identifiable contents were taken from bats captured in January through October (Table 3.1).

Of all the identifiable insects parts, over 90% were legs and tarsi, the remaining 10% being pieces of the body cuticle or wings. The mechanical breakdown of the contents by the stomach reduced the ability to accurately identify all the insect parts. Most of what was left either consisted of small anatomical parts such as fragments of a femur, a few segments of antennae, or something totally unidentifiable that looked like insect mush.

Table 3.1: Number of stomachs collected by month, and percentages of identifiable, empty and unidentifiable contents (Department of Health bats from 2000 and 2001)

Month	Number of Bat Stomachs	% Identifiable	% Empty	% Unidentifiable
January	1			100
April	3	33	33	33
May	1		100	
June	7	71	29	
July	7	72	14	14
August	30	74	13	13
September	3	33	33	33
October	3	67		33
November	1			100

Eptesicus fuscus is thought to stop feeding for the year around late October and doesn't feed during the hibernation period (November-March). In Indiana, Whitaker (1972) examined the stomachs of 11 bats during the third week of October and only found one with a full stomach; only one of 178 bat stomachs collected during the hibernation period held any contents. Similarly in South Dakota, only two stomachs with identifiable material were collected in October and only two stomachs collected during the hibernation period held any contents. The stomach contents from the remaining hibernating bats were unidentifiable and looked like they had been in the digestive tract for a long time based on the discoloration and digestion of the material.

Four orders of insects were identified in the stomach contents of E. fuscus from South Dakota: Coleoptera (beetles), Hemiptera (true bugs), Diptera (flies) and Lepidoptera (moths). Of these, the family Carabidae (ground beetles) occurred at a frequency of 29.1%, followed by unidentifiable insects at 18.2%, Lepidoptera at 12.2 %, unidentified Coleoptera at 7.3%, Pentatomidae (stinkbugs) at 7.3%, hairballs at 5.3% and Diptera at 1.8% (Table 3.2). These insects were identified by the size, shape, or design pattern of different anatomical parts. The anatomical parts used to identify the insects to family or order were: tarsi and tarsal claws for Carabidae; tibia and tarsal claws for Lepidoptera; the veins in the wings for Diptera; tarsi and the spotting design on the legs for Pentatomidae; and by elytra or the presence of a hard outer cuticle for unidentified Coleoptera (Borror and White 1970).

Table 3.2: Frequency and percents of stomach contents from all months, South Dakota Department of Health bats, 2000-2001

Insect	Frequency	Percent
Carabidae (ground beetles)	16	29.1
Empty	10	18.2
Unidentifiable insects	10	18.2
Lepidoptera (moths)	7	12.2
Unidentifiable Coleoptera (beetles)	4	7.3
Pentatomidae (stinkbugs)	4	7.3
Hairball	3	5.5
Diptera (flies)	1	1.8

DISCUSSION

Based on the contents of the few stomachs taken from South Dakota Department of Health bats during 2000-2001, E. fuscus does not feed during the winter (November-March) and stops feeding sometime around late October. When feeding does resume in April, Carabidae beetles were consumed more often than other types of insects, similar to the results of a dietary analysis of E. fuscus from Indiana (Whitaker, 1972).

Only the percentages of coleopterans in the stomach contents of South Dakota bats were similar to other studies (Whitaker, 1972, 1995; Phillips, 1966; Hamilton, 1933). Otherwise, the frequencies of insects varied among the diets of E. fuscus in South Dakota to other studies. The percentages of lepidopterans were higher (12.2%) in the South Dakota bats than any other study.

Seasonal variation of insect abundance may account for some of the variability. In Indiana, coleopterans are not quite available in early spring, so bats seemed to rely on other orders. On April 2, lepidopterans made up 12.7% and dipterans 9.1% of the feces collected in the maternity colonies; while on May 3, coleopterans made up almost 100% (Whitaker, 1995). Analysis of the stomach contents of the bats from South Dakota did not reveal any preference of insects by season but most of the stomachs (80%) were collected from bats during the summer season (May-August), thereby limiting my analysis of seasonal trends in food choice.

Much more information is needed on the feeding habits of bats in South Dakota. Continued analysis of the stomach contents of bats collected from the Department of Health will add to the meager knowledge presented here. Also, collecting insects over the spring, summer, and fall seasons and correlating those collections with stomach content analysis may discover a seasonal variation to the diets of E. fuscus and show which insect orders are selected over others.

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STATUS AND DISTRIBUTION OF RIVER OTTERS, *LONTRA CANADENSIS,* IN SOUTH DAKOTA

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ABSTRACT

Currently, river otters *(Lontra canadensis)* range throughout Canada and northern parts of the United States, which constitutes half their historical range. River otters are a threatened species in South Dakota, although their current status and distribution are relatively unknown. We attempted to determine the status and distribution of river otters in South Dakota. To conduct river otter surveys, 14 rivers and 3 creeks were selected throughout South Dakota based on stream size (orders three to seven), water gradient, and water permanence. At each river or creek, line transects and shorelines (below high water mark) were surveyed for river otter sign. In addition, reports were collected from the Natural Heritage Database and landowners, and observation report forms were mailed to state conservation officers collecting their observations. Thirty-four verified and three unverified sightings were recorded during our research. Eighty-nine percent of the sightings were reported in eastern South Dakota, particularly along the Big Sioux River. There may be a small population of river otters residing in the Big Sioux River watershed, which is possibly the result of reintroduction efforts by the Flandreau Santee Sioux Tribe. From our survey efforts, we found no indication of a remnant river otter population in South Dakota, though a small population of reintroduced river otters may reside in the eastern third of South Dakota. Because river otter populations do not likely exist in other areas of the state, efforts should be taken to restore this native animal to South Dakota's river systems.

Keywords

River otter, *Lontra canadensis,* status, distribution, home range, South Dakota, rivers, sightings.

INTRODUCTION

Historically, river otters *(Lontra canadensis)* occupied all major waterways of the United States and Canada (Halbrook, 1978; Hall, 1981; Jones et al., 1983; Lariviere and Walton, 1998). At present, the river otter is abundant in Alaska, most of Canada, the Pacific Northwest, the Great Lakes region, and most states along the Atlantic Coast and Gulf of Mexico (Andelt, 1992). In other states, particularly the Midwest, river otter populations are not faring as well (Halbrook, 1978; Choromanski and Fritzell, 1982; Toweill and Tabor, 1982). Presently, river otters occupy less than 33% of their historical range in the contiguous 48 states (Fig. 1). River otters are protected in 17 states either as a threatened or endangered species (Melquist and Hornocker, 1983).

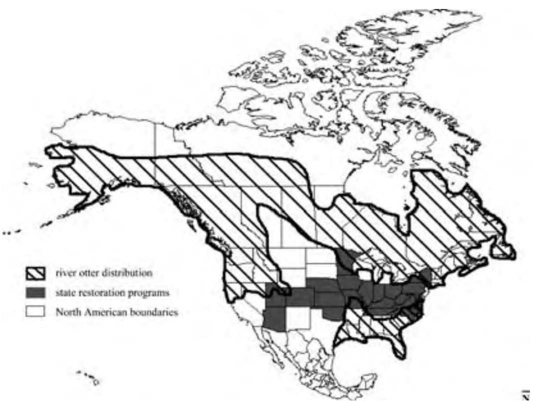

Figure 1. Distribution of river otters in North America (Toweill and Tabor, 1982). Currently, river otters are expanding their range into central areas of the United States, which is the location of state restoration programs.

At one time, river otters inhabited riparian areas and permanent bodies of water throughout South Dakota (Choate and Jones, 1981; Jones et al., 1985). River otters were important furbearers for European trappers and were extirpated from South Dakota's waters due to extensive trapping, loss of habitat, and other human intervention (Over and Churchill, 1941; Choromanski and Fritzell, 1982; Toweill and Tabor, 1982; Jones et al., 1983; Melquist and Hornocker, 1983; Dronkert-Egnew, 1991; Lizotte and Kennedy, 1997; Lariviere and Walton, 1998). More recently, biologists, landowners, and conservation officers have documented occasional sightings of river otters throughout South Dakota. These sightings may be due to river otters dispersing from established populations or from restoration programs in surrounding states, which makes it unclear whether a remnant population of river otters still exists in South Dakota. River otters are a threatened species in South Dakota (Ashton and Dowd, 1991), though the current status and distribution of river otters in South Dakota is relatively unknown. This project was initiated to determine whether a remnant population of river otters exists and to determine the status and distribution of river otters in South Dakota.

STUDY AREA

South Dakota lies in the Northern Great Plains region and is dissected by many rivers, streams, and creeks. Natural ecosystems in South Dakota include northern floodplain forest, tall-grass prairie, mixed-grass prairie, short-grass prairie, and ponderosa pine *(Pinus ponderosa)* woodland. Northern floodplain forests are riparian communities that consist of primarily cottonwood *(Populus deltoides)* and willows *(Salix* spp.). Tall-grass prairies consist of primarily big bluestem *(Andropogon gerardii),* switchgrass *(Panicum virgatum),* and Indiangrass *(Sorghastrum nutans).* Mixed-grass prairies include tall grasses, short grasses (e.g., blue grama *[Bouteloua gracilis]*), and intermediate grasses (e.g., little bluestem *[Schizachyrium scoparium]* and sideoats grama *[Bouteloua curtipendula]*). Short-grass prairies are dominated by species such as buffalograss *(Buchloe dactyloides),* blue grama, needle and thread *(Stipa comata),* and western wheatgrass *(Agropyron smithii).* Ponderosa pine trees dominate the ponderosa pine woodlands with variable undergrowth vegetation (Jones et al., 1985).

To narrow the focus of this research, specific rivers in South Dakota were selected based on three river otter habitat requirements. These characteristics included stream orders three through seven (large rivers or streams) according to the Strahler Order stream order system (Murphy and Willis, 1996), permanent water flow, and low gradient (slower moving waters) (Mack, 1985; Bradley, 1986; Johnson and Madej, 1994; Reid et al., 1994; SDGAP, unpublished report, 2001). Selected stream reaches were the Big Sioux River, James River, Vermillion River, Missouri River, Little Minnesota River, Jorgensen River, North Fork of the Whetstone River, Moreau River, Grand River, Virgin Creek, Cheyenne River, Bad River, Medicine Creek, White River, Little White River, Rapid Creek, and Belle Fourche River (Fig. 2).

METHODS

One to four study sites were selected per study river system. Stream length of the study river system determined the number of study sites. At each study site, we surveyed one habitat transect, which was 50 m long and intersected with six 10 m perpendicular lines every 10 m, for river otter sign. Habitat transects were less than five meters inland from the actual watercourse (Mowbray et al., 1976). We also searched for river otter sign below the high water mark beside each river.

We contacted the South Dakota Natural Heritage Program for information on river otter sightings in South Dakota. The Natural Heritage Database is a sector of the Natural Heritage Program, which serves to inventory and monitor threatened, endangered, and rare species in South Dakota. Furthermore, Indian tribes were contacted for information on reintroduction efforts and river otter sightings within the reservations. Landowners, trappers, and conservation officers provided additional information on river otter sightings within South Dakota.

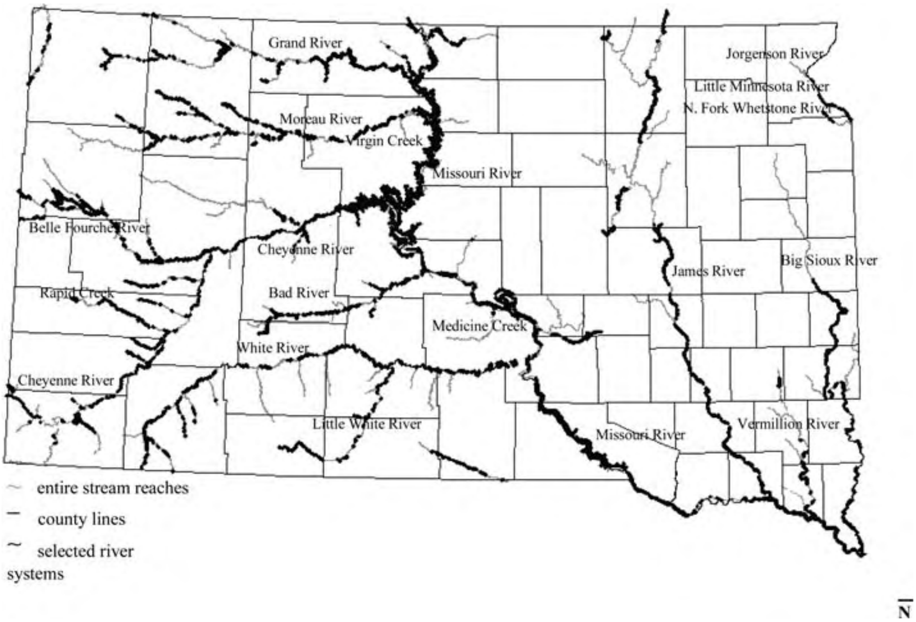

Figure 2. Selected stream reaches in South Dakota with rivers for river otter habitat study sites as determined by permanent water flow, stream orders three through seven, and low gradient.

River otter observation report forms were mailed to all conservation officers in South Dakota. Observation reports were used to record areas within counties where river otters had been sighted and to report detailed information regarding the sighting.

River otter home range and distribution maps were designed using average home range values from other studies. Linear home ranges average 80 km in river systems in Iowa (Andelt, 1992). Polygonal home ranges average 150 km^2 in wetlands and lakes in Canada (Ried et al., 1994). Average home ranges were applied to each river otter sighting, depending on the location, to determine the relative home range and distribution of river otters in South Dakota.

RESULTS

Thirty-four verified and three unverified river otter sightings were recorded prior to and during this study. Of the verified sightings, 12 sightings were reported from 1979 to 2001 to the South Dakota Natural Heritage Database, 20 sightings were received from South Dakota landowners, conservation officers, biologists, and trappers from 1998 to present, and two sightings were found in 2001 during habitat transects surveys (Fig. 3). Footprints were discovered along the Big Sioux River at two locations, Moody and Lincoln counties. In both cases, imprints in riparian zones proximate to water represented river otter sign. Some of the latter verified reports were not reported to the Natural

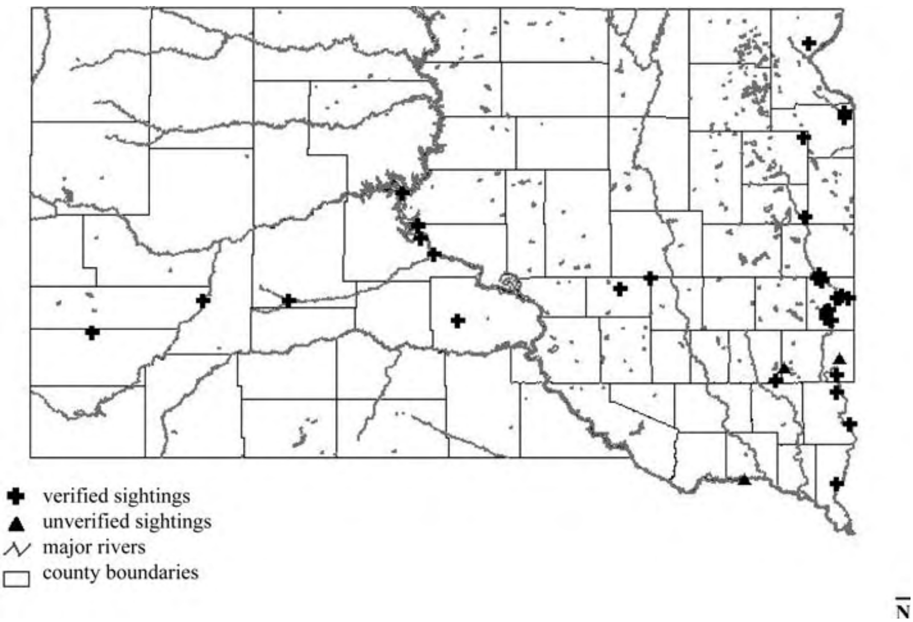

Figure 3. River otter sightings reported to the Natural Heritage Database (1979-2001), by biologists, and the general public.

Heritage Database. Unverified sightings were reported by landowners from 2000 to present.

Eighty-nine percent of the river otter sightings occurred east of the Missouri River (Fig. 4), 76 percent of the sightings occurred in the eastern third of South Dakota (Fig. 5), and 54 percent of the sightings occurred along the Big Sioux River watershed. There likely is a small population of river otters residing along the Big Sioux River, which may be the result of reintroduction efforts by the Flandreau Santee Sioux Tribe. Seventeen river otters were released into the Big Sioux River in 1998-1999 and 1999-2000 (Raesly, 2001; W. Hansen, Flandreau Santee Sioux Tribe, pers. comm.). River otter sightings have persisted for nearly five years, though the released river otters have not been monitored.

DISCUSSION

There was no indication of a remnant population of river otters in South Dakota according to river otter sightings. Only two sightings, which occurred before the late 1980's, may be attributed to river otters from established populations traveling into South Dakota. Each sighting occurred in Hughes County in 1979 and 1983.

The greatest number (20) of river otter sightings occurred in Moody County, near the Flandreau Santee Sioux Tribe. From 1998 to 2000, the Flandreau Santee Sioux Tribe reintroduced 34 river otters into the Big Sioux River near Flandreau, South Dakota, as part of a cultural goal to restore a native species

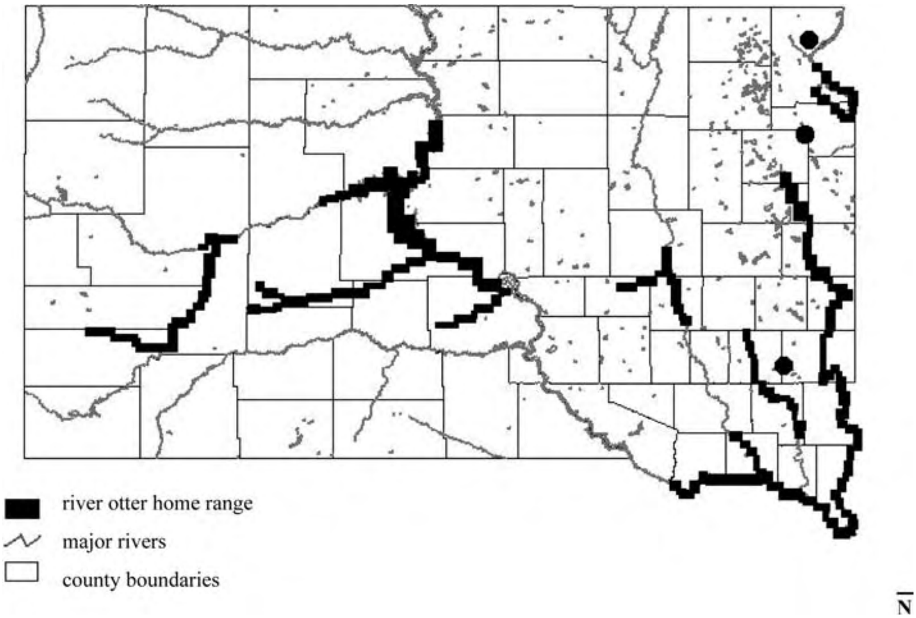

Figure 4. River otter home ranges using average linear home range and polygonal home range values on each river otter sighting. Home range value depends on the location (e.g., wetland or river) of the sighting.

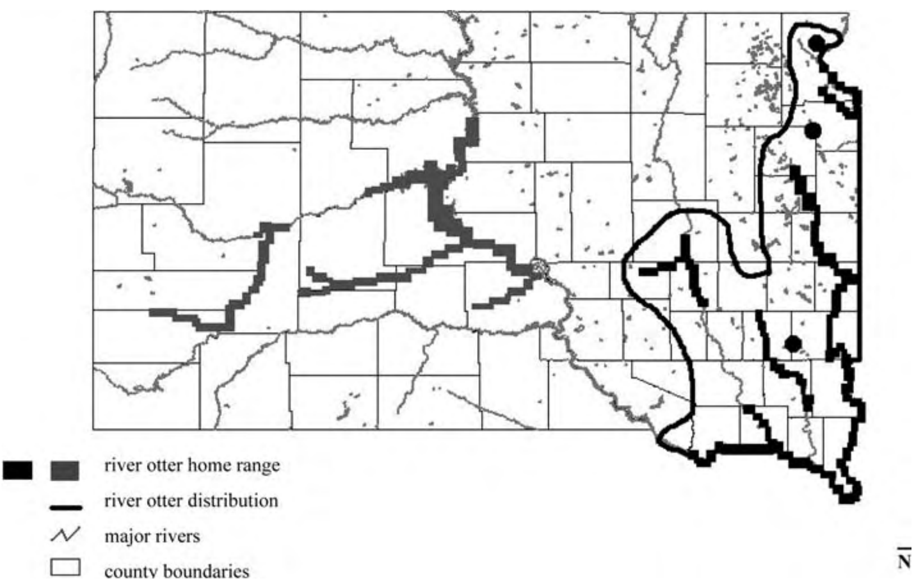

Figure 5. Distribution of river otters in eastern South Dakota as determined by home ranges and number of sightings.

to Tribal Lands (Raesly, 2001). Released river otters were not marked for post-release monitoring, though sightings of river otters have persisted for several years. Sightings of reintroduced river otters along the Big Sioux River during three occasions consisted of groups of three to four river otters. Usually groups of three to four river otters comprise family groups, which consist of the mother and her young. As a result, some reintroduced river otters may have reproduced along the Big Sioux River.

Currently, river otters appear to be distributed primarily in eastern South Dakota along the Big Sioux River. This is likely the result of the reintroduced population. River otters seem to be dispersing westward from the eastern border, which is indicated by the increased number of sightings in east-central South Dakota. Sightings west of the Missouri River are still minimal and probably limited to movements by transient river otters. Whether reintroduced river otters in eastern South Dakota travel west of the Missouri River is unknown.

CONCLUSION

Presently, 20 states in the central United States have or have had river otter restoration programs. As a result, river otters are extending their range into the central region of the United States. Currently, South Dakota Game, Fish and Parks does not have an active river otter restoration program, though efforts have been taken to determine whether habitat is available throughout South Dakota for river otter survival. Future restoration efforts depend on public and professional support as well as the potential for river otters to occupy areas west of the Missouri River. At this time, there may be a small population of reintroduced river otters residing in the eastern third of South Dakota. Whether river otters move further west into other regions of South Dakota remains relatively unknown. In the future, it is hoped that river otters may inhabit all major river systems in South Dakota, as they once did historically. With help from the citizens and biologists of South Dakota, we may be able to restore the threatened river otter to our prairie river systems and help return a unique species to its past range.

ACKNOWLEDGEMENTS

We thank South Dakota landowners, biologists, trappers, and conservation officers for their cooperation and input regarding river otter sightings. Also, we thank South Dakota Game, Fish and Parks for funding my research activities, and South Dakota State University for aiding with this research.

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COMBUSTION SYNTHESIS OF SILICON NITRIDE / SILICON CARBIDE COMPOSITE MATERIALS

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ABSTRACT

Many nonoxide ceramic materials can be synthesized economically and with high purity by a combustion technique. Even complex solid solution, based on silicon nitride structure, could be synthesized by a direct high pressure nitridation of silicon in the presence of other oxides or nitrides. These important materials find application in manufacturing of engine parts, high performance bearings, and cutting tools. This paper focuses on in-situ synthesis of silicon nitride – silicon carbide composites. Silicon carbide/silicon nitride composites exhibit good wear and thermal shock resistance. In this research silicon carbide/silicon nitride composites were synthesized using chemically-assisted combustion technique. During that process composites were formed from elemental silicon and carbon powders in the presence of nitrogen and poly-fluorinated ethylene (teflon). Silicon nitride/silicon carbide composites with the amount of silicon carbide phase varying from 5 to 25 wt% were synthesized using this method. By altering combustion conditions it was possible to synthesize composites with different content of alpha and beta silicon nitride phases. Alteration of those conditions has also a significant effect on average particle size of synthesized composite powders. The effect of silicon carbide composition in combustion synthesized composites on microstructure is presented as well.

Keywords

Chemically enhanced combustion synthesis, Si_3N_4, SiC/Si_3N_4 composites, teflon, ammonium bifluoride.

INTRODUCTION

Silicon nitride/silicon carbide composite materials have their major application as refractory material and as material for structural application (Richerson 2000, Weimer 1997, Weinstein 1991) as automotive valves, high performance bearings, and cutting tools. These materials exhibit a great corrosion resistance and stable mechanical properties at elevated temperatures.
Conventionally, these materials are produced in a reaction sintering process (Eckstroem1993). In the 90's some researchers (Agrafiotis et al. 1991, Puszyn-

ski and Miao 1998) did some pioneering work in the field of the formation of silicon carbide by combustion synthesis. Combustion synthesis can be described as a class of highly exothermic reaction, which become self-sustaining once they are locally ignited by an external force (Liebig and Puszynski 1997, Varma et al.1998). In the case of non oxide ceramic such as TiC, TiN, AlN, Si_3N_4, BN, this synthesis process has proven to be highly effective due to its energy costs, and high purity of the product.

The combustion synthesis of silicon carbide is a two-step process. First Si_3N_4 is formed by combustion of silicon at elevated nitrogen pressure. Then, in the presence of both Si_3N_4 and carbon, the formation of SiC took place. According to the SiC/ Si_3N_4 equilibrium diagram, depicted in Figure 1, the SiC-Si_3N_4 equilibrium depends on the temperature and the gas pressure. The morphology and the phase content of both SiC and Si3N4 can also be controlled by the amount of halide additives such as NH_4HF_2, NH_4F, NH_4Cl, and teflon. This deliberate use of additives during the formation process is called chemical enhanced combustion synthesis. This research paper focuses on recent developments in the field of combustion synthesis of SiC, Si_3N_4, and SiC/Si_3N_4 composites.

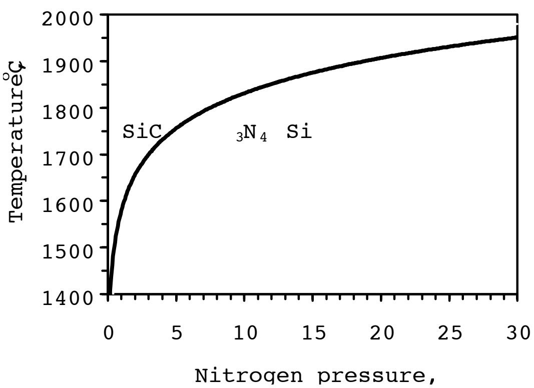


Figure 1. SiC/Si_3N_4 equilibrium phase diagram.

EXPERIMENTAL PROCEDURE

The combustion synthesis experiments were carried out in a high pressure reactor (see Figure 2). The reaction mixture was placed in a refractory boat and ignited with a resistively heated molybdenum wire. The detailed setup can be found elsewhere (Puszynski and Miao 1999).

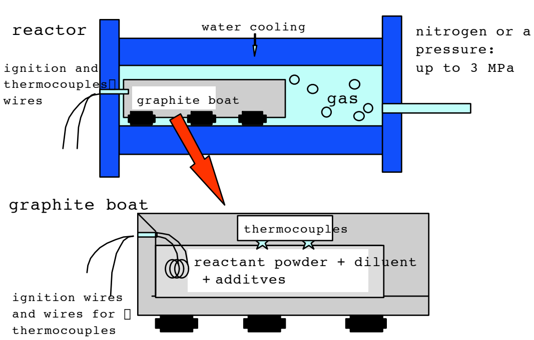


Figure 2. Experimental set-up to carry out combustion synthesis.

The raw materials used were supplied form the following sources. Silicon powder (avg. particle size 7 μm) was provided by Elkem Corp. Ammonium bifluoride and teflon were purchased from Alpha Aesar. Silicon nitride was obtained from Starck (M11). The carbon powder was Carbon Black from Raven Corp. A silicon – silicon nitride mixture with a weight ratio 1:1 was prepared. The amount of ammonium bifluoride added to the reactant mixture varied between 1 wt% and 5 wt%. In order to synthesize the Si_3N_4/SiC composite powders, reactant mixtures consisting of silicon and silicon nitride, in the weight ratio 1:1, were mixed with 5 wt% carbon and a variable amount of teflon (2.5, 5, 10, 20 wt%).

RESULTS AND DISCUSSION

The equilibrium diagram (equilibrium composition (mol %) versus temperature) of the silicon nitrogen system without additives was generated by using HSC-thermodynamic database software from Outokumpo Inc. (see Figure 3). Results of similar calculation with the presence of 5 wt% ammonium bifluoride is shown in Figure 4. It was also possible to determine the adiabatic combustion temperatures with respect to amount of additives. The result of those calculations is a linear decrease of the adiabatic temperature with the increasing amount of ammonium bifluoride, which is shown in Figure 5. The combustion experiments of silicon nitride with 1 wt% to 5 wt% of ammonium bifluoride as additives were carried out. The x-ray diffractograms of the combustion synthesized samples with the addition of 1 wt% and 5 wt% of the ammonium bifluoride as additive are shown below (Figs. 6 and 7). Comparing both diffractograms, it is obvious that the amount of alpha–silicon nitride increased with the amount of halide additive added. A reason for that might be the increased amount of gaseous silicon

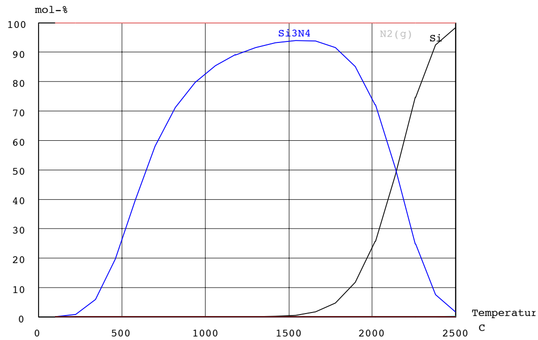


Figure 3. Equilibrium diagram (equilibrium composition (mol %) versus temperature) for the silicon-nitrogen system without any additives at 400 psi.

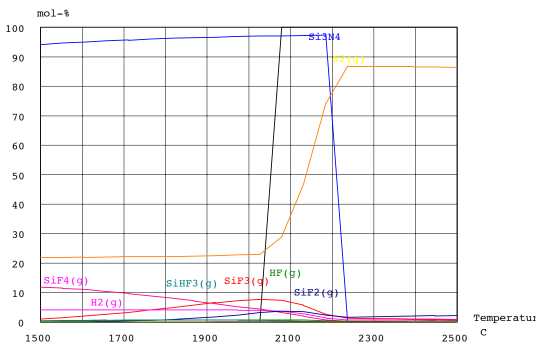


Figure 4. Equilibrium diagram equilibrium composition (mol %) versus temperature for the silicon-nitrogen system with 5 wt% of NH_4HF_2 as additive.

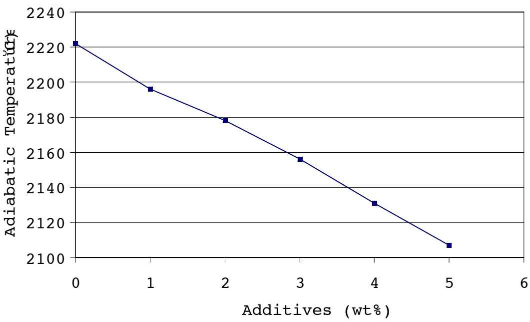


Figure 5. Calculated adiabatic temperature with respect to the amount of ammonium bifluoride added.

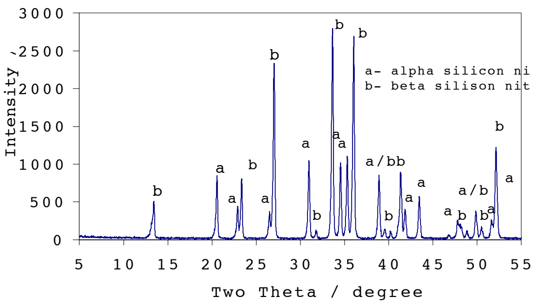


Figure 6. X-ray diffractogram of combustion synthesized Si3N4 with 1 wt % NH_4HF_2.

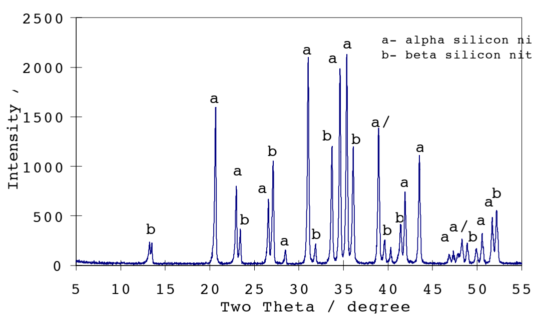


Figure 7. X-ray diffractogram of combustion synthesized Si3N4 with 5 wt % NH_4HF_2.

containing species, which form alpha silicon nitride when reacting with nitrogen. When no additives were used, like in the simulation depicted in Figure 3, it is more likely that the formation of silicon nitride takes place via liquid phase mechanism. This process favors the formation of the high temperature beta phase.

Figure 8 depicts the relation between the quantity of halide additives used and the phase content of combustion synthesized silicon nitride. The larger the amount of additives, the more alpha-Si_3N_4 can be found in the products (see Figure 8). However, if more than 5 wt% ammonium bifluoride were added to the reactant mixture, the combustion reaction was not self-propagating anymore.

In further experiments, the combustion synthesis reaction was modified to synthesize Si_3N_4/SiC composites materials. This objective was achieved by adding a small amount of carbon and poly b-fluorinated ethylene (teflon) to the silicon–nitrogen system. It should be noted that the addition of 2 wt% of carbon already had an impact on the phase content of the product. The x-ray diffractogram depicted in Figure 9 indicates that the amount of alpha silicon nitride increased to 28 wt%. When teflon was added, the beta silicon nitride phase further decreases. This can be observed in the x-ray diffractogram of the sample when 5 wt% teflon was added to the reactant mixture (see Figure 10). Furthermore, when comparing the SEM–images of the samples without telfon (Fig. 11a), and with telfon (Fig. 11b), one can observe a reduction in particle size. Without teflon, an average particle size was 7 µm (Fig. 11a). The fluorine introduced to the system through teflon, reacts with the silicon and lead to the formation of smaller crystals (Fig. 11b — less than 2 µm, needle-like). Figure 12 shows a comparison of the phase content in Si_3N_4/SiC composite powders when different amounts of teflon were used in the reactant mixture. The increased amount of fluoride introduced by teflon decreases the formation beta silicon nitride by (i) enhancing gas phase reaction and (ii) by decreasing the adiabatic temperature.

CONCLUSIONS

Chemical enhanced combustion synthesis can be applied to form Si_3N_4 and SiC/Si_3N_4 with an increased amount of alpha Si_3N_4 phase. Equilibrium calculations support the mechanism of the formation of silicon nitride in the presence of ammonium bifluoride. The calculations also have shown that the adiabatic combustion temperature decreased with in-

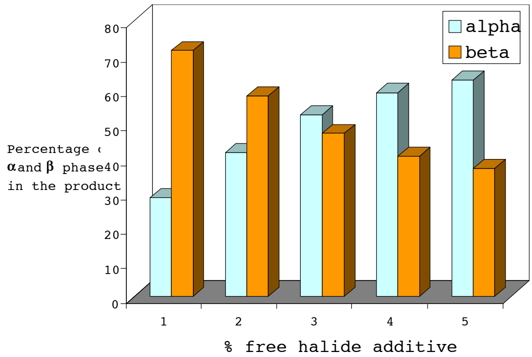


Figure 8. Phase content of alpha and beta Si_3N_4 with respect to the amount of ammonium bifluoride.

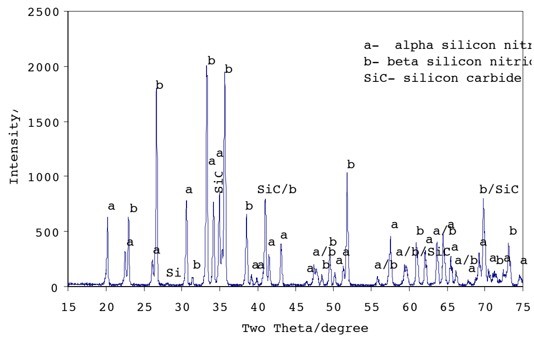


Figure 9. X-ray diffractogram of SiC/Si_3N_4, when only 2 wt% of carbon was used as additive.

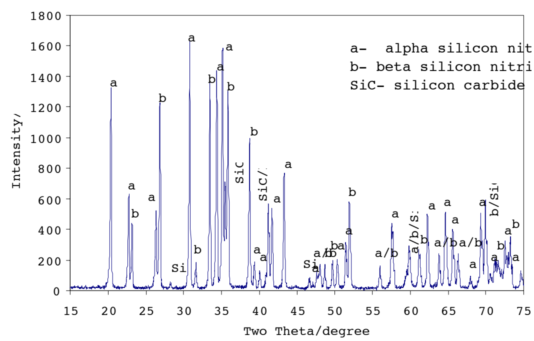
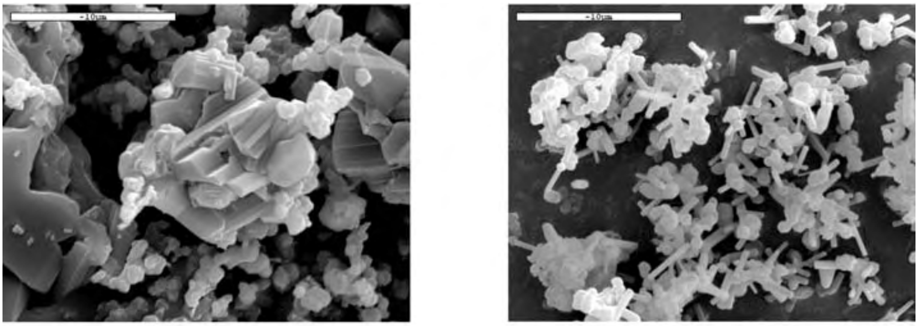


Figure 10. X-ray diffractogram of SiC/Si_3N_4, when 5 wt % teflon was used in the reactant mixture next to the 2 wt% of carbon.



(a) (b)

Figure 11a and 11b. SEM images (5000X) of SiC/Si_3N_4, (a) without and (b) with teflon (5 wt %) added to the reactant mixture additional to the 2 wt% of carbon.

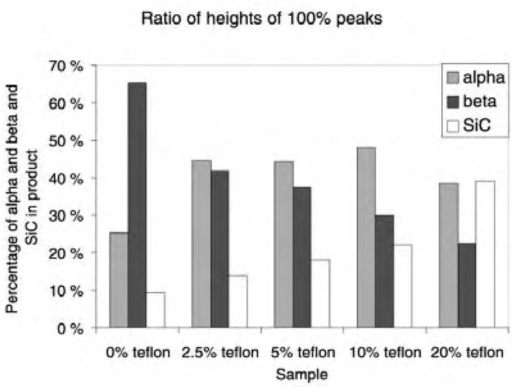


Figure 12. Phase content of combustion synthesized SiC/Si_3N_4 composite powder as a function of concentration of teflon concentration in the reactant mixture.

creasing amounts of that additive. It was found experimentally that the use of ammonium bifluoride significantly effects phase content, morphology, and particle size of combustion synthesized silicon nitride based materials. The addition of teflon to silicon-nitrogen-carbon system results in the formation of the composite powder with smaller particle sizes. Also, the phase content of Si_3N_4-SiC-composite is effected by the addition of teflon. Further sintering experiments to form SiC/Si_3N_4 composite materials for structural application are underway.

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COMBUSTION CHARACTERISTICS OF METAL-BASED NANOENERGETIC SYSTEMS

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ABSTRACT

Recently, it has been found that nanoscale metal-based energetic materials are potentially attractive, due to their increased performance. This increased performance is due to significant increase in specific surface area and small particle size of all involved reactants. This paper is focused on the determination of combustion front velocity of ultra-fast reactions between reactant mixtures consisting of nanosized aluminum and various metal oxides, including WO_3, MoO_3, CuO, and Fe_2O_3 under unconfined conditions. The present work concentrates extensively on the combustion properties of ultra-fast reactions between aluminum and copper oxide nanopowders. Combustion front velocity of Al-CuO system was measured to be 280 m/s, at stoichiometric proportions of reactants. It was also found that the combustion front velocity increased with increase in the amount of aluminum content and the maximum combustion front velocity was measured to be 450 m/s at 30-wt% excess of aluminum compared to stoichiometric proportion.

Keywords

Nanoenergetics, metal-based nanoenergetics, metastable intermolecular composites, condensed phase combustion, nanosize aluminum, metal oxides

INTRODUCTION

In the past few years, a significant effort has been made by the DoD and DoE agencies in the formation of nanopowders and their application in both civilian and military sectors. One example of such an application is the development of nanoscale metal-based energetic materials. Metal-based energetic materials that are produced in nanoscale are potentially attractive due to their rapid energy release [1]. This increased performance is due to a significant increase in the specific surface area and small particle size of all involved reactants. As the specific surface area increases, the number of contact points between the reactants also increases [2]. From the review of recent literature on the combustion of pyrotechnic materials it is clear that there is a significant relation between reaction rate and particle size. Reducing particle size results in increase of combustion front velocity due to reduced diffusional distances between reactant particles [1-5]. One class of nanoscale metal-based energetic materials includes systems consisting of nanosized aluminum and metal oxide as an oxidizer. This type of reacting system is known as metastable intermolecular composite (MIC) [6,7]. MICs, formed by combining aluminum and metal oxide nanopowders, are currently incorporated in formulating the next generation of environmentally friendly primers and lead-free matches [8]. Until now, the general combustion characteristics of MIC reacting systems are not well understood so it becomes important to study both sensitivity and combustion front propagation characteristics. The main objective of the experimental research was to measure the combustion front velocity under unconfined conditions.

EXPERIMENTAL PROCEDURE

Nanoenergetic powders used in this research consisted of, a mixture of aluminum and metal oxide (copper oxide, molybdenum trioxide, tungsten oxide, iron oxide or titanium dioxide). Reactant mixtures were prepared by mixing constituents in stoichiometric and aluminum rich proportions. Aluminum and metal oxide nanopowders were wet mixed in 100 mg batches. The reactants were placed into a 50 ml glass vial, filled with 15 ml of n-hexane and kept in an ultrasonic bath for 15 minutes. After completion of mixing, the slurry was poured on a polished metal plate and dried for 30 minutes in air. After drying, the reactant mixture was transferred into a burn test apparatus.

Measurements of propagation front velocities of combustion reactions under unconfined conditions were conducted using the modified burn test equipment originally developed by the Los Alamos National Laboratory. A schemat-

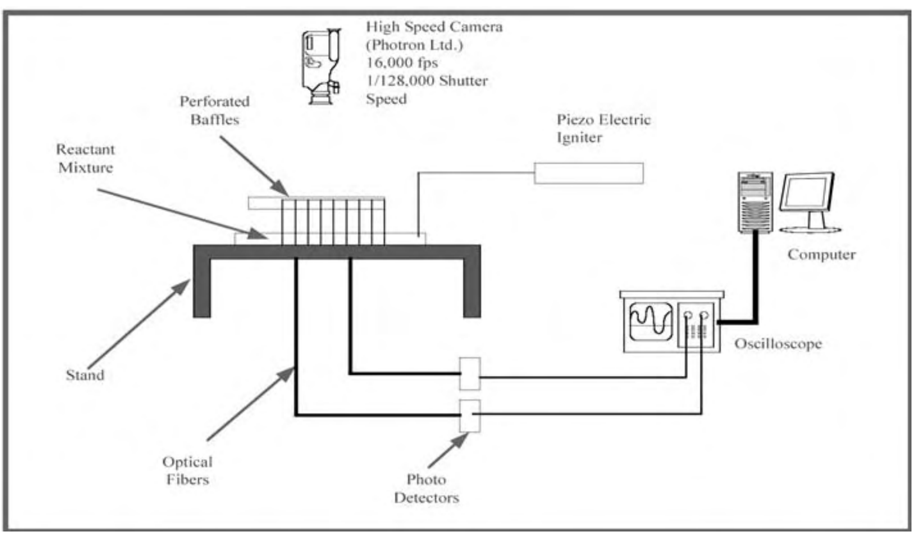

Figure 1. Schematics of burn test equipment.

ic of this setup is shown in Figure 1. The apparatus consists of an open burn tray with a small cavity in which the reactant mixture was placed. This cavity has two small holes, each of diameter 1 mm, separated by a distance of 20 mm. A piezoelectric igniter was used to initiate the combustion process in the reactant mixture. Optical fibers were attached to both holes in the cavity and the other ends were connected to photo detectors. The transient signals, from the optical receivers, were recorded using an oscilloscope. In addition, a high-speed camera, with recording capabilities of 16,000 frames per second and shutter speed of 1/128,000 second, was used to record propagation patterns of the reaction front. A major modification that we did to this burn test apparatus was the inclusion of the perforated baffles. These baffles were included in burn test analysis to minimize powder displacement and premature recording of light signal due to the flame generation above the cavity.

RESULTS AND DISCUSSION

Propagation characteristics in Al-CuO, Al-Fe_2O_3, Al-MoO_3, and Al-TiO_2 reacting systems were investigated in these research studies. Due to a rapid expansion of gases in Al-CuO and Al-MoO_3 systems, unreacted powders ahead of the combustion front were frequently expelled from the burn tray's cavity. Because of this displacement, the measured combustion velocities were erratic. A series of perforated baffles was used to minimize this powder displacement effect. The propagation velocities in the Al-CuO system, measured without the use of baffles, varied from 500 m/s to 1000 m/s. However, when baffles were used, the combustion front velocities measurements became consistent.

Figure 2 shows typical images of a combustion front propagation in the Al-MoO3 system. The recording rate was 8,000 fps with a shutter speed of 1/128,000. Bright plumes, shown in the images, are likely composed of metal vapor and alumina particulates when the combustion was carried out in an inert atmosphere. When the thermite reaction took place in air, a significant plume was formed due to the secondary reaction between generated vapor and gaseous oxygen. Table 1 shows the average combustion front velocities in reacting systems investigated in this research work.

Several experiments were conducted in controlled atmosphere in order to determine the effect of

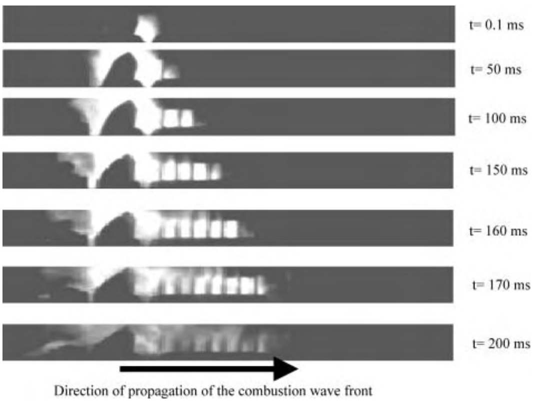

Figure 2. Images of burning loose nanopowders of Al-MoO_3 system recorded, with perforated baffles, using high-speed camera.

an inert gas environment and reactant compositions on combustion front velocities in the Al-CuO system for different Al to CuO molar ratios. The results of these experiments are compared to those obtained in air atmosphere, as shown in Figure 3. The composition of aluminum nanopowder was varied from -30 to +60 % of stoichiometric proportion. In air, the maximum propagation velocity was found at 30% excess of aluminum. In the case of argon gas atmosphere, the maximum velocity was reached at 50% excess of aluminum. A possible explanation for the difference in aluminum content required to attain similar results is the reaction of aluminum with oxygen and/or nitrogen in the air atmosphere. Oxygen and nitrogen in air reacts with unreacted aluminum, during the combustion reaction between aluminum and copper oxide, to form aluminum oxide and aluminum nitride. Thus, the unreacted aluminum in the Al-CuO mixture is been used completely. Due to this complete burning of the fuel i.e. aluminum, experiments done in air atmosphere required less amount of aluminum content to attain the maximum combustion front velocity.

Table 1. Average combustion velocity of the investigated systems under unconfined conditions.

Reacting system (nanosized powders)	Atmosphere	Avg. burn velocity [m/s]
Al (Navy) - MoO_3 (Technanogy)	Air	335
Al (Navy) - MoO_3 (SDSM&T)	Air	362
Al (Navy) - CuO (Technanogy)	Air	488
Al (Navy) - CuO (NanoPhase Tech)	Air	248
Al (Navy) - Fe_2O_3 (Nanophase Tech)	Air	3
Al (Navy) - TiO_2 (Nanophase Tech)	Air	0.1

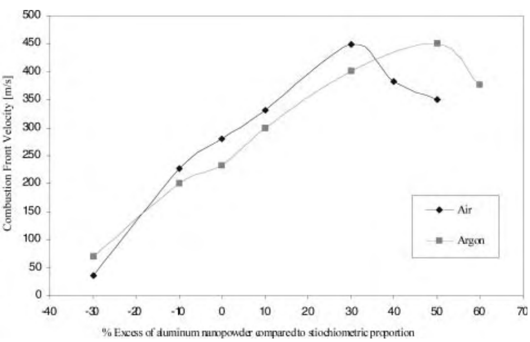

Figure 3. Effect of al nanopowder composition and gas atmosphere on combustion front velocity in Al (Navy, 40 nm) - CuO (Nanophase Technologies, 23nm) reacting system.

CONCLUSIONS

The perforated baffles, incorporated into the burn test equipment, had a significant effect on the measured combustion front velocities. Use of at least four baffles is essential for consistent combustion velocity measurements. The maximum propagation velocity in the Al-CuO system was found to be 448 m/s, at 30-wt% excess of Al with respect to stoichiometric proportion, in air atmosphere, while in argon atmosphere maximum velocity was reached at 50-wt% excess of Al with respect to stoichiometric proportion. This difference in aluminum content to reach same maximum velocity is largely due to the presence of oxygen in air, which is taking part in the combustion reaction between Al and CuO.

ACKNOWLEDGMENTS

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ANATOMICAL STUDY OF *E. ANGUSTIFOLIA* D.C. ROOT STRUCTURE

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ABSTRACT

E. angustifolia roots were collected from plantings on the SDSU Plant Science Farm in Brookings , SD. Field-grown materials were excavated, washed and placed in labeled bags. Roots were examined either fresh or after fixation in ethanol/formalin/acetic acid.. Fixed materials were embedded in plastic (methacrylate) and sectioned. Analyses of the general morphology, including the development of a characteristic dark medullary ray pattern, and the contents of the storage tissues were made using differential staining techniques. Seedlings were grown in the greenhouse on campus. Ten seedlings were inoculated with *Glomus intraradices,* an endomycorrhizal fungus, and 10 were used as controls. These plants were measured for 6 weeks and then harvested. They were removed from their pots, washed, and placed in separate labeled bags. *E. angustifolia* that had been inoculated with mycorrhizal fungus had a better growth rate than the control plants. The black banding pattern, seen in the primary roots had no correlation to the mycorrhizal associations, but were observed in both the parenchyma of inoculated and the control plants. Storage parenchyma in roots of *E. angustifolia* lacked starch but contained large amounts of carbohydrates (most probably inulin). The parenchyma tissues were separated by the xylem bands, which contained the large diameter, water-conducting xylem vessel elements of the roots. Canals, similar to those described for other *Echinacea* species and suggested to contain lipophilic resins, were observed in tangential sections of mature roots.

INTRODUCTION

Echinacea angustifolia is native to the Great Plains (Larson, 1999). This species' range extends from Manitoba to Texas, and west from Wyoming to central Iowa. This common prairie flower, also known as the purple cone flower, is well known for its medicinal properties. Native Americans have used the plant to calm stomachaches and alleviate toothaches (Kindscher, 1992; Larson, 1999). Today it is marketed as an immune stimulant in a multibillion-dollar business. These medicinal properties are derived from over 300 different compounds found throughout the plant (Foster, 1991; Hobbs 1989).

E. angustifolia is able to survive under very arid conditions due to its deep tap root system. The roots are very large and may comprise a much larger total mass than the aerial components. The roots are able to penetrate compacted clay soils that are common in the central United States. Data on the root structure of *E. angustifolia* is limited. Since it is marketed for its biochemical content, the correct identification of the plant by its anatomical features is crucial. *E. angustifolia*'s roots were examined for morphological characteristics including mycorrhizal associations, the unique banding pattern seen in fresh cross sections, the amount of parenchyma in the xylem, the size and distribution of xylem vessel elements, and the occurrence of resin ducts.

MATERIALS AND METHODS

Plant Materials

E. angustifolia roots were collected from plants growing in a common garden on the SDSU Agricultural Research Farm in Brookings, SD. Roots were cleaned in deionized water, cut into 5mm sections and some of the pieces were fixed in FAA (6 parts formalin, 4 parts acetic acid, 50 parts ethanol 40 parts deionizer water), while others were left unfixed for examination of fresh sections.

E. angustifolia seedlings were generated in the greenhouse, using seeds collected from plants growing in Wasta, SD. Seedlings for examination of micorrhizal growth were left untreated or inoculated with *Glomus intraradices.* The plants were maintained at 30 C day temperature and 24 C night temperature for 6 weeks post-germination. Heights were measured every week. After 6 weeks, the plants were removed from the pots, washed in deionized water, and cut into 5mm sections. Some of the root materials were fixed in FAA, and some cleared and stained as described below.

Clearing and staining for micorrhizae

Fresh greenhouse material was cleared and stained in analine blue to detect the presence of mycorrhizal associations following the procedure of Grace and Stribley (1991) Briefly, small portions of the root were cleared with 10% KOH for 45 minutes at room temperature. The roots were rinsed 3 times (3 min each) in deionized water, and neutralized in 5% HCl overnight. Roots were stained at 90 C with 0.1% aniline blue in 70% glycerol and 0.1% HCl for 5 to 7 minutes. Excess stain was removed by transferring the roots into the acidified 70% glycerol lacking aniline blue stain. Samples were stores in this solution until being examined.

Hand Sectioning

Fixed and fresh materials from the greenhouse and field were cross-sectioned by hand using a razor blade and stained following the protocols of Yeung (1998).

1. Safranin: Sections were placed in a drop of water on slide. One drop of 1% aqueous safranin stain was placed directly on the section and allowed to stand for 1 minute. Excess stain was absorbed with a Kim Wipe and rinsed with a few drops of water. Excess water was removed with a Kim Wipe and then a cover slip was applied

2. Safranin and Fast Green: After staining as above with safranin, a drop of 0.5% Fast Green in 50 % ethanol was added to the section. It was allowed to stain for 30 seconds. Excess stain was pulled off and the sections were rinsed with a few drops of water. Excess water was pulled off with a Kim Wipe and a cover slip was added

3. Toluidine Blue: Sections were treated as above using 1-2 drops of 1 % aqueous toluidine blue for 30 to 60 seconds.

4. IKI: Sections were stained as above using a drop of aqueous IKI stain (2% KI with 0.2% Iodine). Sections were stained for 3- 5 min, rinsed with water and covered before examination.

5. Sudan IV: Sections were placed directly into 1% Sudan IV staining solution (85% ethanol). The sections were stained for about 5 minutes. The sections were transferred to 85% propylene or ethylene glycol in water, and agitated for about 30 seconds. This wash removed excessive stain from the sections, allowing a better differentiation of the stain in various structures.

Embedding of Fixed Material:

The embedding procedure was carried out using the manufacturer's specifications (JB-4 Embedding Kit, Polyscience Inc., Niles, IL, 60714, 2003). After the tissues were fixed, they were dehydrated with increasing concentrations of ethanol, they were placed in the prepared JB-4 catalyzed infiltration resin for 24 h at 4 C while being shaken. After the infiltration was complete the tissues were placed in the mold, and the embedding resin was poured on top. Plastic chucks were inserted and the entire tray was placed in a bag, which was filled with nitrogen gas to provide and anaerobic environment for polymerization. The polymerization was complete in 4 hours.

The molds were removed and the tissues were sectioned with an Olympus CUT 4060E Rotary Microtome (4-6 mm, longitudinal, tangential and cross sections). The sections were released into a water bath that contained Ammonium Hydroxide to aid in the flattening of the sections. The sections were then placed on slides that had been coated with poly-1-lysine. The slides were dried on a slide warmer at 45 degrees Fahrenheit for 48 hours before they were stained.

Staining of Plastic-Embedded Sections

Water soluble dyes provided very sharp and brilliant staining of tissue in JB-4 plastic sections, but the stains required at least twice as long as the non-embedded sections. This was due to the fact that many of the stains were unable to quickly penetrate the methacrylate resins that were used for embedment (Burns and Bretschneider, 1981). Therefore, the same stains described above were used on the mounted plastic sections, but all of the times were doubled.

In addition, two additional stains were applied to plastic-embedded sections.

Periodic Acid Schiff

Sections were stained for carbohydrates using reagents and protocols found in the Periodic Acid Schiff (PAS) kit (Newcomer Supply, Middleton, WI) Briefly, sections were oxidized in 0.5% periodic acid solution for 5 minutes. The sections were rinsed in distilled water, the sections were placed in Schiff's reagent for 30 minutes, transferred through 2 changes of sulfurous acid rinse for 2 minutes each, and gently in tap water for 5-10 minutes to develop pink color. The sections were then stained with Harris's hematoxylin for 10-120 seconds, placed in water for a few minutes and rinsed in bluing agent. The sections were dehydrated in several changes of 95% ethanol and several changes of 100% ethanol.

Micrographs

Digital micrographs were made using a Fujifilm HC-300Z digital camera mounted on an Olympus AX70 brightfield microscope.

RESULTS AND DISCUSSION

E. angustifolia produces a deep root system that is often larger the above ground portion of the plants. The primary roots of a plant can be greater than 1 cm in diameter and roots of 0.5 cm diameter are often present at 1 m depth in the soil (Fig.1) In transverse section the roots have a distinctive medullary ray pattern that is visible with the naked eye (Fig. 2) and the roots are very friable, peeling apart into long threads when rubbed between the fingers.

Figure 1. *E. angustifolia* too system from a 4 year old plant grown on the SDSU Plant Science Farm in Brookings, SD. The roots were excavated using a 1 m tree spade.(Standard meter stick provided for reference.)

Micorrhizal infection

E. angustifolia associates with mycorrhizae in nature. This association is very common in the Asteraceae family (Brundrett, 2003). It was evident by the analine blue stained roots that *E. angustifolia* and *Glomus intraradices* formed a symbiotic association (Fig. 3). The inoculated plants grew on average 57% taller (Fig. 4) than the control plants presumably because the mycorrhizae increased the nutrient uptake of the plants. Infection of the roots was easily visualized in the cleared and stained roots, but formation of arbuscula were not visible after 6 weeks post infection (Fig. 3). Mycorrhizae formed the association in the tertiary roots. When roots of approximately the same age were examined they were markedly more developed (Fig.5), indicating a quicker growth rate than the control plants.

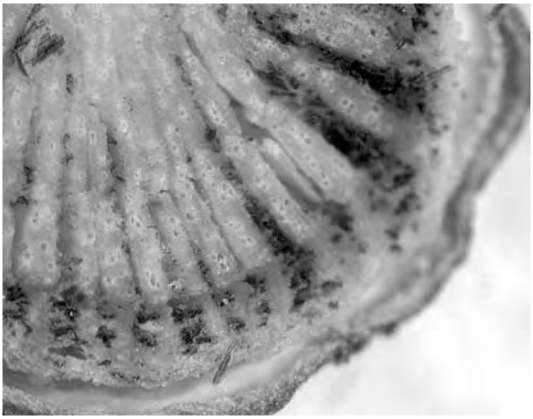

Figure 2. Micrograph of a freehand section of fresh *E. angustifolia root,* unstained, viewed at 100X magnification. The characteristic medullary ray pattern is visible

Figure 3. Aniline blue stained section of cleared *E. angustifolia* root viewed at 200X magnification. The arrow indicates the hypha of *Glomus intraradicies* growing within the root.

General anatomy

Both fresh and fixed plastic-embedded sections revealed a medullary ray pattern with many of the parenchyma cells appearing dark in color. This dark pattern is visible in fresh roots when they are harvested in the field and can be seen in seedlings during the first year (Fig. 3). Development of the medullary ray pattern started in young roots with a scattering of darkened cells and developed completely as roots matured. When the sections were stained in 1% safranin and 0.5% fast green, the parenchyma bands stained green and the xylem of the root stained

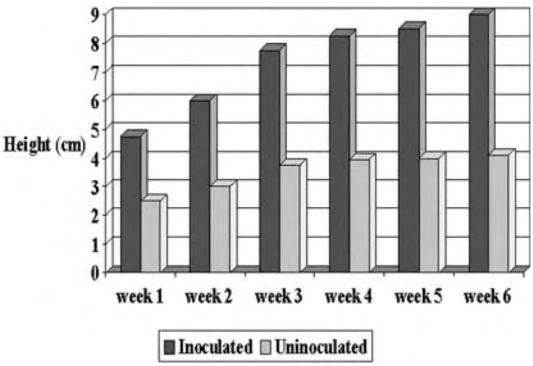

Figure 4. Growth of *E. angustifolia* seedlings in the greenhouse. Inoculated - plants infected with G. intraradicies. Uninoculated - control plants.

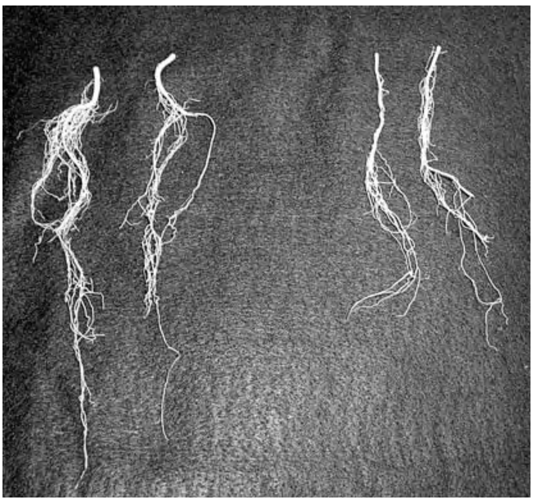

Figure 5. Photograph of root systems of *E. angustifolia* seedlings. Left - 2 plants inoculated with *G. intraradicies.* Right - 2 control plants.

red. It was noted that the black bands tended to be limited to the parenchyma tissue (Fig. 6).

The black bands were analyzed using 1% sudan IV to determine if they were lipophilic in nature. The material did not react with the dye, indicating that it not suberin or any other lipophilic compound. It is possible that the unknown black granules are insoluble tannins. Insoluble tannins have been found in sink tissue of other plants, showing somewhat similar patterns of development (Kao et al., 2002).

The friability of the roots appeared to be the result of large sections of parenchyma separating the xylem strands. Although annual rings were very difficult to observe, a weak pattern was present although large xylem vessels were often found scattered in all regions of the xylem strands (Fig. 6).

E. angustifolia does not appear to store its photoassimilates as starch. When the sections were stained in IKI, the tissue did not exhibit any darkening (not shown), which would have indicated the presence of starch. Like many members of the Asteraceae, the plant appears to store its carbohydrates as inulin, a fructose polymer (Healthnotes, 2002). The roots have been shown to contain up to 20% inulin by weight (Healthnotes, 2002). When the roots were stained with PAS (not shown), the parenchyma stained an intense red, indicating the presence of a complex carbohydrate.

The sclerefied portion of the xylem contained the conducting elements of the roots that allowed the water to be transported from the soil to the aerial portions of the plant. Individual xylem vessel elements could be seen in the micrographs (Fig. 6). The elements were large and well developed, allowing *E. angustifolia* to survive in the semi-arid central United States.

Canals or resin ducts have been described in the aerial portions of the *E. purpurea* plants (Caster and Myers,1987). The presence of resin ducts in the roots of *E. angustifolia* has been previously documented (Kahler, 2002). A random occurrence of canals or resin ducts in tangential and longitudinal sections running perpendicular to the root axis was noted in sections of older, mature roots. These canals appeared to be lined with small parenchyma cells (Fig. 7) and appear to be similar to those reported in *E. purpurea,* which are thought to be involved in the production of lipophilic, biologically active compounds (Caster and Myers, 1987; Many Lightnings et al, 1990).

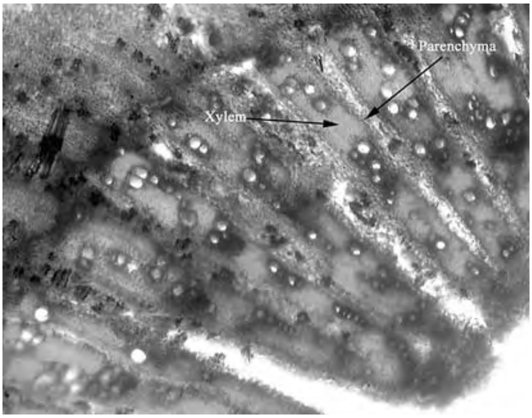

Figure 6. Safranin/Fast Green stained cross section of a mature *E. angustifolia* root viewed at 200X magnification. Bands of xylem parenchyma and xylem sclerenchyma (xylem vessel elements) are indicated by arrows.

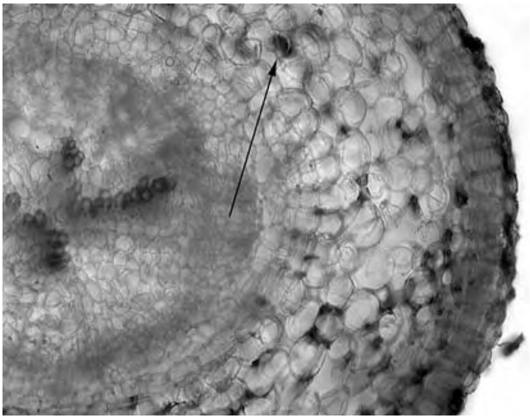

Figure 7. Safranin/Fast Green stained cross section of a 6 week old *E. angustifolia* root viewed at 200X magnification. Arrow indicates the developing pigmented cells forming in the cortical parenchyma.

CONCLUSIONS

The medullary ray pattern viewed in cross section of the larger roots of *E. angustifolia* are the result of deposits of non-lipophilic compounds in the xylem parenchyma (probably condensed tannins). Inoculation of roots with *Glomus intraradicies* and the resulting mycorrhizal infection stimulated plant growth. The black pigment creating the medullary ray pattern had no correlation to the mycorrhizal associations. It was present in both the inoculated and the control plants PAS staining indicated that the xylem parenchyma also contains storage carbohydrates (probably inulin). The wide bands of xylem parenchy-

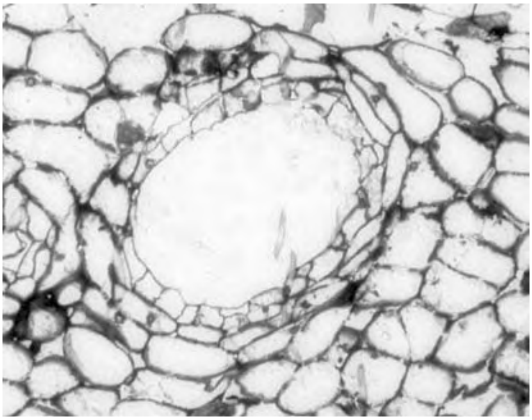

Figure 8. Canal in *E. angustifolia* root tangential section stained with toluedine blue and viewed at 400X magnification. Note the small parenchyma cells lining the duct.

ma separate the water-conducting band of xylem vessel elements in the roots of *E. angustifolia* and give the roots their characteristic friability. The parenchyma also contain a few laterally-oriented canals that appear to be analogous to those described in *E. purpurea* aerial tissues.

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MORPHOLOGICAL EXAMINATION OF PRAIRIE TURNIP (*PSORALEA ESCULENTA* PURSH) ROOT

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ABSTRACT

Psoralea esculenta Pursh is an herbaceous perennial legume, native to the Great Plains, that has a tuberous-thickened taproot. We have been examining its potential food value and unique anatomy as part of a larger ethnobotany program because this plant has long used been used by Native American populations as food source. The *Psoralea* root has a tough inedible outer covering (bark) and a fleshy interior that contains starch and protein reserves. The fleshy root shows development of visible rings early in its first year of growth and contains numerous isolated vascular strands. Root tissues from mature and young roots were fixed and embedded in JB-4 plastic. Differential staining methods using Safranin and Fast Green, Toluidine Blue, IKI, and Aniline Blue were used to examine the tissue morphology. Digital pictures were made using a Fuji camera attached to an Olympus bright field microscope. The root of *Psoralea esculenta* possesses a unique arrangement of vascular tissues embedded in secondary parenchyma with regions of cells containing large deposits of either protein or starch. Further analysis at different developmental stages will help to clarify the unique anatomical features observed in the root of *Psoralea esculenta*.

INTRODUCTION

Psoralea esculenta Pursh is an herbaceous perennial legume, native to the Great Plains, that has a tuberous-thickened taproot. The plant emerges in late spring to early summer in the Northern Great Plains. Flowering occurs from the first to the middle of July, with fruit maturation near the end of July. Abscission of the shoot system happens with the dehiscence of the legume, as a result of the formation of an abscission layer that is usually about 2-5 cm below ground. The upper, herbaceous portion of the stem is then released and the seeds are scattered as the shoot system tumbles across the prairie. Formation of shoot buds occurs on the underground crown of the woody portion of the stem, with the development of the tuber-like growth an additional 2-5 cm below the crown (Fig. 1).

Native Americans used the root of the prairie turnip as a staple in their diet. The tuber has been found to contain about 7.5% protein and up to 70% starch (Perera and Reese, 2002). Field observations suggest that the starch and protein are stored in parenchymous tissues that expand laterally each year.

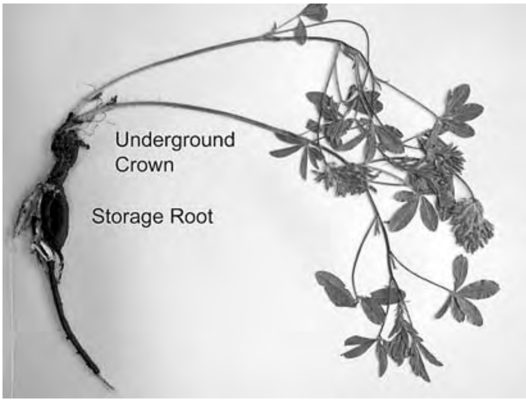

Figure 1. Photograph of a herbarium mount of *Psoralea esculenta* showing the general structure, with the underground crown and storage tissues labeled.

MATERIALS AND METHODS

Collection of plant material

Plant materials from the greenhouse and field were examined. Seeds were scarified in November, planted into four inch pots, and placed on a mist-bench. After three months the seedlings were removed from the pots and cleaned with water, cut into pieces and fixed in AFA (50 parts ethanol, 6 parts formalin, 4 parts acetic acid and 40 parts deionized water) in preparation for plastic infiltration.

Field material was collected at the end of January from the Native garden test plots at SDSU. Roots, from plants that were 3 years old, were excavated, rinsed in DI water and prepared as above for plastic infiltration.

JB-4 Hydrophilic plastic infiltration of field and seedling root material

JB-4 hydrophilic plastic (Polysciences Inc.) was used to embed the plant tissue following the protocols provided by the manufacturer. .

Sectioning tissue

Cross sections, tangential sections, and longitudinal sections were made from the seedling roots and field root material. The plant tissue was sectioned to a thickness of 4 microns using an Olympus Cut 4060E Rotary Microtome with a steel knife. The sections were removed with forceps and placed into water containing drops of ammonium hydroxide to relax the plastic. The sections were then placed onto glass slides previously coated with poly-L-lysine and stained appropriately.

Staining for protein and general morphology

After the tissue had dried the tissue sections were stained with 1% aqueous toluidine blue, fast green & safranin (1% aqueous safranin followed by 0.5% Fast Green in 50 % ethanol), iodine (2% KI with 0.2% Iodine), or 1% Coomassie Brilliant Blue in 50% ethanol. Toluidine blue (hydrophilic) is a common stain which stains proteins, cell walls, nucleic acids, and RNA. Fast green (lipophilic) and safranin (hydrophilic) were used in combination. Fast green stained the cytoplasm and membranous tissue green and safranin stained the

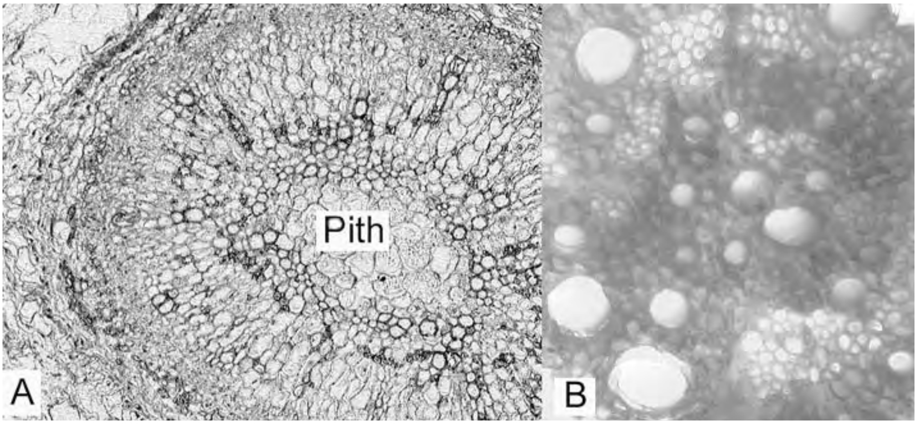

Figure 2. Micrographs of *Psoralea esculenta* root sections stained with Toluidine Blue. A) Cross section of the upper portion a 2 month old plant showing the presence of a central pith in the developing storage tissue - 10X objective. B) Cross section of the base of a mature storage root showing xylem vessel elements in the central vascular cylinder - 40X objective.

cell walls and phloem red. Iodine was used to stain for starch while Coomassie Brilliant Blue was used to stain for protein.

Micrographs made with an Olympus AX70 bright field microscope

Micrographs were made with a Fuji film camera attached to an Olympus AX70 bright field microscope. The objectives used were the 4X, 10X, 20X, and 40X.

Figure 3. Near median cross section of a *Psoralea esculenta* storage root stained with Safranin and Fast Green. Elongation of cells can bee seen to be in a radial orientation - 4X objective.

RESULTS AND DISCUSSION

The thickened root of *Psoralea esculenta* appears to be developmentally similar to that of *Daucus* and *Beta* in that the storage tissue seems to contain both hypocotyl tissue and the upper portion of the taproot (Esau, 1965). Cross sections through the upper portion of the storage tissue reveal that there is a central pith surrounded by the xylem, while cross sections of the base show a

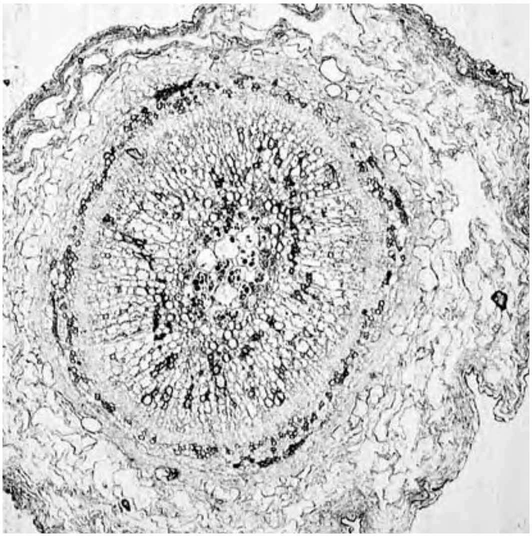

Figure 4. Cross section of a 2 month old *Psoralea esculenta* storage root. The annular pattern of vascular tissue deposition is visible - 4X objective.

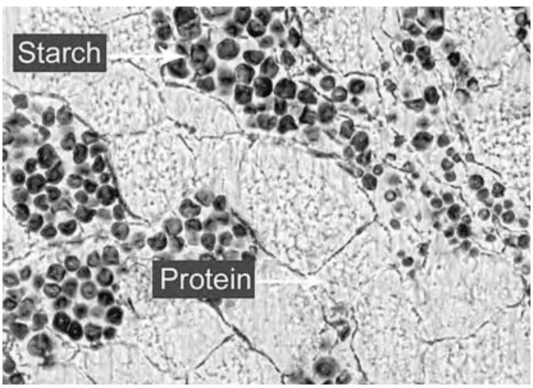

Figure 5. IKI-stained section of mature *Psoralea esculenta* storage-root tissue. The large starch grains are darkly stained. Protein bodies, unstained, can be observed in adjacent cells - 40X objective.

central vascular cylinder with the xylem vessel elements centrally distributed forming a loose diarch to triarch pattern (Fig. 2 A and B).

The developing storage tissue appears to be predominantly xylem parenchyma laid down by vascular cambia with much lateral elongation. In central sections of mature storage tissues, many of the cells are 3 or more times as long in the lateral (radial) direction as compared to their vertical axis. In some younger tissues (1 to 2 months old), there appears to be more than one "annual" ring, which may indicate that the production of the xylem is periodic or that, as with sugar beets, the product of supernumerary cambia (Esau, 1965).

The storage of starch and proteins occurs predominantly in the xylem parenchyma. Clusters of cell containing either starch or protein are found juxtaposed to each other, but do not appear to commingle. The starch and protein can be seen to be in membrane bound vesicles. Those containing starch are large and appear to represent amyloplasts, while the proteins occur in smaller protein storage vesicles similar to those found in seeds (Taiz and Zeiger, 2002) Analyses of these storage tissues indicates that they contain 7.5% protein and 70% starch by weight (Perera and Reese, 2002).

Psoralea has been a staple of the indigenous peoples of the northern plains (Kindscher, 1987). Morphologically their development appears to follow that of other root crop species. However, the development of both protein and starch storage parenchyma makes them somewhat unique. Planting of this species in the South Dakota State University Plant Science Research Farm in Brookings, SD indicates that development of this structure requires several years to reach maturity. Growth of the storage organ occurs as a result of the production of xylem tissues by the vascular cambium and perhaps additional supernumerary cambia. This aspect of development, however, requires further study for complete elucidation.

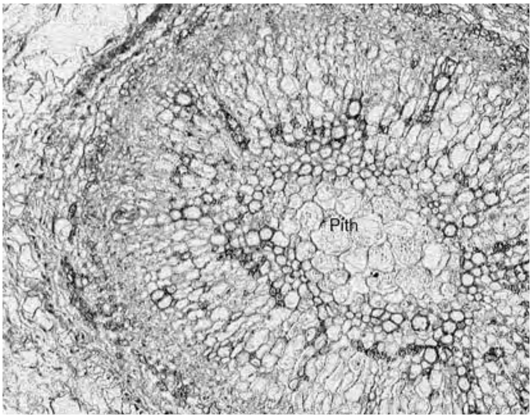

Figure 6. Mature *Psoralea esculenta* storage-root stained with Coomassie Brilliant Blue. Small protein-containing vesicles are darkly stained. Unstained starch grains can be seen in adjacent cells - 10X objective.

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A SYNTHESIS OF THE EFFECT OF WOODY VEGETATION ON GRASSLAND NESTING BIRDS

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ABSTRACT

Sixty-nine articles with references to grassland nesting species associations with woody vegetation were annotated to summarize our current knowledge on the effect of woody vegetation on these species. Bird relationships to woody vegetation were summarized at 4 levels: amount within the grassland patch, perimeter comprised of woodland, distance of a nest or survey from woodland habitat, and the proportion of woodland habitat within the surrounding landscape. Overall, these studies indicate woody vegetation at all levels has a deleterious effect on occurrence, density and/or nesting success of both game and nongame grassland nesting birds. Only 2 grassland nesting species responded positively to a measure of woody vegetation in ≥ 2 studies. Edge effects associated with woody vegetation have been detected in pheasants, ducks, grouse and nongame birds in studies conducted over a broad geographical range (Montana, South Dakota, Minnesota, Missouri, Oklahoma, Wisconsin, Iowa, Manitoba).

INTRODUCTION

Grassland ecosystems have been transformed from vast mosaics of grassland into fragmented agricultural landscapes characterized by large blocks of cropland interspersed with smaller, more isolated grassland patches. Planted woodlands, most of which are linear, further fragment remaining grasslands and create abrupt boundaries that can exacerbate edge effects. Additionally, the suppression of ecological processes such as fire has allowed an increase in woody encroachment into grassland habitats. Grassland birds are declining more rapidly than any other group of North American birds. Linked to the declines are the loss and degradation of grassland habitats. This bibliography was completed to summarize current knowledge of the effects of woody vegetation on habitat suitability for grassland nesting species.

METHODS

Sixty-nine articles with references to species associations with woody vegetation were obtained. Few studies were designed solely to determine the effect of woody vegetation on avian species, rather woody vegetation was one of several variables analyzed. Bird relationships to woody vegetation were summarized at 4 levels: within the grassland patch (i.e., woody stem density, shrub coverage, presence of mature trees), perimeter comprised of woodland (shrubs, trees, hedgerows), distance of a nest or survey from woodland habitat, and the proportion of woodland habitat within the surrounding landscape (Table 1). Results from studies with rigorous statistical analyses as well as observational studies are annotated in this bibliography.

RESULTS

Game Birds. All seven studies on grouse detected a negative relationship with woody vegetation (Table 1). In southwest Missouri, 3 of 17 Greater Prairie-Chicken nests hatched when woody cover was >5% near nest sites. When woody cover was <5% 15 of 26 nests hatched. Active Greater Prairie-Chicken, Lesser Prairie-Chicken, and Sharp-tailed Grouse leks had significantly lower proportions of woody cover within the landscape than inactive leks. In Minnesota, it was determined that Sharp-tailed Grouse were sensitive to even small increases (1-2%) in the amount of woody vegetation in their homerange and successful management should include an assessment of planted conifers within the lek vicinity to determine the efficacy of management. In Manitoba, it was determined the habitat within 1 km of a lek can be comprised of no more than 44% closed aspen forest and at least 23% prairie to sustain a non-prairie population of grouse. Once aspen succeeds to >56% forest and less than 15% prairie remains, the lek will likely be abandoned.

Ring-necked Pheasant nests placed within shelterbelts had higher levels of predation than those located in other habitats. While dense shelterbelts increased survival of pheasants during the most severe winters in South Dakota, cattail wetland, tall grass (>75cm) and food plot habitats ranked highest in hen use during a typical winter. Woody vegetation variables also appeared to be negatively associated with winter food plot use. The presence of wetland and grass cover in the surrounding landscape was the most important variables in determining food plot use during 4 consecutive winters in South Dakota.

Results from artificial nesting studies (primarily simulating pheasant/duck nests) demonstrate a negative relationship with woody vegetation inside the patch, surrounding the patch, within 60 m of the patch and within the surrounding landscape. Woodland block cover, wooded roadsides, and wooded fencerows were positively associated with predation of artificial nests at all spatial scales (200-1600 m of the nest transect) in Iowa. Artificial nests had higher predation rates near edges and within American Crow home ranges in studies in Illinois and Manitoba. One study found no difference in woody vegetation between depredated and undisturbed artificial duck nests. Stock pond use by Mallard broods was negatively associated with the occurrence of trees along the pond edge in western South Dakota.

Nongame Birds. Several studies have indicated that woody vegetation negatively affects presence, abundance, and nesting success of nongame species. While some studies have indicated no effect, only 3 nongame species, Clay-colored and Vesper Sparrows and Dickcissels, responded positively to woody vegetation at any level in the studies compiled in this bibliography. Two of these species, Clay-colored Sparrows and Dickcissels, were positively associated with woody vegetation within the patch, where they may use it for nesting or perching, but were negatively associated with woody vegetation at other levels. Dickcissels were positively associated with woody cover inside the grassland in two studies but exhibited negative associations with woody vegetation at all other levels studied (Table 1). No other grassland nesting passerine was positively associated to woody vegetation at any level. However, this relationship has been studied <3 times in several species and requires additional research.

Savannah Sparrows had the most consistently negative associations with woody vegetation. Fifteen of 22 analyses indicated decreased occurrence, density and/or nesting success associated with woody vegetation inside and adjacent to grasslands as well as with decreasing distance to woodland patches and increasing woodland habitat within the landscape (Table 1). Grasshopper Sparrows were negatively associated with woody vegetation in 16 of 24 studies. Neither of these species was positively associated with woody vegetation at any level (Table 1).

Several studies have found negative relationships between woody vegetation and nesting success. Nest predation rates were lower for 5 species (Clay-colored, Savannah and Grasshopper Sparrows, Bobolink, Western Meadowlark) in large fragments (≥130 ha or 321 ac) and in fragments ≥45 meters from woody vegetation in Minnesota. Brood parasitism also was lower for all 5 species far (≥45) from wooded edges. The authors recommended making grasslands as large as possible and removing woody vegetation that creates edges to enhance nesting success. In Wisconsin pastures, daily survival rates of a combined group of grassland bird nests <100 m from non-wooded edges were significantly higher than nests <100 m from wooded edges. Nests located <50 m from non-wooded edges had significantly higher daily survival rates and lower daily depredation rates than nests near wooded edges. Management recommendations included prioritizing landscapes with little woods and removal of wooded areas, treelines, and shrubby hedgerows near pastures when feasible. Dickcissels and Henslow's Sparrows experienced decreased nesting success within 50 m of a shrubby edge versus at greater distances on 13 prairie remnants in Missouri. Artificial nest survival was lower within 30 m of forest edges. Evidence indicated mid-sized carnivores were the major predators within 30 m of forest edges and visited track stations most frequently within 50 m of forest edges. The authors concluded that edge effects were more pronounced than area effects because proximity of woody habitat explained more variation in nest survival and mammal activity than did fragment size. Frequency of brood parasitism by Brown-headed Cowbirds on Dickcissels also increased significantly with proximity to shrubby edge and was highest within 50m of shrubby edges in Missouri.

Total density of grassland bird species of management concern (12 species) was highest when woodlots were farther from transects in Wisconsin. The study recommended prioritizing landscapes with low cover and patch size of nonlinear woody habitats such as woodlots to manage for grassland species. Recommendations from a study conducted in eastern South Dakota include placing high priority on purchasing and conserving grasslands in landscapes with high amounts of grassland habitat (> 40% within 1600 m of the patch) and low amounts of woodland habitat (<1.0% within 400 m).

SUMMARY

Edge effects associated with woody vegetation have been detected in pheasants, ducks, grouse and nongame birds in studies conducted over a broad geographical range (Montana, South Dakota, Minnesota, Missouri, Oklahoma, Wisconsin, Iowa). Results from these studies indicate that grassland nesting birds appear to avoid woody edges. Edge effects associated with woody vegetation may be more pronounced due to predators and parasites associated with woods. Many authors speculated that woody vegetation provides cover for mammalian predators and elevated perches for avian predators. In addition, some predators (American crows, raccoons) may have affinities for wooded habitats and use them for travel and foraging. The presence of wooded cover increases the likelihood that predators will come in contact with nests. The negative effects of woody vegetation on nest survival appear to be caused mainly by greater exposure of nests to mid-sized carnivores. Regardless of whether the avoidance of edges by grassland birds is an evolved trait or a response to a perceived threat of greater predation or parasitism, managers need to seriously consider the deleterious effects of woody vegetation on grassland nesting birds when planting trees into formerly treeless grassland habitats.

ACKNOWLEDGMENTS

I thank K. Higgins, R. Johnson and D. Granfors for thorough reviews of this bibliography. T. Pischke, P. Symens and D. Sulzbach provided assistance in obtaining literature. Funding was provided by the Habitat and Population Evaluation Team and Migratory Birds and State Programs, US Fish and Wildlife Service.

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Studied the distribution and density of birds in relation to wolfberry *(Symphoricarpos occidentalis)* and Silverberry *(Elaeagnus commutate)* shrub cover-

ages in prairie grasslands. Transects with 30-80% shrub coverage contained 19 different passerines species while transects with <10% coverage contained 10. Eleven species were detected only in shrubby transects, 9 of which were shrub nesting species (Willow Flycatcher, Gray Catbird, Brown Thrasher, Yellow Warbler, Song Sparrow, American Goldfinch). Clay-colored Sparrows, and Brown-headed Cowbirds were the most abundant species on shrubby transects, comprising 57% of the total bird density. Bobolinks occurred in both transect types. Savannah and Baird's Sparrows occurred only on shrubless transects. Grasshopper Sparrows and Chestnut-collared Longspurs were the most abundant species on shrubless transects.

Bakker, K.K. and K.F. Higgins. 2003. Avian Use of Natural versus Planted Woodlands in Eastern South Dakota, U.S.A. Natural Areas Journal. 23:121-128.

Avian use of naturally occurring and planted woodlands in eastern South Dakota was compared to evaluate whether planted woodlands support the same avian communities as natural woodlands. Eighty-five species of birds were detected in eastern South Dakota woodlands, 36 of which occurred in ≥ 5 of 524 patches surveyed. The probability of occurrence for 8 of 13 woodland obligate species was significantly greater in natural versus planted woodland habitats. Four of these breed in relatively high numbers in eastern South Dakota. Only one woodland obligate occurred less frequently in natural woodlands. Probability of occurrence for 6 edge and generalist species, including the brown-headed cowbird [*Molothrus* ater (Boddaert)], was significantly higher in planted woodlands. The avian community of planted woodlands was dominated by edge and generalist species. The homogeneous vegetation structure typical of planted woodlands does not appear to provide the habitat characteristics needed by woodland obligate birds. It was concluded that planted woodlands do not support significant numbers of woodland obligates species and may negatively impact grassland nesting birds by attracting edge and generalist bird species and predators into previously treeless habitats. Management may require discriminating between naturally occurring woodland habitat and manmade additions such as tree plantings. Managers need to seriously consider the tradeoffs that exist with introducing trees into formerly treeless grassland habitats. The preservation and maintenance of natural woodlands is critical for woodland obligate species diversity in the northern Great Plains.

Bakker, K.K., D.E. Naugle, and K.F. Higgins. 2002. Incorporating landscape attributes into models for migratory grassland bird conservation. Conservation Biology 16: 1638-1646.

Grasslands (n=380) were studied throughout eastern South Dakota to investigate the influence of local and landscape attributes on the occurrence and density of grassland birds. Variables analyzed included percent perimeter comprised of woody vegetation (>1 row of trees or shrubs) and proportion of trees within 400 m (50 ha/124 ac), 800 m (201 ha/497 ac), and 1600 m (804 ha/1987 ac) radii from the transect center. Four grassland species (Sedge Wren, Savannah Sparrow, Grasshopper Sparrow, and Western Meadowlark) exhibited a significant decline in probability of occurrence on grasslands as perimeters comprised of woody vegetation increased. Bobolinks, Dickcissels, and Clay-colored sparrows did not exhibit a relationship with increased wooded patch edge. Density was not associated with woody vegetation. The authors recommended high priority be placed on conserving large, continuous blocks of grassland habitat as well as both small and large grassland patches embedded within landscapes with a high proportion of grassland habitat and little or no woodland.

Bakker, K.K. 2000. Avian occurrence in woodlands and grasslands on public areas throughout eastern South Dakota. Ph.D. dissertation, South Dakota State University, Brookings.
Grasslands (n=380) were studied throughout eastern South Dakota to investigate the influence of local and landscape attributes on the occurrence and density of grassland birds. Variables analyzed included percent perimeter comprised of woody vegetation and proportion of trees within 400 m (50 ha/124 ac), 800 m (201 ha/497 ac), and 1600 m (804 ha/1987 ac) radii from the transect center. Savannah Sparrow occurrence was halved when woodland habitat within 400m of a surveyed transect increased from 0 to 2% in grasslands in eastern South Dakota. Grasshopper Sparrows, Bobolinks, and Western Meadowlarks were also negatively associated with increased proportions of woodland habitat in the landscape. Management recommendations included removing woodland habitat within or adjacent to grasslands and acquiring/preserving grassland patches large enough [≥125-250 ha (309-618 ac)] to attract the majority of grassland obligates. Additionally, it was recommended to place priority on purchasing and conserving grasslands in landscapes with high amounts of grassland habitat (≥ 40% within 1600 m of the patch) and low amounts of woodland habitat (<1.0% within 400 m).

Berger, R.P. and R.K. Baydack. 1992. Effects of aspen succession on sharp-tailed grouse, Typmpanuchus phasianellus, in the Interlake Region of Manitoba. Canadian Field-Naturalist 106:185-191.
Seven leks of aspen-parkland populations of Sharp-tailed Grouse were abandoned between 1976 and 1986 in the Narcisse Wildlife Management Area in Manitoba. During this time, the closed forest area within 3.14 km^2 of each lek increased from an average of 1.3 km^2 to 2.0 km^2. The authors concluded that the habitat within 1 km of a lek can be comprised of no more than 44% closed aspen forest and at least 23% prairie to sustain a population of grouse. Once aspen succeeds to >56% forest and less than 15% prairie remains, the lek will likely be abandoned.

Bergin, T.M., L.B. Best, and K.E. Freemark. 1997. An experimental study of nest predation on artificial nests in roadsides adjacent to agricultural habitats in Iowa. Wilson Bulletin 109:437-448.
The relationship between the characteristics of roadsides and artificial nest success was examined in south-central Iowa. Transects containing 10 nests were set up along 136 transects and categorized as follows: 1) disappearance of

eggs with no disturbance, 2) disappearance of eggs with disturbance, and 3) broken or crushed egg shells in or near nest bowl and roadsides where characterized as wooded, herbaceous vegetation with fencerows and herbaceous vegetation without fencerows. Variables measured included habitat of the roadside and adjacent habitat. Wooded roadsides and roadsides with fencerows had significantly greater nest predation in the first category than did herbaceous fencerows. The authors speculated that these fencerows provide cover for mammalian predators and elevated perches for avian predators. In addition, some predators (American crows, raccoons) may have affinities for wooded habitats and use them for travel and foraging.

Bergin, T.M., L.B. Best, K.E. Freemark, and K.J. Koehler. 2000. Effects of landscape structure on nest predation in roadsides of a Midwestern agroecosystem: a multiscale analysis. Landscape Ecology 15:131 143.

The relationship between the landscape surrounding roadsides and artificial nest success was examined in south-central Iowa. Transects containing 10 nests were set up along 136 transects and categorized as follows: 1) disappearance of eggs with no shell left behind 2) broken or crushed egg shells in or near nest bowl. Landscape structure was quantified within 200, 400, 800, 1200, and 1600 m of the transect line as proportion of habitat types. Proportions of woody vegetation variables included woodland block cover, wooded strip cover, wooded fencerows, and wooded riparian strips. Woodland block cover, wooded roadsides, and wooded fencerows were positively associated with predation of artificial nests at all spatial scales. The authors speculated that woody vegetation provides cover for mammalian predators and elevated perches for avian predators. In addition, some predators (American crows, raccoons) may have affinities for wooded habitats and use them for travel and foraging. The presence of wooded cover increases the likelihood that predators will come in contact with nests in roadsides.

Bollinger, E.K. 1995. Successional changes and habitat selection in hay field bird communities. Auk 112:720-730.

In a study on the effects of successional changes in vegetation on grassland bird communities in 90 hayfields in New York, the first variable entering regression models for abundance of Savannah Sparrows was a negative association with the percentage of the field bordered by woods. Red-winged Blackbirds, Bobolinks, Eastern Meadowlarks, Upland Sandpipers, and Henslow's and Grasshopper Sparrows did not exhibit a relationship with percent of field edge in woods.

Bollinger, E.K. and T.A. Gavin. 1992. Eastern Bobolink populations: ecology and conservation in an agricultural landscape. In Ecology and Conservation of neotropical land birds, ed. J.M. Hagen III and D.W. Johnston. Smithsonian Institute Press, Washington, D.C., pp. 497-506.

In New York, Bobolink abundance was significantly lower (0.01 males/100 ha or 247 ac) in fields with approximately 25% woody coverage (woody shrubs and saplings) than in old hayfields (2.5 males/100 ha) with little (<25%) woody cover. Habitats with >25% woody coverage were determined to be unsuitable for Bobolinks.

Burger, L.D., L.W. Burger, Jr., and J. Faaborg. 1994. Effects of prairie fragmentation on predation on artificial nests. Journal of Wildlife Management 58(2):249-254.
In a study using artificial nests containing quail eggs in 15 prairie fragments in southwest Missouri, it was determined that nests <60 m from woody cover were less successful (28.7 vs. 7.9% predation rates) than those > 60 m from woody cover. Additionally, distance to woody cover explained twice as much variation in predation rates as grassland size. Woody cover was defined as woodlots, riparian areas, hedgerows, and fencerows.

Coppedge, B.R., D.M. Engle, R.E. Masters, and M.S. Gregory. 2001. Avian response to landscape change in fragmented southern Great Plains grasslands. Ecological Applications 11:47-59.
This study was conducted to examine avian response to landscape changes associated with juniper *Juniper virginianus* invasion into native grasslands and agriculture conversion by CRP in Oklahoma from 1965-1995 using 3 Breeding Bird Survey routes. Composition of 11 cover types were delineated within 400 m of each survey point within BBS routes. Most grassland birds exhibited population declines related to the invasion of woody vegetation. From 1981-1995, grassland bird populations declined or exhibited negative associations with woody vegetation gradients. In particular, Western Meadowlark populations declined across a gradient of increasing encroachment.

Cully, J.F., Jr. and H.L. Michaels. 2000. Henslow's sparrow habitat associations on Kansas tallgrass prairie. Wilson Bulletin 112:115-123.
Habitat characteristics of Henslow's Sparrows were examined on the Fort Riley Military Reservation in Kansas, 1995-1996. Survey points were located in tallgrass prairie habitat defined as grassland (n=35), savanna (n=44), or woodland edge (n=40, located within 100 m of extensive riparian habitat). Henslow's Sparrows selected grassland habitat (21/36) significantly more often than either savanna (10/36) or woodland edge (5/36). The presence of some low woody vegetation did not affect use at the microhabitat scale.

Davis, S.K., D.C. Duncan, and M. Skeel. 1999. Distribution and habitat associations of three endemic grassland songbirds in southern Saskatchewan. Wilson Bull. 111:389-396.
Bird surveys were conducted throughout the prairie ecozone of Saskatchewan to determine habitat associations of 3 grassland birds (Sprague's Pipit, Baird's Sparrow, Chestnut-collared Longspur). Baird's Sparrows were associated with pastures having greater coverage of grasses >10 cm tall and sparse shrub coverage.

Davis, S.K. and S.G. Sealy. 2000. Cowbird parasitism and nest predation in fragmented grasslands of southwestern Manitoba. *In* J.N.M. Smith, T.L. Cook, S.I. Rothstein, S.G. Sealy, and S.K. Robinson, eds. Ecology ad Management of Cowbirds: Studies in the conservation of North American Passerine Birds. Univ. of Texas Press, Austin.

The authors found that female cowbirds were more abundant and nests were more frequently parasitized on the smallest (22 ha/54 ac) of 3 grassland sites where nesting studies were conducted. This site also had shrubs (wolf willow, western snowberry, and *Salix* spp.) bordering nearly the entire site. The authors attributed increased cowbird activity to the increased availability of perches found at this site as compared to the other study areas.

Delany, M.F., H.M. Stevenson, and R. McCracken. 1985. Distribution, abundance, and habitat of the Florida grasshopper sparrow. Journal of Wildlife Management 49:626-631.

Grasshopper Sparrows in Florida used treeless habitat on poorly drained soils that averaged 19.2% shrub cover. This is not a prairie population of Grasshopper Sparrows and it was noted that the shrub coverage was much higher than reported in habitats used by other races of Grasshopper Sparrows.

Delisle, J.M. and J.A. Savidge. 1996. Reproductive success of grasshopper sparrows in relation to edge. The Prairie Naturalist 28:107-113.

In southeast Nebraska Conservation Reserve Grasslands, none of the 10 Grasshopper Sparrow nests were located within 50 meters of edge habitat (wooded draws, roadsides, and cropland).

Esler, D. and J.B. Grand. 1993. Factors influencing depredation of artificial duck nests. Journal of Wildlife Management 57:244-248.

Four 10 ha (25 ac) plots were established within a 187 ha (462 ac) meadow complex to assess depredation rates on artificial duck nests in Alaska. All plots were bordered on one side by forest habitat. Distance to nearest forest edge did not differ between depredated and undisturbed nests.

Fuhlendorf, S.D., A.J.W. Woodward, D.M. Leslie, Jr., and J.S. Shackford. 2002. Mulitscale effects of habitat loss and fragmentation on lesser prairie-chicken populations. Landscape Ecology 17:617-628.

This study was conducted to determine the effect of landscape structure and change (1959-1996) on population dynamics of the Lesser Prairie-chicken in western Oklahoma and northern Texas. Population trends were calculated using long-term data obtained from the Oklahoma Department of Wildlife Conservation and Texas Parks and Wildlife. Landscape composition was quantified surrounding 10 leks using aerial photographs taken between 1959 and 1996. Landscapes with declining Lesser Prairie-chicken population trends also had significantly greater increases in tree cover types (riparian, windbreaks, juniper encroachment) standardized to per decade basis at the 7,238-ha scale than landscapes with sustained populations. Landscapes with declining populations also had significantly more cropland [7,238-ha (17,886 ac) scale], changes in landscape composition between 1959 and 1996 [3,619- and 7,238-ha (8,943 and 17,886 ac) scales], and edge density [452-, 905- and 1,810-ha (1,117-, 2,236-, and 4,473-ac) scales].

Gabbert, A.E., A.P. Leif, J.R. Purvis, and L.D. Flake. 1999. Survival and habitat use by ring-necked pheasants during two disparate winters in South Dakota. Journal of Wildlife Management 63:711-722.

Pheasant survival and habitat use during 2 consecutive winters (a typical winter followed by a severe winter) were compared at 3 sites in eastern South Dakota. The proportion of 10 habitat types within 1,035 ha (2,558 ac) study areas was delineated using a Geographical Information System (GIS) to determine habitat preference of wintering hens. During the typical winter and the early part of the severe winter, cattail wetland, tall grass (>75cm) and food plot habitats ranked highest in hen use. For the surviving pheasants, woodland/farmstead and food plot habitats were preferred during the late stages of the severe winter. Overall mortality was higher during the severe winter but mortality due to weather was not different between winters. Mortality due to predation was significantly greater than mortality due to weather in both winters. Data from 31 of 41 deaths during the severe winter corresponded with blizzards, indicating an increased vulnerability during severe weather. The authors concluded that cattail wetlands, grassland habitat and food plots are crucial for winter survival of pheasants. During severe winters (1 every 15-10 years), dense woody habitat may prevent near or total pheasant loss.

Gates, J.E. and L.W. Gysel. 1978. Avian nest dispersion and fledgling success in field-forest ecotones. Ecology 59(5):871-883.

Fledging success and increasing distance from edge were positively correlated and highly significant. Higher rates of nest predation <46 m from edges versus habitat interiors was attributed to higher nest densities of open-nesting or edge species as well as increased predator activity by ecotones. Brown-headed cowbird parasitism was also higher near edges.

Gazda, R.J., R.R. Meidinger, I.J. Ball, and J.W. Connelly. 2002. Relationships between Russian olive and duck nest success in southeastern Idaho. Wildlife Society Bulletin 30:337-344.

The relationship between Russian olive abundance, nesting magpies, and duck nest success was investigated on management areas in southeastern Idaho at both the local and landscape scale, 1992-1993 and 1995-1996. Management areas were classified by the proportion of the area dominated by Russian olive (0-5%=low, 10-30%=moderate, >50%=high). Russian olive was considered dominant at ≥1 tree per hectare. Incorporating nest search results with unpublished annual estimates of duck nest success (429 nests), a total of 1,134 nests were analyzed. Duck nest success was 6.8% where Russian olive abundance was high, 19.8% in moderate areas and 42.9% in areas with low Russian olive abundance. During the second time period a 654-ha management area was divided into a treatment area (Russian olive removed) and a control area (no removal). A total of 705 duck nests were monitored. Mallard and other upland nesting duck species (grouped) nest success did not differ after removal of Russian olive. Median distance to active magpie nest and median distance to nearest Russian olive did not differ between successful and depredated nests. Artificial nests were established along transects with increasing distance to nearest Russian olive (5, 25, 75, and 150 m). Artificial nest survival exhibited an increasing trend with distance from nearest Russian olive. The authors recommended controlling the invasion of Russian olive early on while it is still effective and economically feasible and urged managers to carefully consider the risks associated with accepting or introducing trees into historically treeless areas.

Hanowski, J.M., D.P. Christian, and G.J. Niemi. 2000. Landscape requirements of prairie sharp-tailed grouse *Tympanuchus phasianellus campestris* in Minnesota, USA. Wildlife Biology 6(4):257-263.

Landscape composition was quantified around active and inactive lek sites at 4 spatial scales (200, 500, 1000, and 3000 m buffers around lek points) in brush landscapes in northeast Minnesota. Active prairie sharp-tailed grouse leks had significantly lower proportions of upland forest and brush cover types and higher percentages of native grasses within 500 and 1000 meters of the site than inactive leks. No differences were detected at the 200 m scale. Logistic regression indicated that active lek sites were located in areas with less conifer regeneration and upland forest. The authors determined that grouse were sensitive to even small increases (1-2%) in the amount of woody vegetation in their homerange and successful management should include an assessment of planted conifers within the lek vicinity.

Hanson, L.E. and D.R. Progulske. 1973. Movements and cover preferences of pheasants in South Dakota. Journal of Wildlife Management 37:454-461.

Movement patterns of ring-necked pheasants were studied from June to October using radiotelemetry. Nine cover types were used by pheasants (corn, small grains, residual cover, pasture, summer fallow, alfalfa, shelterbelts, ditches, spoil plots). Residual cover and small grains were the most heavily used during June and the first _ of July. Seventy-five percent of all locations during the second _ of summer were in corn fields. Alfalfa was the preferred habitat in both day and night and during all months. Shelterbelts were used intermittently.

Helzer, C.J. 1996. The effects of wet meadow fragmentation on grassland birds. M.S. Thesis, University of Nebraska, Lincoln.

Grasshopper Sparrow abundance increased significantly when >75 meters from wooded edges and >50 meters from cornfield edges in Nebraska.

Herkert, J.R. 1994a. Breeding bird communities of Midwestern prairie fragments: the effects of prescribed burning and habitat-area. Natural Areas Journal 14:128-135.

Three edge species, Common Yellowthroats, Song Sparrows, and American Goldfinches, were positively associated with woody stem density in 24 grasslands in Illinois. Grassland nesting species were not associated with woody stem density. The author recommended management to remove woody encroachment and scattered trees to eliminate features attractive to nest predators and nest parasites.

Herkert, J.R. 1994b. Status and habitat selection of the Henslow's sparrow in Illinois. Wilson Bulletin 106: 35-45.

Native and restored prairies and non-native cool-season grass and fallow fields (n=24) were studied in Illinois to identify habitat features that influence the distribution and abundance patterns of Henslow's Sparrows. There was no significant difference in woody stem density between occupied and unoccupied fields.

Hughes, J.P., R.J. Robel, K.E. Kemp, and J.L. Zimmerman. 1999. Effects of habitat on dickcissel abundance and nest success in conservation reserve program fields in Kansas. Journal of Wildlife Management 63:523-529.

Dickcissel abundance was negatively associated with the percentage of woody perimeter and the amount of woodland habitat within 800 meters of the CRP field (n=11) in northeastern Kansas. Daily nest survival rates were associated only with field-level vegetation attributes.

Johnson, R.G. and S.A. Temple. 1990. Assessing habitat quality for birds nesting in fragmented tallgrass prairies. In J. Verner, M.L. Morrison and C.J. Ralph, eds. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Univ. Wis. Press, Madison, Wis.

Nest productivity and probability that a species' nest would occur in grassland habitat types defined by size of the grassland fragment, its proximity to forest edge, and the number of growing seasons since last burn were compared in western Minnesota. Nesting success was significantly higher for nests located >45 m from a forest edge. The highest rate of nest productivity for each species (Clay-colored Sparrow, Savannah Sparrow, Grasshopper Sparrow, Bobolink, Western Meadowlark) was detected in habitats far (>45 m) from forest edges. Probability of occurrence of a Clay-colored Sparrow nest was significantly higher in habitats <45 m from a forest edge.

Probability of Grasshopper Sparrow and Western Meadowlark nest occurrence was lower in habitats <45 m from forest edges. It was recommended that management decisions be based on nest productivity rather than occurrence and that prairie fragments managed for grassland birds should be devoid of forest edges.

Johnson, R.G. and S.A. Temple. 1990. Nest predation and brood parasitism of tallgrass prairie birds. Journal of Wildlife Management 54(1):106-111.

Nest predation rates were lower for 5 species (Clay-colored, Savannah and Grasshopper Sparrows, Bobolink, Western Meadowlark) in large fragments (≥130 ha or 321 ac) and in fragments ≥45 meters from woody vegetation. Brood parasitism also was lower for all 5 species far (≥45) from wooded edges. The authors recommended making grasslands as large as possible and removing woody vegetation that creates edges to enhance nesting success.

Johnston, D.W. and E.P. Odum. 1956. Breeding bird populations in relation to plant succession on the Piedmont of Georgia. Ecology 37:50-62.

Grasshopper sparrows were found in fields with ≤10% shrub coverage and were absent from fields containing ≥35% shrub cover. Eastern Meadowlarks were found primarily in fields with shrub cover ≤10%.

Kahl, R.B., T.S. Baskett, J.A. Ellis, and J.N. Burroughs. 1985. Characteristics of summer habitats of selected nongame birds in Missouri. University of Missouri-Columbia, Agricultural Experiment Station Research Bulletin 1056, Columbia, Missouri.

The authors studied old fields and grasslands in Missouri to determine characteristics of nongame bird habitat associations. They found Eastern Meadowlarks mainly in grasslands which had few woody stems <2.5 cm dbh and no woody stems ≥2.5 cm dbh. Habitat around Dickcissel song perches contained few or no woody stems <2.5 cm dbh and no woody stems ≥2.5 cm dbh. Typical Grasshopper and Henslow's Sparrow habitat was characterized as having no woody invasion >1m tall.

Kantrud, H.A. and K.F. Higgins. 1992. Nest and nest site characterisitics of some ground-nesting, non-passerine birds of northern grasslands. Prairie Naturalist 24:67-84.

Nests of grassland birds other than waterfowl were found in various nesting studies from 1963-1991. Researchers searched a minimum of 5600 ha (13,838 ac) of native grasslands, 1400 ha (3,460 ac) of seeded grassland, and 1000 ha (2,471 ac) of cropland. Northern Harrier nests were located in mainly in undisturbed grasslands with short brush. Stands of shrubs, particularly western snowberry, contained over 1/2 of the 129 Northern Harrier nests.

Larsen, D.T., P.L. Crookston, and L.D. Flake. 1994. Factors associated with ring-necked pheasant use of winter food plots. Wildlife Society Bulletin 22:620-626.

Thirteen food plot and surrounding landscape characteristics were evaluated to determine associations with winter food plot (n=174) use by Ring-necked Pheasants. Food plots were studied during 4 consecutive winters (1988-89 through 1991-92). Woody vegetation variables included percent tree cover and percent tree understory with high visual obstruction of shelterbelts, distance to nearest tree cover, and distance to trees with high visual obstruction. The presence of wetland and grass cover in the surrounding landscape were the most important variables in determining food plot use. Woody vegetation variables appeared to be negatively associated with winter food plot use.

Madden, E.M., R.K. Murphy, A.J. Hansen, and L. Murray. 2000. Models for guiding management of prairie bird habitat in northwestern North Dakota. American Midland Naturalist 144:377-392.

Bird use and vegetative characteristics were surveyed in 160 (1993) and 150(1994) sample points distributed over 9 prescribed burn units exhibiting a wide range of postfire successional stages. Clay-colored sparrows had a 69% probability of occurrence in grasslands with 3% shrub coverage. Probability of occurrence increased to 95% when shrub coverage reached 20%. Baird's Sparrow incidence dropped below 50% with 18% shrub coverage.

Mankin, P. C. and R. E. Warner. 1992. Vulnerability of ground nests to predation on an agricultural habitat island in East-central Illinois. American Midland Naturalist 128:281-291.

Artifical ground nests (n=388) in a 61 ha (151 ac) study area in Illinois were studied to determine the effects of local habitat characteristics on predation. Pheasant and/or brown chicken eggs were placed in each nest. The authors speculated that crows from an adjacent woodlot may have been responsible for total removal of eggs in artificial nests during one trial of the study.

McCarthy, C., T. Pella, G. Link, and M.A. Rumble. 1997. Greater prairie chicken nesting habitat, Sheyenne National Grassland, North Dakota. USDA Forest Service, General Technical Report RM-GTR-298.

A habitat suitability index (HIS) based on vegetation height/density was used to evaluate nesting habitat conditions on the Sheyenne National Grassland (SNG). The HIS predicts that adequate nesting cover is present when 80% of the area supports herbaceous vegetation with a VOR of 2-3. The authors determined that the prairie chicken population on the SNG is avoiding extirpation by nesting in small limited areas with adequate nesting cover and that the encroachment of woody vegetation is contributing to a decrease in adequate nesting cover.

McKee, G.M., R. Ryan, and L.M. Mechlin. 1998. Predicting greater prairie-chicken nest success from vegetation and landscape characteristics. Journal of Wildlife Management 62:314-321.

The authors measured nest site vegetation characteristics (including percent woody cover) and distance from nest to nearest edge (any transition in vegetation, e.g., fencerows, habitat types, woody draw, creeks, trails) or tree (woody stems ≥2 m high) to determine the effects on nest success in 2 public areas [1,670 and 485 ha (4,127 and 1198 ac) in size] in southwestern Missouri. Sixty nests were studied over 3 years, 1990-1992. Nest success declined with increasing woody cover and litter. Only 3 of 17 nests hatched when woody cover was >5%. Conversely, when woody cover was ≤5% 15 of 26 nests hatched. Models using litter and woody cover correctly predicted greater prairie-chicken nest success 81% of the time. Models combining litter cover and distance to tree did produce significant models which correctly predicted nest success 76% of the time but models including only distance to tree were not significant.

Merrill, M.D., K.A. Chapman, K.A. Poiani, and B. Winter. 1999. Land-use patterns surrounding greater prairie-chicken leks in northwestern Minnesota. Journal of Wildlife Management 63:189-198.

From 1986-1996, 389 unique Greater Prairie-Chicken leks were observed and classified as either traditional (males displayed in lek ≥6 of 11 years) or temporary (leks used <5 of 11 years). Lek points had significantly less forest (1.6 vs11.0%) and residential land and more Conservation Reserve Program grasslands (20 vs. 15.9%) within 810 ha (2,002 ac) than did non-lek points. Temporary leks had significantly greater percentages of forest (3.1 vs. 1.6% means) and cropland (49.8 vs. 43.9%) within 810 ha than did traditional leks.

Michaels, H.L. and J.F. Cully, Jr. 1998. Landscape and fine scale habitat associations of the loggerhead shrike. Wilson Bulletin 110:474-482.

Loggerhead Shrikes were positively associated with savannah habitat (sites that contained >15 shrubs or trees but no continuous woody habitat) within 250 meters of surveyed points (n=119) on Fort Riley Military Reservation, Kansas. However, there were no significant differences in mean tree or shrub density within the patch between used and unused sites. The authors concluded Loggerhead Shrikes were selecting for tallgrass prairie with scattered woody vegetation.

Munson, E.S. 1992. Influence of nest cover on habitat selection in clay-colored sparrows. Wilson Bulletin 104:525-529.

Clay-colored Sparrows selected territories containing dense stands of 2 species of woody vegetation (1.8 and 7.6 stems per meter within territories versus 0.02 and 4.3 outside territories) in central Wisconsin.

Naddra, R. and D. Nyberg. 2001. Effects of afforestation of pastures on bird abundance. Transactions of the Illinois State Academy of Science 94: 243-250.

Bird abundance in an afforested area (land not previously forested that had trees planted on it), a remnant forest, and a grassland habitat was studied in a 400 ha (988 ac) preserve in Illinois. Seventeen species were observed only in the grassland, 9 only in remnants, and 5 only in afforested areas. Overall species richness between habitats was similar, 32 in both the grassland and afforested area and 39 in the remnant forest. The abundance of birds per station per visit was 11.2 for forest remnants, 8.4 for grassland habitats, and 3.8 for afforested areas. The afforested area was determined to be fairly mature with an estimated plant date of 1955. The authors determined that the negative impacts of woodland habitats on grassland birds are not offset by a substantial benefit of afforested areas to woodland birds.

Newton, J.L. and E.J. Heske. 2001. Predation on artificial nests in small grassland patches in east-central Illinois. American Midland Naturalist 145:29-38.

Predation of artificial nests containing quail (June and July) and zebra finch (July only) eggs was studied in 11 fields [0.8 to 12.6 ha (2.0 to 31 ac)] to determine the relationship between distance to woodland edge (<10, 25 and 50m) and nest fate. Quail egg depredation was 33% in June and the quail finch depredation rate was 78% in July. Predation rates did not decrease with increasing distance to woody edge or patch area. The authors speculated that the small size of fields studied is below the threshold at which edge effects are detectable (i.e., the entire patch is functioning as edge habitat).

Niemuth, N.D. 2000. Land use and vegetation associated with greater prairie-chicken leks in an agricultural landscape. Journal of Wildlife Management 64:278-286.

Landscape was quantified at 5 spatial scales (400, 800, 1200, 1600, 2000, and 2400 m concentric rings) around active leks and random points in central Wisconsin. Active leks had higher percentages of grassland, shrub, and wetland cover and lower percentages of row crop, hay, and forest cover than random points. Forest cover was lower at active sites at the 400 (approx. 6 vs 20%) and 800 (approx. 15 vs 28%) m scales. The positive association with shrub cover was attributed to the degradation of grassland habitat and strong site fidelity to leks, not a preference for shrub cover during the nesting season.

O'Leary, C.H. and D.W. Nyberg. 2000. Treelines between fields reduce the density of grassland birds. Natural Areas Journal 20:243-249.

Grassland species set up territories primarily in the interior of fields with woody edges. Numbers of singing males of 5 species (Savannah Sparrow, Grasshopper Sparrow, Henslow's Sparrow, Eastern Meadowlark, and Bobolink) increased in fields of similar size with progressively less woody edge. Savannah Sparrow numbers increased from 2 in a 16.3 ha (5 to 40 ac) field with 8 trees and 20 shrubs per ha to 14 in a 15.1 ha (37 ac) field with 0.1 trees and no shrubs per ha. All fields were located in the same study area in Cook County, Illinois.

Olson, R.A. and L.D. Flake. 1975. Nesting of ring-necked pheasants in eastern South Dakota. Proceedings of the South Dakota Academy of Sciences 54:126-136.

Ring-necked pheasant nests (n=184) were located in nine habitat types during a 2 year study in eastern South Dakota. A total of 56 nests were found in idle farmland, 28 in roadsides, 24 alfalfa fields, 17 in tame hay, 16 in small grain fields, 15 in fencerows, 15 n pastures, 8 in shelterbelts, and 5 in flax fields. The highest hatch rate was 34.1% in idle farmland, followed by 13.6% in both roadsides and small grain fields. The hatch rate for shelterbelts was 9.1%. The lowest hatch rates were detected in fencerows and pastures (2.3%).

Overmire, T.G. 1962. Nesting of the dickcissel in Oklahoma. Auk 79: 115-116.

In central Oklahoma, 74.5% of 94 Dickcissel nests were located off the ground, mainly in woody vegetation.

Pasitschniak-Arts, M. and F. Messier. 1996. Predation on artificial duck nests in a fragmented prairie landscape. Ecoscience 3:436-441.

Artificial duck nests (n=1110) were analyzed in 3 habitats: native grassland, delayed hay fields, and rights-of-way, in 2 Canadian National Wildlife Area in southcentral Saskatchewan. Except in rights-of-way, nest transects were placed at right angles to habitat edge. In the first area, nests were placed 75, 150, 250, and 400 m into the habitat interior. In the second area, nests were placed 75 and 150 m in. Higher predation rates were detected along the edges versus habitat interiors in the first wildlife area. No significant effect of distance to edge was detected in the second area. The authors inferred that shorter, less dense grassland vegetation may facilitate medium and large-sized predator movement farther into grasslands. Type of edge was not delineated in this study.

Renfrew, R.B. 2002. The influence of patch and landscape characteristics on grassland passerine density, nest success, and predators in southwestern Wisconsin pastures. Ph.D. Dissertation, University of Wisconsin-Madison.

Grassland bird (Savannah Sparrow, Grasshopper Sparrow, Bobolink, Eastern Meadowlark) density and nesting success was studied in 74 pastures in southwestern Wisconsin 1997-1999. Woody vegetation variables measured included the percent woods at 3 spatial scales (200-, 700-, and 1200-m), a woodland connectivity index, nest distance to woody and non-woody edge, and nest distance to nearest type of edge. Savannah Sparrows avoided smaller pastures and concentrated in larger areas as the percentage of woodlands increased within the landscape. Similarly, when the landscape was comprised of many woods, the density of Savannah Sparrows increased with proportion of grassland in the landscape. Eastern Meadowlark density was negatively associated with the proportion of woods in the landscape. Total nest density for 3 analyzed groups: total of all species, Savannah Sparrow, and species other than Savannah Sparrows(Grasshopper Sparrow, meadowlarks, Bobolink), increased linearly with distance from edge. However, the type of edge, wooded or non-wooded, was not a significant predictor of nest density within 50 m of the edge for any group. Savannah Sparrow daily survival rates (DSR) and daily predation rates (DPR) did not differ between nests near wooded or non-wooded edges. For all other species combined, DSR of nests <100 m from non-wooded edges were significantly higher than nests <100 m from wooded edges. Nests located <50 m from non-wooded edges had significantly higher DSR and lower DPR than nests near wooded edges. Video camera footage indicated at least 11 species depredating bird nests. One-third of the documented predation events were caused by predator species that prefer wooded edges. These species usually depredated nests closer to wooded than any other edge type and traveled up to 190 m into pastures. Management recommendations included prioritizing landscapes with little woods and removal of wooded areas, treelines, and shrubby hedgerows near pastures when feasible.

Ribic, C.A. and D.A. Sample. 2001. Associations of grassland birds with landscape factors in southern Wisconsin. American Midland Naturalist 146:105-121.

Grassland birds (Savannah Sparrow, Bobolink, Eastern Meadowlark, Grasshopper Sparrow) were surveyed in 38 south-central Wisconsin fields. Woody vegetation variables included distance to woodlot (the distance from the transect perimeter to the nearest trees, hedgerows or shrubs) and proportion of the landscape within 200, 400, and 800 m from the perimeter of the surveyed transect comprised of shrub swamps, upland shrubs, woodlots, scattered trees and shrubs, hedgerows, and isolated trees. Bobolink abundance was negatively associated with the area of woodlots within 800 meters of the transect edge. Eastern Meadowlark abundance was higher the farther the woodlots were away from the survey transect. Total density of grassland bird species of management concern (12 species) was highest when woodlots were farther from transects. The authors recommended prioritizing landscapes with low cover and patch size of nonlinear woody habitats such as woodlots to manage for grassland species.

Roseberry, J.L. and W.D. Klimstra. 1970. The nesting ecology and reproductive performance of the eastern meadowlark. Wilson Bulletin 82:243-267.

Data from 450 nests studied in Illinois indicated that Eastern Meadowlarks nested in pastures, hayfields, soilbank fields, winter wheat fields, and idle and fallow areas. The only prerequisites for utilization appeared to be the absence of woody vegetation or shrubs in the immediate area and the presence of dead grass stems at ground level.

Rumble, M.A. and L.D. Flake. 1983. Management considerations to enhance use of stock ponds by waterfowl broods. Journal of Range Management 36:691-694.

Stock pond (n=36) use by Mallard broods was negatively associated with the occurrence of trees along the pond edge in western South Dakota.

Sample, D.W. 1989. Grassland birds in southern Wisconsin: habitat preference, population trends, and response to land use changes. M.S. Thesis, Univ. Wisconsin-Madison.

Bobolink density was negatively associated with the percent woody cover 1-3 and 3-6 m above the ground. Western Meadowlarks preferred treeless areas with <0.7% woody cover. Upland Sandpiper density was negatively correlated with percent woody cover. Horned Larks were negatively related to percent woody cover 1-3 m above ground and total percent woody cover. Sedge Wrens occupied areas with an average of 2% total woody cover. Savannah Sparrows used areas with less than 1% woody cover.

Shugart, H.H. and D. James. 1973. Ecological succession of breeding bird populations in northwestern Arkansas. Auk 90:62-77.

Horned Larks, Grasshopper Sparrows, and Eastern Meadowlarks were not present in fields invaded by shrubs and smaller trees in a study of breeding bird communities in different stages of ecological succession.

Shutler, D., A. Mullie, and R.G. Clark. 2000. Bird communities of prairie uplands and wetlands in relation to farming practices in Saskatchewan. Conservation Biology 14:1441-1451.

In a study comparing upland and wetland habitats within 4 treatment types (conventional farming, minimum tillage farming, organic farming, and wild plots) in Saskatchewan, Sedge Wrens and LeConte's, Savannah, and Clay-colored Sparrows were more numerous on wild plots. Horned Larks and Savannah Sparrows were negatively associated with the area of woody habitat within a 100 m buffer of the transect. Five species (Blue-winged Teal, American Coot, Black Tern, Barn Swallow, and Savannah Sparrow) exhibited a significant negative relationship between presence and the percentage of the habitat margin occupied by trees and shrubs.

Smith, R.L. 1963. Some ecological notes on the grasshopper sparrow. Wilson Bulletin 75:159-165.

Grasshopper Sparrows were not present in fields invaded by shrubs in Pennsylvania.

Snyder, W.D. 1984. Ring-necked pheasant nesting ecology and wheat farming on the high plains. Journal of Wildlife Management 48:878-888.

Ring-necked Pheasant hens were radio marked and monitored throughout the nesting season (1979-81) on a 2,327 ha northeastern Colorado site to determine the relationships of weather, vegetation, and land use to nest site selection and nesting success. Woody cover use ranked second to wheat stubble during prelaying, dispersal and harem formation. Little nesting occurred in woody cover. Nest predation was greater on or near (<0.6 km) an area with extensive tree plantings than at more distant locations (33 vs 14%). Near this area, both avian and mammalian predators decreased nesting success, whereas mammals were the major source of predation far (> 0.6 km) from the tree plantings.

Stauffer, D. F. and L. B. Best. 1980. Habitat selection by birds of riparian communities: evaluating effects of habitat alterations. Journal of Wildlife Management 44:1-15.

Pastures and haylands were preferred by Western Meadowlarks over woody areas. Western Meadowlark density was negatively correlated with sapling/tree richness.

Sullivan, B.D. and J.J. Dinsmore. 1990. Factors affecting egg predation by American crows. Journal of Wildlife Management 54:433-437.

The study was conducted on artificial duck nests to determine what variables determine the extent of crow predation on duck nests in southwestern Manitoba. Crows nested in shelterbelts, willow near wetlands or in small quaking aspen woodlots. Artificial nests were placed overwater and in the upland at varying distances from crow nests both within and outside of the crow's home-range. Nests located within a crow's home range had higher depredation rates than those outside of the home range. Depredation rates decreased as distance from the nest increased up to 700 meters from a nest. Upland nests had higher predation rates than overwater nests. The authors recommended placing upland habitat at least 700 meters and preferably >1000 meters from areas likely to be inhabited by crows.

Trautman, C.G., R.B. Dahlgren, and J.L.Seubert. 1959. Pheasant nesting. South Dakota Conservation Digest 26:18-21.

The heaviest predation rates on pheasant nests were in roadside, fencerow, and shelterbelt habitats.

Wedgwood, J.A. 1976. Burrowing owls in south-central Saskatchewan. Blue Jay 34:26-37.

Burrowing owl habitat was characterized as pasture with short prairie cover, no trees, and devoid of brush.

Whitmore, R.C. 1981. Structural characteristics of grasshopper sparrow habitat. Journal of Wildlife Management 45:811-814.

Grasshopper Sparrow territories in West Virginia had lower shrub cover than nonterritories with an average of 0.7%. Burning to remove encroaching shrubs was recommended for preservation of grasshopper habitat.

Whitmore, R.C. and G.A. Hall. 1978. The response of passerine species to a new resource: reclaimed surface mines in West Virginia. American Birds 32:6-9.

Vesper sparrows were commonly observed in open grasslands bordered by trees while Red-winged Blackbirds were reported in grasslands as well as the surrounding forest.

Wiens, J.A. 1969. An approach to the study of ecological relationships among grassland birds. Ornithological Monographs 8:1-93.

The author intensively sampled birds and vegetation in a 37 ha (91 ac) habitat in Dane County, Wisconsin during 1966. Territories of all species studied were located from 100-370 meters from woodland, on average. No Western Meadowlark, Henslow's Sparrow or Vesper Sparrow territories contained trees while 8% of Savannah Sparrow and 10% of Grasshopper Sparrow territories contained trees.

Wiens, J.A. 1973. Pattern and process in grassland bird communities. Ecological Monographs 43:237-270.

Lark Buntings and Horned Larks inhabited areas with lower densities of woody stems and decreased percentages of woody cover compared to unoccupied areas in the short grass prairie region of Colorado.

Winter, M. 1999. Nesting biology of dickcissels and Henslow's sparrows in southwestern Missouri prairie fragments. Wilson Bulletin 111:515-527.

Dickcissel nests found in 13 prairie fragments were located in forbs (45%), shrubs (29%), grass (16%), and litter (10%). There were no Henslow's Sparrow nests located within shrubby edge habitat or in close proximity to woody vegetation.

Winter, M., D.H. Johnson, and J. Faaborg. 2000. Evidence for edge effects on multiple levels in tallgrass prairie. The Condor 102(2):256-266.

Dickcissels and Henslow's Sparrows experienced decreased nesting success within 50 m of a shrubby edge versus at greater distances on 13 prairie remnants in Missouri. Artificial nest survival was lower within 30 m of forest edges. Nesting success was not affected by distances to roads, agricultural fields, or forests. Evidence indicated mid-sized carnivores were the major predators within 30 m of forest edges and visited track stations most frequently within 50 m of forest edges. The authors concluded that edge effects were more pronounced than area effects because proximity of woody habitat explained more variation in nest survival and mammal activity than did fragment size. Edge effects appeared to be caused mainly by greater exposure of nests to mid-sized carnivores. Frequency of brood parasitism by Brown-headed Cowbirds on Dickcissels increased significantly with proximity to shrubby edge and was highest within 50 m of shrubby edges.

With, K.A. 1994. The hazards of nesting near shrubs for a grassland bird, the McCown's longspur. The Condor 96:1009-1019.

In the shortgrass prairie of northcentral Colorado, over half of 78 McCown's Longspur nests were lost to predation. Nests placed beside shrubs suffered 2-3 times higher predation rates than nests in other cover types. No measurable shrub coverage was present within 1 m of successful nests. Increased predation of these nests was apparently due to increased activity of their primary predator, the thirteen-lined ground squirrel *Spermophilus tridecemlineatus*. This species places burrows in areas with high amounts of vertical cover.

Woodward, J.W.M., S.D. Fuhlendorf, D.M. Leslie, Jr., and J. Shackford. 2001. Influence of landscape composition and change on lesser prairie-chicken *(Tympanuchus pallidicinctus)* populations. American Midland Naturalist 145:261-274.

Populations of declining lesser prairie-chickens (1959-1996) in western Oklahoma, northern Texas and eastern New Mexico were associated with landscapes with greater rates of total landscape change than were populations that did not decline. Landscape change after 1959 was primarily attributed to increased tree dominated cover types (juniper encroachment into rangelands, increased riparian areas, intentional tree plantings). Most conversions of rangeland to cropland occurred prior to 1959.

Wray, T., II, K.A. Strait, and R.C. Whitmore. 1982. Reproductive success of grassland sparrows on a reclaimed surface mine in West Virginia. Auk 99:157-164.

The authors concluded that the surrounding habitat, woodlots, and pastureland, concentrated predators and resulted in low nesting success for Grasshopper, Savannah, Vesper, and Field Sparrows in the 41.5 ha (103 ac) site. American Crows were determined to be one of the major predators.

Zimmerman, J.L. 1988. Breeding season habitat selection by the Henslow's sparrow *(Ammodramus henslowii)* in Kansas. Wilson Bulletin 100:17-24.

Survey points within Henslow's Sparrow territories contained significantly less coverage by woody vegetation than points outside territories in the Flint Hills Upland. The author determined that Henslow's Sparrows prefer sites with little woody vegetation.

Table 1. The number of studies in which a species was negatively/positively associated with a measure of woody vegetation. Categories of wood include woody vegetation within the grassland patch, the percentage of the patch encompassed by woody vegetation, distance from a point (survey point, nest, etc.) to woodland habitat, and a measure of the proportion or increase of woodland habitat in the landscape surrounding a grassland patch. The number in parentheses is the total number of studies conducted on a species in each category (one study can fall into multiple categories).

Species	Woody Vegetation Within Patch +/-	% Woody Perimeter +/-	Distance to Woody +/-	Landscape +/-
Artificial nests	0/1 (1)	0/1 (1)	1/2 (4)	0/1(1)
Duck spp.	0	0/2 (2)	0/1 (1)	0/2 (2)
Northern Harrier				
Circus cyaneus	1/0 (1)	0	0	0
Ring-necked Pheasant				
Phasianus colchicus	0	0	0/3 (4)	0
Greater Prairie-Chicken				
Tympanuchus cupido	0/2 (2)	0	0/0 (1)	0/3 (3)
Lesser Prairie-Chicken				
Tympanuchus pallidicinctus	0	0	0	0/2 (2)
Sharp-tailed Grouse				
Tympanuchus phasianellus	0	0	0	0/2 (2)
Burrowing Owl	0/1 (1)	0	0	0
Upland Sandpiper				
Bartramia longicauda	0/1 (3)	0/0 (2)	0	0/0 (1)
Loggerhead Shrike				
Lanius excubitor	0/0 (1)	0	0	1/0 (1)
Horned Lark				
Eremophila alpestris	0/4 (4)	0/1 (2)	0	0
Sedge Wren				
Cistothorus platensis	0/0 (1)	0/1 (3)	0	0/0 (1)
Sprague's Pipit				
Anthus spragueii	0/2 (2)	0/1 (1)	0	0
Clay-colored Sparrow				

Table 1 (continued).

Species	Woody Vegetation Within Patch +/-	% Woody Perimeter +/-	Distance to Woody +/-	Landscape +/-
Spizella pallida	3/0 (3)	0/0 (2)	0/2 (2)	0/0 (1)
Grasshopper Sparrow *Ammodramus savannarum*	0/8 (11)	0/4 (6)	0/4 (5)	0/1 (3)
Baird's Sparrow *Ammodramus bairdii*	0/3 (3)	0/1 (1)	0	0
Henslow's Sparrow *Ammodramus henslowii*	0/4 (7)	0/1 (2)	0/3 (3)	0
LeConte's Sparrow *Ammodramus leconteii*	0/0 (1)	0/0 (1)	0	0
Lark Bunting *Calamospiza melanocorys*	0/1 (2)	0/1 (1)	0	0
Savannah Sparrow *Passerculus sandwichensis*	0/5 (7)	0/6 (7)	0/3 (6)	0/2 (3)
Vesper Sparrow *Pooecetes gramineus*	0/2 (3)	1/0 (2)	0/1 (1)	0/0 (1)
Chestnut-collared Longspur *Calcarius ornatus*	0/1 (3)	0/1 (1)	0	0
McCown's Longspur *Calcarius mccownii*	0/1 (1)	0	0	0
Dickcissel *Spiza Americana*	2/1 (6)	0/1 (2)	0/1 (1)	0/1 (2)
Bobolink *Dolichonyx oryzivorus*	0/3 (6)	0/2 (5)	0/3 (3)	0/2 (2)
Eastern Meadowlark *Sturnella magna*	0/4 (6)	0/1 (4)	0/1 (1)	0/1 (2)
Western Meadowlark *Sturnella neglecta*	0/3 (4)	0/2 (3)	0/3 (3)	0/2 (2)
Grassland Bird Group	0	0/1 (1)	0/3 (3)	0/1 (2)

MENINGEAL WORM *(PARELAPHOSTRONGYLUS TENUIS)* IN SOUTH DAKOTA: THE PARASITE IN TERRESTRIAL GASTROPODS

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ABSTRACT

Terrestrial gastropods were collected from wetland, grassland, and forested habitats throughout eastern and southcentral South Dakota from May-August of 1999 and 2000 to assess the role of gastropods in transmission of meningeal worm *(Parelaphostrongylus tenuis)* to white-tailed deer *(Odocoileus virginianus)* populations throughout the state. A total of 4,063 gastropods representing 14 species, five of which were known intermediate hosts for *P. tenuis*, were collected throughout South Dakota during the summers of 1999 and 2000. Significantly more ($P < 0.0001$) gastropods were collected from eastern than western South Dakota. Six species of snails *(Zonitoides nitidus, Z. arboreus, Discus cronkhitei, Succinea ovalis, Gastrocopta pentadon,* and *Vallonia* sp.) and one slug species *(Deroceras laeve)* accounted for 87% of the gastropods collected. A total of 3,468 gastropods were examined for presence of *P. tenuis* larvae. Three species of snails *(Z. arboreus, Z. nitidus,* and *D. cronkhitei)* and one slug species *(Deroceras laeve)* accounted for 93% of the total number of infected gastropods (i.e., 66 of 71). Significantly more ($P = 0.005$) infected gastropods were collected from semipermanent wetlands than from grasslands or forested habitats, suggesting that wetland habitats are important transmission sites of *P. tenuis* from gastropods to white-tailed deer in South Dakota.

Keywords

Gastropod, intermediate host, meningeal worm, *Parelaphostrongylus tenuis,* prevalence, South Dakota, white-tailed deer

INTRODUCTION

Meningeal worm (*Parelaphostrongylus tenuis*) is a nematode parasite that infects white-tailed deer (*Odocoileus virginianus*) populations throughout eastern North America (Eckroade et al. 1970, Carpenter et al. 1972, Thurston and Strout 1978). Although *P. tenuis* typically does not cause neurologic disease in white-tailed deer, its usual host, natural infection in moose *(Alces Alces)* (Smith and Archibald 1964, Anderson 1965), elk *(Cervus elaphus nelsoni)* (Anderson et al. 1966, Carpenter et al. 1973), fallow deer *(Dama dama)* (Kistner et al. 1977, Davidson et al. 1985), caribou *(Rangifer tarandus)* (Trainer 1973), and reindeer *(Rangifer tarandus tarandus)* (Anderson 1971) typically resulted in severe neurologic disease. Experimental infection in mule deer *(O. hemionus)* (Tyler and Hibler 1980) and black-tailed deer *(O. h. columbianus)* (Nettles and Prestwood 1977) also resulted in severe neurologic disease.

Distribution of *P. tenuis* infected white-tailed deer also is dependent on the presence of suitable terrestrial gastropod intermediate hosts (Gleich et al. 1977, Maze and Johnstone 1986, Upshall et al. 1986). Although many species of terrestrial snails and slugs act as suitable *P. tenuis* intermediate hosts, several species are the most abundant and most commonly infected. Gleich and Gilbert (1976) documented two snail species *(Discus cronkhitei, Zonitoides arboreus)* and two slug species *(Deroceras reticulatum, D. laeve)* to be the most abundant and most commonly infected species in central Maine. Van Es and Boag (1981) also found *Z. arboreus* and *D. cronkhitei* to be important in transmission of the parasite in central Alberta. Upshall et al. (1986) found that *D. laeve* accounted for 40% of the gastropods collected in New Brunswick. Although Wasel (1995) documented 14 species of terrestrial gastropods, six of which were known *P. tenuis* intermediate hosts in eastern North Dakota, no attempt was made to determine the number of individuals infected with meningeal worm. To our knowledge, the role of terrestrial gastropods in transmission of *P. tenuis* to white-tailed deer populations in South Dakota has not been documented. The objectives of this study were to determine distribution and relative abundance of terrestrial gastropods populations throughout South Dakota, to determine which species of gastropods are most important in transmission of *P. tenuis* to white-tailed deer populations in South Dakota, and to determine the number of *P. tenuis* infected gastropods with respect to habitat type and time of year in South Dakota.

STUDY AREA

As a whole, South Dakota is characterized by prairie grassland and is composed of two regions (e.g., eastern and western South Dakota), which are separated by the Missouri River (Fig. 1). Eastern South Dakota is comprised of the Prairie Coteau, Missouri Coteau, and James River Lowland Physiographic Regions (Westin et al. 1967). Brookings, Beadle, and Hughes counties (Fig. 1) are representative counties of the Prairie Coteau, James River Lowland, and the Missouri Coteau physiograhic regions, respectively. Eastern South Dakota is characterized as mid- and tall grass prairie habitat (Higgins 1999) and contains more water and receives more precipitation than semi-arid areas of western South Dakota (Johnson 1995).

Western South Dakota (Fig. 1) is comprised of the Pierre Hills, Northern Plateau, Southern Plateau, and Black Hills physiographic regions. Most of the area in western South Dakota is treeless, semi-arid, rolling upland characterized as mixed grass prairie habitat (Johnson 1976, Johnson 1988) that is drier and receives less precipitation than areas of eastern South Dakota. Gregory,

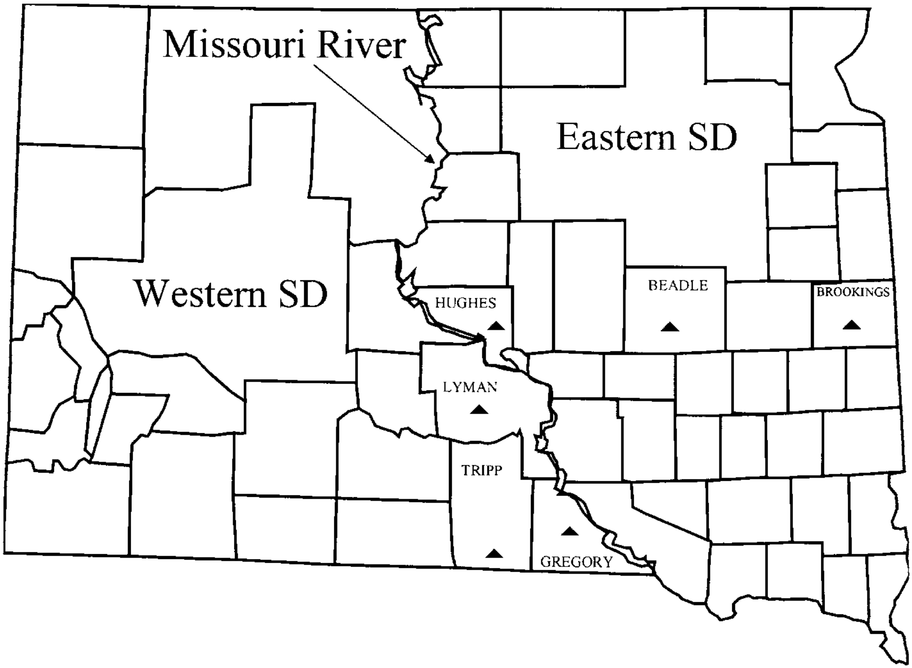

Figure 1. Terrestrial gastropod sampling in eastern and western South Dakota, 1999-2000. Note separation of eastern from western South Dakota by the Missouri River. Black lines delineate individual boundaries while names identify specific counties; ▲ denotes gastropod collection sites.

Tripp, and Lyman counties (Fig. 1) lie in the Great Plains and Southern Plateau physiographic regions of western South Dakota.

MATERIALS AND METHODS

Terrestrial gastropods were collected from the wet meadow zone of semi-permanent wetlands, mid-grass prairie habitats, and forested habitats in Brookings, Beadle, and Buffalo counties from May-August 1999 and in Gregory, Mellette, and Lyman counties from May-August 2000. Gastropods were collected from five randomly selected study locations per habitat type per county sampled. Gastropods were trapped using 30 x 30 cm cardboard traps (Gleich and Gilbert 1976). Traps were soaked in water and laid flat on the ground. In each study location, a location center was chosen. Once the location center was chosen, a random compass bearing was taken and traps were placed every 15 m along a 150-m transect. All traps were consecutively numbered along established transect lines. There were four gastropod collection periods (15-30 May, 15-30 June, 15-30 July, 15-30 August) and collection in each of the six counties was completed in one to two days. Following each collection period, each trap was soaked in water and randomly relocated three meters from the original trap location.

Gastropods were identified according to the criteria of Pilsbry (1940, 1946, 1948). To detect the presence of *P. tenuis* larvae recovered from collected gastropods, gastropods were artificially digested using a pepsin-HCl procedure described by Kocan (1985). Gastropod tissue placed in petri dishes was artificially digested in a solution of 1.0% pepsin and 1.0% HCl for four to six hours at 37° C. Slides prepared with all of the digestate were examined microscopically for meningeal worm larvae. Infective third-stage *P. tenuis* larvae were distinguished from other nematode larvae based on body measurements and tail morphology (Anderson 1963, Ballantyne and Samuel 1984).

RESULTS

A total of 4,063 terrestrial gastropods representing 14 species, five of which were known intermediate hosts for *P. tenuis*, were collected throughout South Dakota during the summers of 1999 and 2000. Six species of snails *(Z. nitidus, Z. arboreus, D. cronkhitei, Succinea ovalis, Gastrocopta pentadon,* and *Vallonia* sp.) and one slug species *(Deroceras laeve)* accounted for 87% of the gastropods collected (Table 1). *Deroceras laeve* was the most ubiquitous species and was collected from each of the three habitat types in all six counties. Furthermore, 36 of 71 (51%) infected gastropods were *D. laeve.* Three species of snails *(Z. arboreus, Z. nitidus,* and *D. cronkhitei)* accounted for 42% of the total number of infected gastropods. Furthermore, *S. ovalis* also was found to be infected with *P. tenuis* (Table1).

Table 1. Terrestrial gastropods, including known *Parelaphostrongylus tenuis* intermediate hosts, collected from South Dakota, 1999-2000.

Gastropod species	Number collected	Known intermediate hosts[1]
Snails		
Zonitoides arboreus	229	*
Gastrocopta pentadon	832	
Euconulus fulvus	107	
Helicodiscus parallelus	2	
Vallonia sp.	389	
Hawaiia minuscula	205	
Succinea ovalis	472	*
Succinea avara	3	
Zonitoides nitidus	342	*
Discus cronkhitei	489	*
Oxyloma sp.	55	
Vertigo sp.	148	
Haplotrema sp.	16	
Slugs		
Deroceras laeve	774	*
TOTAL	**4,063**	

[1] Known intermediate hosts in the literature and this study.

Relative abundance of gastropods was significantly higher (χ^2 = 280.72; *df* = 28, 3561; *P* < 0.0001) in eastern (*n* = 3,221) than in western South Dakota (*n* = 841). There were no significant differences (*F* = 1.40; *df* = 2, 3464; *P* = 0.246) in relative abundance of gastropods between semipermanent wetlands (*n* = 1,320), forested habitats (*n* = 1,750), or grassland habitat types (*n* = 993) throughout eastern and western South Dakota.

A total of 3,468 randomly selected gastropods were examined for the presence of *P. tenuis* larvae. Prevalence of infection with *P. tenuis* in gastropods differed significantly (*F* = 5.33; *df* = 2, 3467; *P* = 0.005) between habitat types. Significantly more infected gastropods were collected from semipermanent wetlands (mean = 0.033, SE = 0.004) than from grasslands (mean = 0.016, SE = 0.005) or forested habitats (mean = 0.015, SE = 0.004). There was no significant difference (*F* = 0.094; *df* = 1, 2457; *P* = 0.759) in prevalence of infection between grassland and forested habitat types. Prevalence of infection did not differ with time of year (*F* = 2.476; df = 3, 3466; *P* = 0.060). Similarly, 33 of 71 (46.5%) infected gastropods were collected from semipermanent wetlands while 23 of 71 (32.4%) infected gastropods were collected from forested habitats. Only 15 of 71 (21%) infected gastropods were collected in mixed-grass prairie habitats. Furthermore, 72% (51/71) of infected gastropods were collected in June (24 of 71 infected gastropods) and July (27 of 71 infected gastropods). Only eight of 71 (11.3%) infected gastropods were collected in May. And 12 of 71 (16.9%) infected gastropods were collected in August.

DISCUSSION

For *P. tenuis* to become established in a region, a number of ecological conditions must first be satisfied to facilitate transmission, including the presence of suitable terrestrial gastropod intermediate hosts. In this study, significantly (*P* < 0.0001) more gastropods were collected in eastern than in western South Dakota. This may be related to differences in precipitation and wetland density between the two regions of the state. Johnson (1995) reported a higher prevalence of wetland habitats in eastern than in western South Dakota. Furthermore, eastern South Dakota receives more rain than drier areas of western South Dakota (Johnson 1995). Upshall et al. (1986) suggested that gastropods prefer habitats that provide a moist refuge in which to estivate during hot, dry weather. Eastern South Dakota may provide more suitable gastropod habitat than western South Dakota.

Similarities in gastropod abundance between habitat types in South Dakota possibly reflects the difficulty in obtaining an accurate numerical assessment of gastropod abundance due to the influence of temperature change and variable precipitation throughout the trapping period (May-August). Boag (1990) reported that gastropod population estimates are confounded by the high variance in the number of gastropods collected at any one trapping period. In this study, abundance of gastropods varied unpredictably with daily temperature, precipitation, time of day during gastropod collections, and trap condition (e.g., wet vs. dry) upon recovery of gastropods. In a study to assess the validity of gastropod abundance estimates using cardboard traps, Wasel (1995) found that repeated surveys of the same area revealed that species richness was most consistent when traps remained damp, undisturbed, and checked during cooler daytime temperatures associated with early morning. The time of day gastropods were recovered and the frequent dry condition of the traps at the time of recovery possibly contributed to the lack of a significant difference in gastropod relative abundance between habitat types in South Dakota. Furthermore, collection activities often extended into mid-afternoon when daily temperatures were at or approaching a maximum. In these hot, dry conditions it is unlikely that gastropods sought refuge under traps.

Prevalence of infection with *P. tenuis* was significantly ($P = 0.005$) higher in gastropods collected from wetland habitats than from forested or mixed-grass prairie habitats. Upshall et al. (1986) suggested that hardwood forests in New Brunswick may have served as important *P. tenuis* transmission sites from infected gastropods to deer and moose due to the availability of gastropods and the feeding site selection of these ungulates. Stewart and Kandrud (1971) reported that the wet meadow zone of semipermanent wetlands in the glaciated prairie region were mostly dominated by low to medium-height grasses, rushes, sedges, and forbs or woody vegetation. Moreover, white-tailed deer have been described as concentrate selectors, meaning they selectively forage for high-quality, easily digestible plant parts (Demarais et al. 2000). Regular sampling from a wide range of species allows deer to continually evaluate new sources of nutrition (Demarais et al. 2000). Vegetation consumed in the wet meadow zone of semipermanent wetlands may provide deer with a high-quality, easily digestible energy source. Furthermore, because 46.5% (33/71) of infected gastropods were collected from the wet meadow zone of semipermanent wetlands, we suggest that wetland habitats are important transmission sites of *P. tenuis* from gastropods to white-tailed deer in South Dakota.

Prevalence of infection with *P. tenuis* in gastropods did not differ ($P = 0.060$) with time of year, however, differences tended toward significance. In this study, 72% (51/71) of infected gastropods were collected between 5 June and 31 July. Only eight of 71 (11.3%) infected gastropods were collected in May while 12 of 71 (16.9%) infected gastropods were collected in August. Upshall et al. (1986) suggested the low number of gastropods infected in May would be an important factor with respect to potential transmission of infected gastropods to cervids. Getz (1959) reported that *D. laeve* is seldom active at temperatures below 14° C and was relatively unavailable for ingestion by deer and moose until this temperature was reached. In South Dakota, it is possible that cooler spring temperatures might restrict gastropod activities, rendering them relatively unavailable for ingestion by foraging white-tailed deer until a minimum ambient temperature is reached. We suggest that most white-tailed deer in South Dakota likely become infected with *P. tenuis* between mid-June and late July.

Upshall et al. (1986) and Lankester and Anderson (1968) found *D. laeve* to be the most abundant and most commonly infected intermediate host in New Brunswick and Navy Island, Ontario, respectively. Furthermore, Lankester and

Anderson (1968) reported that relative to other gastropod species collected, *D. laeve* was unusually active on Navy Island. In this study, *D. laeve* was the most abundant and most heavily infected gastropod collected in South Dakota. Because *D. laeve* has been reported as being unusually active, it is likely that these individuals encountered greater numbers of infective third stage *P. tenuis* larvae than other known intermediate host species. The importance of *D. laeve* as an intermediate host in South Dakota might possibly reflect the activity level of this species.

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HATCHING DATES AND DAILY GROWTH OF AGE-0 BLACK CRAPPIES IN PICKEREL LAKE, SOUTH DAKOTA

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ABSTRACT

We assessed hatch dates and daily growth rates of age-0 black crappies *Pomoxis nigromaculatus* during 2001 and 2002 in Pickerel Lake, South Dakota. Hatching of black crappies in Pickerel Lake during 2001 occurred over a duration of 39 d, beginning on May 26 (day 146) and continuing until July 5 (day 185). Hatching duration during 2002 was much shorter, occurring over a 19-d period from June 5 (day 157) to June 25 (day 176). Mean hatch date was significantly different ($P = 0.01$) between 2001 (June 14) and 2002 (June 16); however, this represented a difference of only 2 d. Daily growth rate of age-0 black crappies was significantly correlated ($r = 0.48$, $P = 0.03$) to hatch date in Pickerel Lake during 2001 indicating that later hatched crappies tended to exhibit faster growth than crappies hatched earlier in the year; this relationship was not apparent in 2002. Daily growth rates did not significantly differ ($P > 0.05$) between years, and on average age-0 black crappies grew 0.68 mm/d (SE = 0.01) from swim-up until time of capture in August. In both years, hatch date and daily growth explained 99% of the variability in total length (TL) of age-0 black crappies collected in August ($R^2 = 0.99$, $P = 0.0001$). In both years, daily growth explained the majority of variation (62-68%) in TL of age-0 black crappies, while hatch date explained most of the remaining variability (31-37%)

INTRODUCTION

Black crappie *Pomoxis nigromaculatus* populations in many South Dakota natural lakes demonstrate erratic recruitment (Guy and Willis 1995). Hatching date can influence the growth rates (Travnichek et al. 1996; Sammons et al. 2001) and potential survival (Pine and Allen 2001) of age-0 crappies *Pomoxis* spp., consequently affecting crappie recruitment. Previous studies have shown a positive relationship between individual body sizes and overwinter survival in other centrarchids (Shuter and Post 1990; Miranda and Hubbard 1994; Cargnelli and Gross 1997). DeAngelis et al. (1993) linked starvation vulnerability of smallmouth bass *Micropterus dolomieu* to body size, with the smaller individuals exhibiting higher mortality than larger individuals. Shuter and Post (1990) reported a reduction in the ability of age-0 fishes to compensate metabolic demands and survive winter due to reduced feeding activity experienced for the duration of ice cover on a lake. Hatch timing can determine age-0 centrarchid sizes entering their first winter (Goodgame and Miranda 1993; Cargnelli and Gross 1996; Sammons et al. 1999), consequently affecting age-0 fish survival and the size distribution of age-0 cohorts following cold-water periods (Shuter and Post 1990; DeAngelis et al. 1993).

Earlier-hatched crappies often grow slower than later-hatched individuals within the same age-0 cohort (Travnichek et al. 1996; Pine and Allen 2001; Sammons et al. 2001). However, earlier hatch dates could offset faster growth rates achieved by later-hatched individuals (Ludsin and DeVries 1997). Consequently, earlier-hatched individuals of an age-0 cohort can potentially attain larger sizes before winter onset relative to later-hatched members within the same cohort (Cargnelli and Gross 1996; Ludsin and DeVries 1997; Sammons et al. 1999).

Increased growth rates of later-hatched black crappies have been shown to compensate for delayed hatching dates and later-hatched cohorts may disproportionately contribute to year class strength (Pine and Allen 2001). However, Sammons et al. (2001) documented faster mean growth across years for earlier-hatched crappies relative to later-hatched cohort members in a Tennessee reservoir. To determine if hatch timing influenced age-0 black crappie size structure and daily growth in Pickerel Lake, South Dakota we estimated hatching dates and daily growth rates of age-0 black crappies.

METHODS

Age-0 black crappies were collected from 380-ha Pickerel Lake (Day County) during the first week of August in 2001 and 2002 using a bag seine (15.2-m long, 6.4-mm bar mesh). Sampling sites (N = 20) were randomly selected and remained fixed throughout the duration of the study to reduce bias in catch per unit effort (CPUE; number per seine haul) that might result from inconsistent black crappie catchability among sites. All black crappies were measured (total length, TL) to the nearest mm and sagittal otoliths were removed from randomly selected fish for hatch-date estimation from daily ring enumeration (Sweatman and Kohler 1991). Otoliths were wiped clean on a paper towel and placed in vials to air dry for a minimum of 2 weeks prior to mounting. One whole otolith per fish was mounted to a slide (convex side down) with cyanoacrylic cement and otolith images were projected through a binocular compound microscope (400 x) to a television monitor to aid in enumeration of daily rings. An individual reader counted daily rings three times under magnification and the average of the three counts was used to estimate hatching date. In some instances, otoliths were wet polished on 1,000-grit sandpaper and a drop of immersion oil was added to improve clarity. Daily growth (DG) from swim-up until time of capture was determined as:

$$DG = (TL - 4\text{ mm})/(\text{average ring count} - 4\text{ d}),$$

because black crappies hatch at approximately 4 mm and swim-up approximately 4 d after hatching (Travnichek et al. 1996).

Mean hatch dates were compared between years using a t-test for unequal variance between samples (Schlotzhauer and Littell 1997). Variance in daily growth rates and variance in TL of age-0 black crappies in seine hauls were equal between years; hence, means were compared with a t-test. The relationship between hatch date and daily growth was assessed using Pearson correlations. For both years, stepwise multiple regression was used to determine the relative importance of hatch date and daily growth in explaining variation in TL of age-0 black crappies collected in August.

RESULTS AND DISCUSSION

Mean seining CPUE for black crappies in Pickerel Lake ranged from 21.7 per haul (SE = 17.4) in 2002 to 86.9 per haul (SE = 3.8) in 2001. Total lengths of age-0 black crappies in August seine hauls varied substantially, ranging from 19 to 56 mm (Fig. 1). Mean TL of age-0 black crappies was not significantly different (*P* > 0.05) between years (36 mm).

Hatching of black crappies in Pickerel Lake during 2001 occurred over a duration of 39 d, beginning on May 26 (day 146) and continuing until July 5 (day 185; Fig. 2). Hatching duration during 2002 was much shorter, occurring over a 19-d period from June 5 (day 157) to June 25 (day 176; Fig. 2). Mean hatch date was significantly different (t = -2.69, df = 27, P = 0.01) between 2001 (June 14) and 2002 (June 16); however, this represented a difference of only 2 d. In 2001, black crappies in

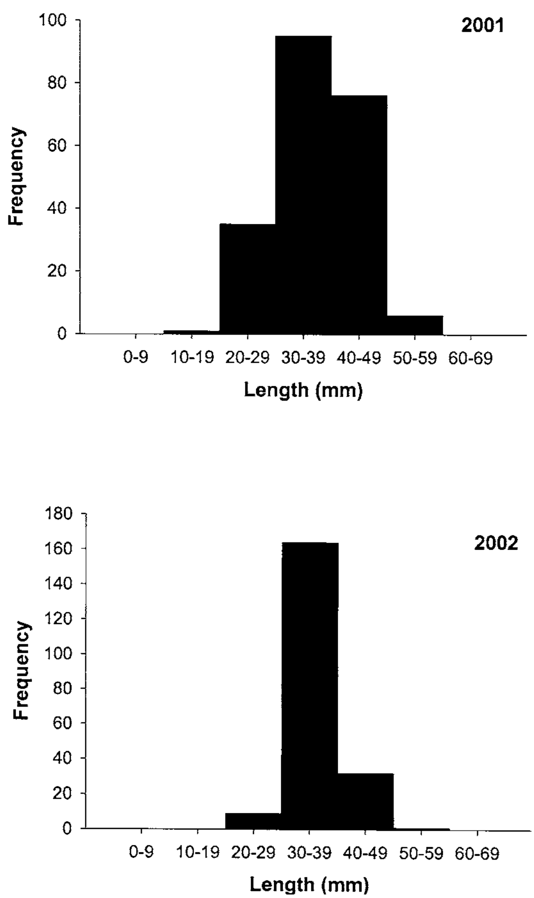

Figure 1. Length frequency of age-0 black crappies collected by shoreline seining during August of 2001 and 2002 from Pickerel Lake, South Dakota.

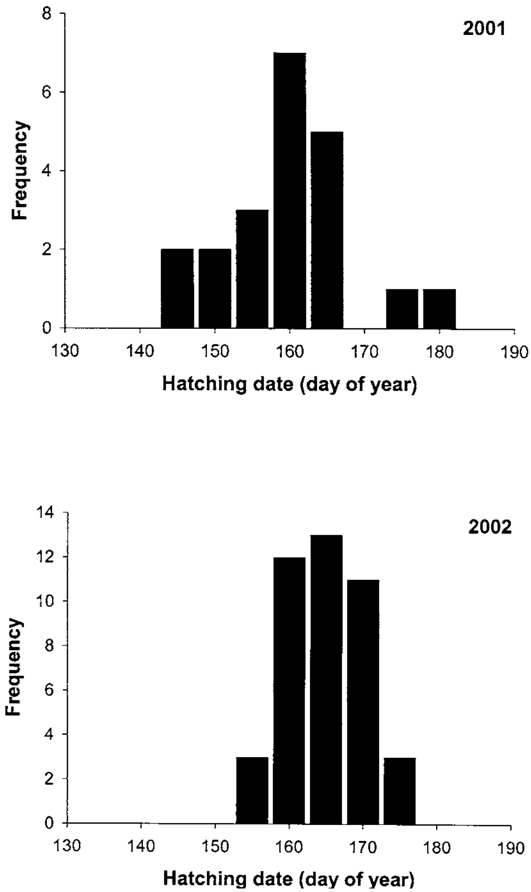

Figure 2. Hatching-date distributions for age-0 black crappies collected from Pickerel Lake, South Dakota during August of 2001 and 2002. Day 152 = June 1.

Pickerel Lake began hatching approximately 10 d earlier and continued hatching 5-8 d longer than in 2002.

Hatching durations reported here may be shorter than in other South Dakota waters. Previous larval sampling in South Dakota lakes revealed the presence of larval crappie during late July and early August (Pope and Willis 1998). Additionally, August 2001 seine surveys on Waubay Lake, a 6278-ha lake located approximately 1.6 km from Pickerel Lake, yielded numerous age-0 black crappies that were < 20 mm TL (D. Isermann, unpublished data). Pickerel and Waubay lakes differ greatly in size and volume, which likely results in differential water warming rates, which could affect the timing of black crappie spawning events. Although the presence of these smaller fish throughout the summer suggests that in some South Dakota lakes black crappie hatching may be much more protracted than reported here, age-0 crappies of this size may not have been adequately sampled by our seine. In Pickerel Lake, black crappies < 20 mm were rare (1 of 419) in the August seine samples we collected.

Hatching durations reported here were shorter than those reported for age-0 black crappies in one Florida lake (12 weeks; Pine and Allen 2001) and for age-0 white crappies *P. annularis* in a Tennessee reservoir (42-53 d; Sammons et al. 2001), but were similar to crappies (21-32 d; white, black, and F1 hybrid) in Weiss Lake, Alabama (Travnichek et al. 1996) and hatch durations reported by Pope and Willis (1998) for two other South Dakota waters. Pope et al. (1996) did find evidence of multiple egg clutches in some female black crappies collected from a South Dakota impoundment.

Mean daily growth rates did not significantly differ between years (t = -0.43, df = 61, P = 0.67), and on average age-0 black crappies grew 0.68 mm/d

(SE = 0.01) from swim-up until time of capture in August (Fig. 3). Mean daily growth rate exhibited by age-0 black crappies in Pickerel Lake was substantially lower than those reported by Pope and Willis (1998) for two other South Dakota waters (1.03-1.18 mm/d); however these earlier estimates did not account for crappie size at time of swim up (4 mm; Chatry and Conner 1980), which likely inflated estimates of daily growth. Mean daily growth rates of age-0 black crappies in Pickerel Lake were similar to or lower than rates reported for populations in the southeastern United States (0.52-0.82 mm/d; Travnichek et al. 1996; Pine and Allen 2001; Sammons et al. 2001).

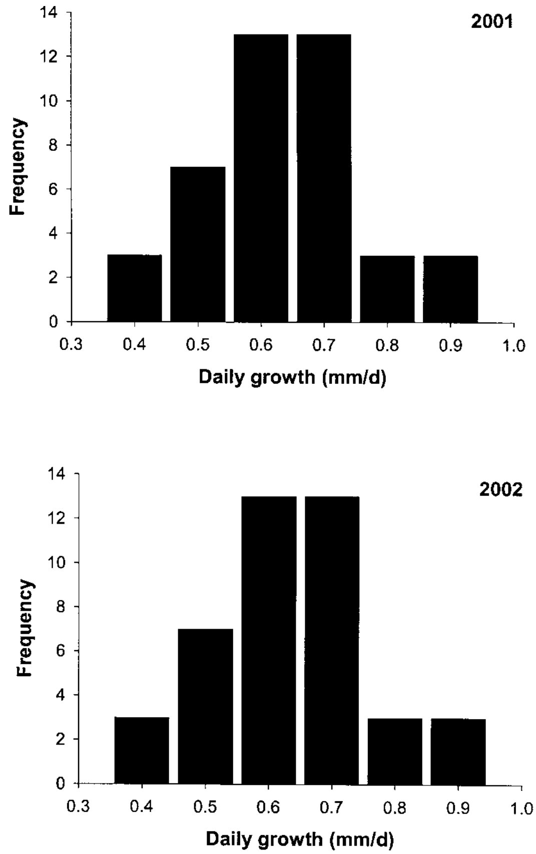

Figure 3. Daily growth rates (mm/d) for age-0 black crappies collected from Pickerel Lake, South Dakota during August of 2001 and 2002.

Daily growth rates of age-0 black crappies were significantly correlated to hatch date in Pickerel Lake during 2001 (r = 0.48, df = 21, P = 0.03) when hatch duration was more protracted, indicating that later-hatched crappies tended to exhibit faster growth than crappies hatched earlier in the year; this relationship was not apparent in 2002 when hatching occurred over a shorter duration. Previous studies have noted relationships between hatch timing and daily growth of age-0 crappies, demonstrating that crappies hatched later in a given year exhibited faster daily growth than earlier-hatched members of the same cohort (Travnichek et al. 1996; Pine and Allen 2001; Sammons et al. 2001). Increased growth of later-hatched crappies has been potentially linked to warmer water temperatures experienced by later-hatched fish (Pine and Allen 2001; Sammons et al. 2001). Our results suggest that the relationship between hatch timing and daily growth may occur as a function of hatching duration, with shorter hatching windows resulting in a reduced probability of differential growth among crappies hatched on different dates.

In both years, hatch date and daily growth explained 99% of the variability in TL of age-0 black crappies collected in August (R^2 = 0.99, P =0.0001). Dai-

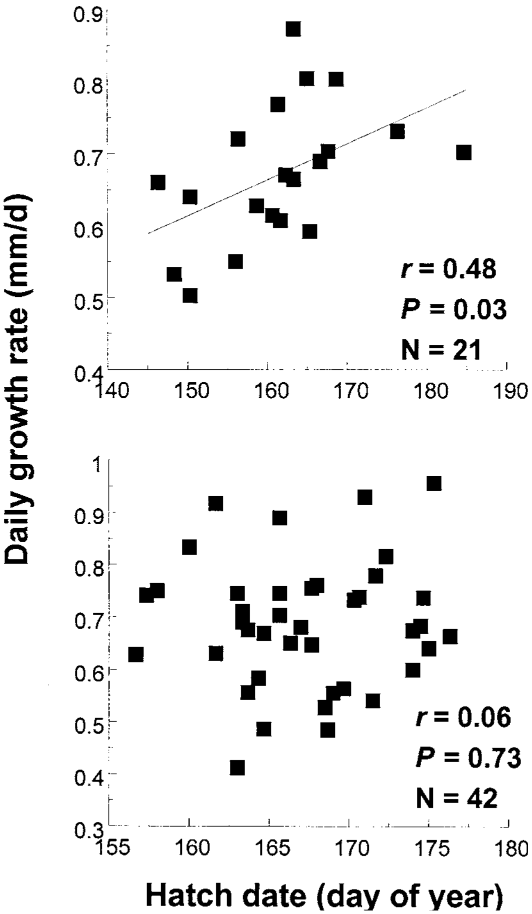

Figure 4. Relationship between daily growth and hatching date for age-0 black crappies collected from Pickerel Lake during August of 2001 and 2002.

ly growth explained the majority of variation in TL of age-0 black crappies (r^2 = 0.62-0.68; P < 0.05), while hatch date explained most of the remaining variability (r^2 = 0.31-0.37; P < 0.05). Multicollinearity may have existed between hatch date and daily growth in 2001, as we found a significant correlation between these two variables.

Previous research has suggested that hatch date may regulate recruitment of centrarchids through differential growth and survival of fish hatched during different time periods (Cargnelli and Gross 1996; Pine et al. 2000; Pine and Allen 2001). Despite the positive relationship between daily growth and hatch date in 2001, our results suggest that, regardless of hatch timing, daily growth rates play an important role in determining the size attained by age-0 black crappies in Pickerel Lake during their first growing season. Hence, variation in daily growth within an age-0 black crappie cohort could result in differential survival if mechanisms such as foraging efficiency, predation, and overwinter survival operate in a size-selective manner similar to that reported for other species (Cargnelli and Gross 1996; Fullerton et al. 2000; Pine et al. 2000).

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STRETCHING A BARBED WIRE FENCE

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ABSTRACT

A barbed wire suspended between two fence posts forms a catenary. Fixed at one post, a 213 ft span of barbed wire was tightened to 113 lb tension by a fence stretcher located near the other end post. The sag in the middle of the catenary was 3.30 ft. Tightening the wire to 177 lb reduced the sag to 2.30 ft. This single catenary was then lifted onto nails in a straight line on three evenly-spaced in-between posts; thus reducing the tension to 158 lb. Based on the wire weight, a mathematical analysis shows the theoretical cable tension to be reasonably close to the observed value. The barbed wire posses some elasticity, and Young's Modulus was estimated to be 15.8 X 10^6 psi.

Keywords

Catenary, barbed-wire fence

INTRODUCTION

Catenary, a word derived from Latin, means chain. Today the word catenary refers to the shape taken under the influence of gravity by a chain or flexible cable of uniform density freely suspended between two fixed points.

The mathematics of the shape of a catenary, and its application to suspension bridges, goes back hundreds of years. Galileo in 1638 thought the shape of a hanging chain was a parabola, the curve of a projectile in flight (Boyer, 1991). Cables hanging under their own weight are loaded uniformly along the horizontal, and do not form a perfect parabola (Beer and Johnston, 1977). The difference between a parabola and a catenary is small, however, when the cable is tight. In the early part of the eighteenth century Bernoulli formulated complex catenary equations under different loadings, and showed the effects of elasticity ("stretch") of a cable by incorporating Hooke's law into the equations. The mathematics of inelastic and elastic cables, including those used for suspension bridges, is given by Irvine (1981). The dynamics of suspended cables involves rigorous mathematics and has numerous applications ranging from the aerodynamic failure of the Tacoma Narrows bridge in 1940 to the pitch of vibrating stringed instruments as a result of tension.

Figure 1 shows a profile of a uniform inextensible cable hanging from two fixed end points (A and B) at the same elevation. "Span" is the straight-line distance between the end points, and is designated by the letter L. "Sag" is the deflection to the lowest point, and is designated by the letter h. For this paper, using Cartesian coordinates, x and y are the horizontal and vertical distances from the center point C.

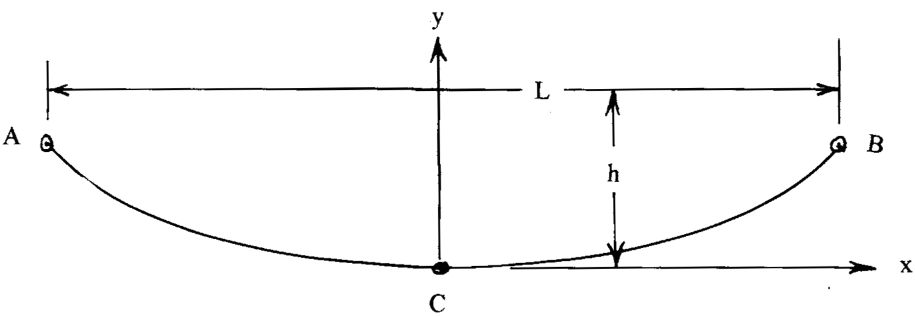

Figure 1. Cartesian coordinates for a cable suspended between two fixed points.

BARBED WIRE FENCE EXPERIMENT

The purpose of this paper is to evaluate the applicability of catenary equations during the installation a barbed wire fence. Barbed wire is a cable and follows the mathematical analyses developed for cables.

In October, 2002, a fence was built near Hill City, SD, on the author's property. The area is located on a nearly flat flood plain of Slate Creek, and the end posts are very nearly at the same elevation. Figure 2 is a sketch of the fence installation. The span is 213 ft. [Note: for the purpose of the accuracy required in the following calculations, it is assumed that this span measurement is accurate to six significant figures.] The end posts are typical in that they con-

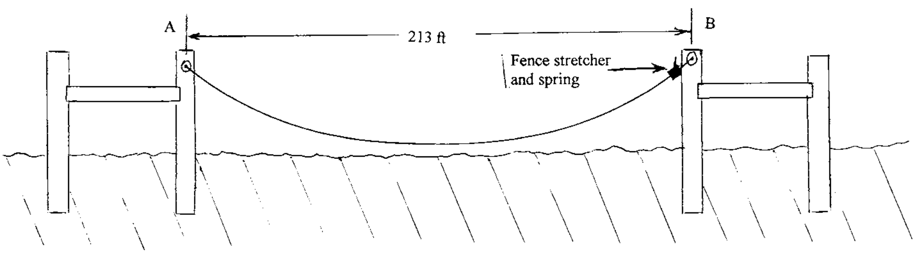

Figure 2. Sketch of barbed wire and fence posts at Slate Creek. The span is 213 ft.

sist of double posts supported by a cross beam and diagonal wires. A barbed wire was to be attached to the end posts approximately 3 ft above the ground. It is assumed that the end posts at A and B are completely immovable and the span is a constant 213 ft. End point A is the location of a staple ("U-nail") firmly attaching the wire. Point B is the location of another staple that has not been firmly affixed; the wire is free to move through it.

The barbed wire is double-wound, galvanized, two point, Sierra 12¾ gauge barbed wire. Each strand has a diameter equal to 1/12.75 = 0.07843 inch = 1.99 mm. A roll of barbed wire 80 rods in length (1320 ft) weighs 68 lb. [Note: in the English system the unit of force is pound (of force). To avoid ambiguity this is often referred to as lb_f. In the metric system the unit of force is a Newton.] The unit weight (w) of the barbed wire equals 68 lb_f/1320 ft = 0.0515 lb_f/ft.

To develop tension in the wire, a standard fence tightener ("fence stretcher") was utilized. This device was located very near end post B (Fig. 3). A calibrated spring was attached to the fence stretcher so that tensional force could be measured. The spring is capable of measuring up to 200 lb force, and was calibrated before and after the experiment to ensure that it functioned correctly.

Figure 4 shows the initial setup when 113 lb of tensional force was applied to the wire. This lifted the wire off the grass, forming a catenary. The deflection at 1/8 spacing between the end points A and B is shown. The sag (in the center) is 3.03 ft. The reason the deflection is not perfectly symmetrical is undoubtedly due to the weight (7 lb) of the fence stretcher located 2 ft from end

Figure 3. Photograph of end post B showing fence stretcher and spring.

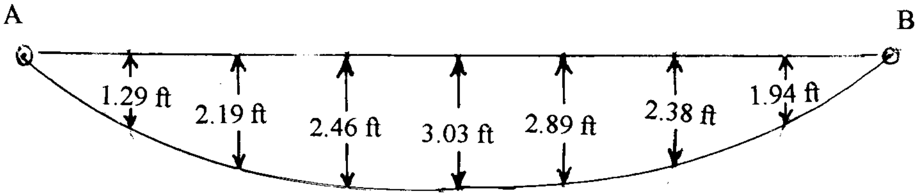

Figure 4. Initial setup using 113 lb tension, showing deflection at 1/8 spacing.

point B. The weight of this device actually constitutes a small point load, but for the purpose of this experiment does not negate the general conclusions relating to a wire forming a catenary by its own unit weight.

The fence stretcher was then cranked tighter, increasing the tension while reducing the sag. At 127 lb the sag was 2.76 ft, at 138 lb the sag was 2.60 ft, at 157 lb the sag was 2.35 ft, and finally at 177 lb the sag was 2.30 ft.

At this last setup (177 lb tension), the wire was then manually lifted and loosely draped over a nail in the exact center of the 213 ft span. This nail is on a straight line between A and B; its coordinates are (0,h). Two catenaries were thus formed, and the tension was observed to drop from 177 lb to 162 lb. The sag in the middle of the two catenaries averaged 0.54 ft.

The wire was then further lifted so as to be draped over nails on a straight line on three posts evenly spaced between end posts A and B. Four catenaries were thus formed, and the tension dropped to 158 lb. The sag in the middle of the four catenaries averaged 0.14 ft.

WIRE LENGTH AND EXTENSION

The theoretical basis for catenary length is shown in Beer and Johnston (1977). If the sag (h) is small relative to the span (L), then the length (s_B) of a suspended cable is:

$$s_B = x_B\{1 + 2/3(y_B/x_B)^2 - 2/5(y_B/x_B)^4 + \ldots\}.$$

Figure 1 shows end point B that has the coordinates x_B and y_B. Because the origin of the Cartesian system is point C, s_B is the cable length from point C to point B only. Since the span is 213 ft, x_B = 106.5 ft. Accordingly, y_B is the sag (h). Using the initial setup where h = 3.03 ft, the cable length is:

$$\begin{aligned} s_B &= 106.5 \text{ ft}\{1 + 2/3(3.03 \text{ ft}/106.5 \text{ ft})^2 - 2/5(3.03 \text{ ft}/106.6 \text{ ft})^4 + \ldots\} \\ &= 106.5 \text{ ft}\{1 + 0.000,539,6 - 0.000,000,066 + \ldots\} \\ &= 106.555,746 \text{ ft.} \end{aligned}$$

Therefore the entire cable length is 213.114,92 ft, which can be rounded off to 213.115 ft.

Similarly, when the sag was reduced to 2.30 ft, the cable length would be only 213.066 ft. The difference between these two (theoretical) lengths is 0.049 ft.

When the fence stretcher was cranked from 113 to 177 lb, it was observed that 0.3125 ft of barbed wire actually advanced through it, thus diminishing the length of the wire. This advance was partially offset by the attached spring which extended 0.1823 ft as the stretcher was cranked. Therefore the net advance of the wire towards point B was 0.1302 ft.

Considering both the change in the (theoretical) length of the catenary (0.049 ft) during the 113 lb and 177 lb setups, and the net advance of the wire towards point B (0.1302 ft), the barbed wire actually extended 0.1302 ft – 0.049 ft = 0.0812 ft. This shows that the barbed wire is not completely inelastic. [Most theoretical catenary loading equations assume the wire is completely rigid, somewhat like a steel chain. But an elastic material behaves differently. Consider, for example, a very long coiled spring hung as a catenary. If this spring were lifted in the center to form two catenaries the change in length of the spring would be so negligible compared to the total span length that there would be practically no reduction in tension at all.]

Based on the elasticity measurements cited above, a crude determination of Young's modulus can be made (Fig. 5). It is assumed that stress and strain plotted on arithmetic paper form a straight line through the origin (Hooke's Law). Figure 4 shows that the wire extended 0.0812 ft when the tension increased from 113 to 177 lb. This increment is plotted along a straight line going through the origin. The slope of the line can be used to determine Young's modulus (also called E, the Modulus of Elasticity). The slope of this line is 0.0014 ft/lb. Since the wire is 213.115 ft long, the strain is 6.569 X 10^{-6} ft/ft per pound. The inverse of this is a more common way of expressing Hooke's law; therefore this can be restated as 1.52 X 10^5 lb_f are required to produce a strain of 1 ft/ft. In the English system, the units for Young's modulus are pounds (force) divided by square inches (cross sectional area). The cross sectional area of the two wires = 2 (3.1416) $(0.995 \text{ mm})^2$ = 6.2205 mm^2 = 0.9641 X 10^{-2} in^2. Therefore Young's modulus is 1.52 X 10^5 lb_f/0.9641 X 10^{-2} in^2 = 15.8 X 10^6 psi. This is reasonable close to published values of Young's Modulus for steel, approximately 27 to 30 X 10^6 psi (Marks, 1941; Sears and Zemansky, 1955). It is possible that some of the extension observed in this experiment may have been

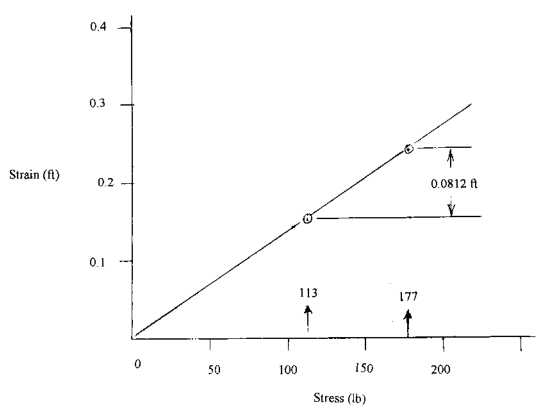

Figure 5. Data used for calculation of Young's modulus. The plot shows the change in length of the 213 ft span based on different tensional loadings.

plastic-like deformation as the barbed wire straightened along kinks as it was stretched.

DEFLECTION AND TENSION

Theoretically, the profile of an inextensible cable hanging from two fixed points at the same elevation forms a catenary. The equation for the form of a catenary utilizes a hyperbolic cosine function (Irvine, 1981). This complex formula is a result of the changing slope of the cable, and the fact that the vertical load per horizontal cable length is not everywhere the same as the vertical load measured along the inclined cable. As pointed out by Beer and Johnston (1977): "…certain catenary problems involve transcendental equations which must be solved by successive approximations." However, where the sag is small relative to the span, a hanging cable can be analyzed as a simpler parabolic curve as follows (after Beer and Johnston, 1977).

Figure 6 shows the forces involved in a catenary. The uniformly distributed load (w) is simulated by a point load (W) so that:

$$W = w \text{ (cable length).}$$

Using the initial setup:

$$\begin{aligned} W &= 0.0515\ lb_f/ft\ (213.115\ ft) \\ &= 10.9754\ lb_f. \end{aligned}$$

This vertical load occurs at the middle of the cable (point C on Figure 6A), and this would be supported by W/2 = 5.4877 lb_f upward force at the end points A and B.

For the initial setup, the sag was 3.03 ft. Considering the right half of the catenary (from point C to B), half of the total load (W/2) is shown acting at a distance L/4 = 53.25 ft from point B. The tension T_C in the cable at point C can be determined by equating the moments about point B:

$$M_B \text{ clockwise} = M_B \text{ counterclockwise}$$
$$h\ (T_C) = L/4\ (W/2)$$
$$3.03\ ft\ (T_C) = 53.25\ ft\ (5.4877\ lb_f)$$
$$T_C = 96.4425\ lb_f$$

The cable is horizontal at point C; hence T_C acts horizontally. At point B, the horizontal component must be the same as T_C, but point B also has a vertical force of 5.4877 lb_f. Therefore, the resultant cable tension at point B (T_B) can be solved as:

$$\begin{aligned} T_B &= [T_C^2 + (W/2)^2]^{0.5} \\ &= [(96.4425)^2 + (5.4877)^2]^{0.5} \\ &= 96.60\ lb_f. \end{aligned}$$

During the initial setup 113 lb tensional force was actually observed at point B. This is 17% greater than the 96.60 lb theoretical tensional force. The weight of the stretcher device undoubtedly caused the observed tension to be greater than the theoretical value.

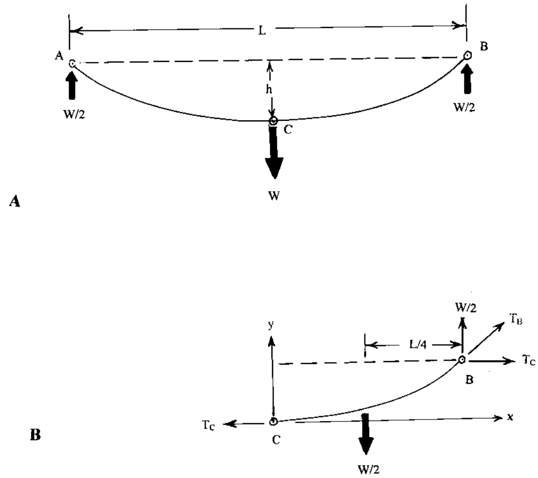

Figure 6. Free-body diagrams for catenary with span (L) and sag (h).
A. Uniformly-distributed load simulated by a point load (W) at the center.
B. Right side of catenary used for balance of moments about point B.

PRACTICAL APPLICATION

When installing a barbed wire fence, there is a natural tendency to hang the wire between the two end posts and hammer it firmly into place. This is the wrong way to do it. A barbed wire, firmly affixed and hanging in a catenary between two fence posts, contains a certain tension. Lifting this wire up onto nails in a straight line on posts in-between the end posts reduces the tension. Therefore, from a practical point of view, the best way to string a barbed wire fence is to first support it in a straight line on as many posts as practical. In other words, lift the wire up into position so that is its draped over a nail (or is free to slide through a staple) on a straight line on all the posts to be utilized between the end posts. Then apply tension to the wire. Then hammer the staples into all the posts. This approach is merely a manifestation of the common dictum that a straight line is the shortest distance between two points.

There are other practical uses of the catenary equations. For example, where a topographic low exists between the two end posts, the barbed wire may initially hang above a post in the valley. If a certain tension is ultimately sought, a sag in this catenary can be precisely established so that the ultimate desired tension is achieved when secured to the central post.

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A LONG-TERM DATABASE FOR PLANKTON POPULATIONS AND NUTRIENT LEVELS IN PRAIRIE LAKES

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ABSTRACT

A database for prairie lake phytoplankton populations, zooplankton populations, physical variables and chemical variables is presented. Samples are taken from two time periods, 1970-1979 and 1988-1997. Six lakes, Pickerel, Enemy Swim, Cochrane, Hendricks, Oak and Bitter were sampled during both time periods. Bluedog lake was sampled only in the earlier time period and Roy, East Oakwood, Tetonkaha, Round, and South Buffalo lakes were only sampled in the later time period.

Water transparency and population numbers of copepods and cladocerans declined in five of the six lakes sampled in both time periods. Chlorophyll a concentrations and Trophic State Index increased in those five lakes, even though total nitrogen concentrations did not change and total phosphorus concentrations actually decreased slightly in three of the five lakes. The lack of increase in nutrients suggests that the decrease in water transparency and increase in trophic state is cause by biological factors, particularly the decline in numbers of the larger cladocerans and copepods which filter the water and increase transparency. The sixth lake, Bitter, experienced greatly increased water tranparency, increased numbers of cladocerans and copepods, decreased Chlorophyll a concentrations, and decreased trophic state after a dramatic rise in water levels that more than doubled the volume of the lake in the mid 1990's.

As the decrease in water tranparency, and increase in Chlorophyll a may result in increased shallowness and decreased future recreational value of the lakes, investigation into reasons for the changes should be of highest priority.

INTRODUCTION

The glacial lakes of South Dakota provide recreation to citizens and habitat for wildlife and fisheries. However, the lakes have experienced growth of algal blooms (eutrophication) resulting in decreased water clarity. Incomplete decomposition of these blooms results in accumulation of black, nutrient-rich sediments, which make the lakes shallower.

Traditionally, eutrophication has been attributed to inputs of nutrients, particularly nitrogen and phosphorus (Vollenweider 1968, Dillon and Rigler 1974, Smith 1982). These nutrients can come from many sources; surface runoff from agriculture, construction, and lakeside lawn fertilization carrying nitrogen and phosphorus, ground water transporting dissolved nitrates and bioicides, leakage of oil and gas and associated trace elements from two-cycle engines on outboard motorboats, and aerial deposition of soil particles as well as particulates and other effluents from industry and power production. The latter may be a source of sulfate which may increase phosphorus release from sediments (Caraco et al 1989. Lamers et al 2002). Iron, manganese, copper and silica are also algal nutrients, and changes in these elements may bring on undesirable algal blooms (Schelske and Stoermer 1972, Goldman et al 1975, Murphy et al 1976, Storch et al 1986, Vymazol 1995).

In addition, many authors have suggested that biological changes within lakes may influence the clarity and quality of the water. Abundance of larger grazing zooplankton is associated with clearer water and less eutrophic conditions (Hrbacek et al 1961, Haney 1973, Haertel 1979, Sommer et al 1986), *Daphnia* is particularly important because of its high filtration rate; at high population densities, the lake water can be filtered several times a day (Haney 1973, Haertel 1979). Conversely, overpopulation of zooplanktivorous fishes results in loss of the larger grazing zooplankton to fish predation and subsequent increase of nuisance algal blooms. Pesticides may also reduce zooplankton populations resulting in algal blooms (Hurlburt et al 1972, Shapiro 1980). Conversely, factors which reduce the overpopulation of zooplanktivorous fishes such as winter kill (De Bernardi and Giussani 1978, Haertel and Jongsma 1982), or ecosystem management to restore the populations of larger predatory fishes (Shapiro et al 1975, Carpenter et al 1985a) may not only increase water clarity but also improve fisheries (Anderson and Weithman 1978).

This paper compiles data taken in other studies conducted on eleven lakes between 1970-1979 and 1988-1997 (hereafter refered to as the 1970's and the 1990's). During both decades nine years of data were collected over a ten year period (Haertel 1976, 1977, 1979, 1996, unpublished data, Thoreson et al 1976, Haertel and Jongsma 1982, Buskerud and Haertel 1992, Haertel and Tucker, 1993, Haertel et al 1995 and Haertel and Troelstrup 1998). Six of the lakes were sampled during both decades, allowing for long-term comparisons. This paper summarizes the midlake, openwater season data base of chemical and physical variables and phytoplankton and zooplankton populations. Littoral zone chemistry and algal populations are reported in Haertel et al (1995), Haertel (1996), and Haertel and Troelstrup (1998). Results of the statistical analyses and discussion of interactions between variables wlll be reported in a later paper.

The objectives of this study are to (1) document changes over time in the six lakes that were sampled in both decades, and (2) provide a data base for comparison with future studies of eastern South Dakota lakes.

DESCRIPTION OF THE LAKES

All of the lakes in this study are associated with glacial moraines dating back to the Wisconsin Stage of the Pleistocene Glaciation. The moraines are found on both the eastern and the western borders of the Prairie Coteau, and vary in age from 13,000 to 14,000 years, as mapped by Flint (1955) and dated by Mickelson et al (1983). Some of the lakes are located in glacial till, and some are located in outwash (Table 1). Older till sites are covered by a layer of yellowish oxidized loess about a meter thick (Flint 1955), which is absent from both the younger till sites and the outwash sites. Lakes situated in the older till which are sufficiently shallow for wave-resuspension of bottom sediments often show a yellowish color on windy days.

A major factor influencing lake ecology is the depth of the lake relative to wind exposure. Lakes which are shallower than the critical depth of the wind-generated waves experience wave resuspension of midlake sediments (Haertel 1976). These lakes will usually have more than sufficient nutrient concentrations to permit midsummer algal blooms (Harrison 1972, Barica 1974, Haertel and Troelstrup 1998). Pickerel and Enemy Swim are the deepest lakes in the study and are located in outwash associated with the older moraines (Table 1). Cochrane and Roy are the next deepest lakes and are located in till associated with the younger moraines. These four lakes are too deep to experience wave-resuspension of midlake sediments. They are not deep enough to experience more than transitory temperature stratification, however, and the water column is mixed throughout the summer season. All of the rest of the lakes in this study may experience resuspension of midlake sediments on windy days. Blue Dog, Hendricks, South Buffalo are located in outwash and may show a greyish-black color on windy days from black bottom deposits. Tetonkaha, Round and Oak are located in older till, and may appear yellowish to green on windy days depending on the amount of algae and sediment resuspension. East Oakwood is on outwash, immediately downstream from till, and intermediate in characteristics.

Both Bitter and Cochrane have no natural outlet at present water levels. Bitter Lake is a saline lake located in outwash, however, it also shows a yellowish color on windy days as sediments transported to it do not leave. Cochrane is naturally less saline than Bitter, and in addition, has an artificial outlet that was constructed in the late 1980's and an artificial inlet from less saline Lake Oliver that was opened up in 1993.

METHODS

Lakes were sampled almost weekly during the open water seasons of 1970-1972 and approximately twice a month during 1974-1979 and 1988. They were sampled from three to five dates a year during 1990-1997. When lakes were sampled only three dates per year they were always sampled at least once in the spring (after icemelt and before June 15). During most years they were also sampled during both early summer (June 15 and July 14) late summer (July 15 through September 5) Sampling during the fall (September 6 through freeze-up) was sporadic. On all dates after 1972, replicate samples were taken of all variables.

Lake Cochrane was sampled 1970-1972, 1975-1979, 1990-1994, and 1997. Hendricks was sampled 1970-1972, 1975, 1978-1979, 1990-1991, and 1994. Oak was sampled 1970, 1978-1979, 1990-1991 and 1994-1997. Pickerel was sampled 1974-1975, 1990-1992, and 1994-1996. Enemy Swim was sampled 1974-1975 and 1990-1994. Bitter was sampled 1974, 1990-1991 and 1995-1996. The following lakes were sampled in only one of the two decades, East Oakwood, 1988 and 1994, Roy, 1995-1996, Blue Dog 1974, Tetonkaha, 1988, Round 1988, and South Buffalo, 1994.

In the deeper lakes, Pickerel, Enemy Swim, Cochrane and Roy, samples were taken just below the surface and about one meter above the bottom using a Van Dorn bottle in the 1970's and a Kemmerer Bottle in the 1990's. However, in 1974, only surface samples were taken. Shallower lakes were sampled just below the surface, except for Hendricks, which was sampled at two depths in 1970-1972.

In all of the lakes, on all dates, water transparency was measured with a Secchi disc. From 1992-1997, it was also measured with a Hach 2001 P or a portable Helege turbidometer. Temperature was measured with a bucket thermometer or a Scout Model probe (Hydrolab Corporation, Austin TX). Station depth was taken with a measured line. Conductivity was measured with an Industrial Instruments Conductivity bridge model RC16B2 in the 1970's and either a LaMotte DA DS or a Scout Model in the 1990's.

During the 1970's the following methods were used for chemical variables (American Public Health Association 1971): Sodium and Potassium (atomic absorbtion), carbonate and bicarbonate (calculated from alkalinity titration), Nitrate plus nitrite nitrogen (brucine), ammonia nitrogen (direct nesslerization), organic nitrogen (total Kjeldahl), total and soluble reactive phosphorus (stannous chloride), oxygen (azide modification of the Winkler technique), silica (heteropoly blue). In addition the following variables were measured monthly during 1970-1972: Manganese and copper (atomic absorbtion), iron (phenanthrolene), calcium (EDTA titrametric) magnesium (EDTA hardness minus calcium), chloride (mercuric nitrate), and sulfate (turbidometric). Chlorophyll a was measured using the Strickland and Parsons (1968) technique (acetone extraction, colorimetric).

During the 1990's the following methods were used for chemical variables (U.S. Environmental Protection Agency 1983): Nitrate plus nitrite nitrogen, 300A ion chromatography and 354.1 colorimetric, ammonia nitrogen, 350.2 colorimetric, nessler reagent, organic nitrogen from total Kjeldahl, 353.3 colorimetric, soluble reactive phosphorus 365.2, colorimetric, ascorbic acid, total phosphorus 365.2 after persulfate digestion, and cations by atomic absorbtion (sodium 273.1, potassium, 258.1, calcium 215.1, magnesium 242.1). Chloride and sulfate were measured using USEPA method 300.6-1 (ion chromatography). Bicarbonate and carbonate were calculated from alkalinity (2320 B, 281). After 1993, the following variables were measured directly in the field: chloride (Hach 8P, silver nitrate), sulfate (Hach DR 100 colorimetric), bicarbonate and carbonate (calculated from alkalinity, Hach AL-DT, sulfuric acid), calcium and magnesium (calculated from hardness, LaMotte PHT-CM-DR). The following variables were always measured directly in the field: Silica (heteropoly blue, Hach SI-5 or SI-7, depending on concentration), iron (Hach IR-21, TPTZ), manganese (Hach MN-PAN). Chlorophyll a was measured by a modification of the Strickland and Parsons technique (1968).

Samples of water for phytoplankton counts were immediately preserved in lugol's solution and counted in a Sedgewick-Rafter cell after settling at least 20 minutes. The one milliliter thickness of the cell enabled focusing up and down through the water column to check for gas vacuole containing bluegreen algae. During the 1970's the Sedgewick-Rafter cell was inverted on a Nikon inverted microscope and random fields were counted at 400x until 100 of most abundant taxon were counted (Lund et al 1958). During 1976-1978, additional counts were made at 100x for larger taxa. During 1988-1997, a compound microscope with a short focal depth lens was used to avoid problems with refraction in inverted cell counting. Cells were counted at 300x in 1988 (three or more random fields) and both 100x and 300x from 1990-1997 (three or more crosswise swipes of the Sedgewick Rafter Cell). During all years a Whipple Disc was used to measure the filament length or colony size of larger bluegreens. Values were then converted to cells by counting average number of cells per square and multiplying by the number of squares covered. Eukaryotic cells were counted individually. Biovolume per cell is reported in Buskerud and Haertel (1992) and Haertel (1996).

During the 1970's zooplankton were collected with a closing-type Clarke-Bumpus sampler with a 153um mesh. During 1970-1972 samples were taken just above the bottom and just below the surface. During 1974-1979, oblique tows were taken. During the 1990's vertical tows were taken using 0.3m aperture conical net with 80um mesh. In some years larger zooplankton including *Leptodora kindtii*, aquatic insects, mites and fish larvae were sampled using oblique tows with a conical net with 1.0 ml mesh. A 1.0 m aperture net was used from 1976-1988, and a 0.3 m aperture net was used 1990-1996. Samples were immediately preserved in 10% formalin (1970-1979) OR 70% ethanol (1988-1997), and counted using a Wild M5 microscope. Aliquots of 1 ml were taken with a Hensen-Stempel pipette until 100 individuals were counted (1970-1972) or 100 individuals of the most abundant species counted (1974-1997).

Weather data shown were taken from the nearest National Weather Service monitoring station to each lake. Seven-day averages (including the day of sampling) are given for rainfall, windstress (Small 1963) and for the 1970's only, solar radiation (William Lytle, personal communication). All variables were tested for normality (SAS 1989), but most were not normally distributed. Thus, medians, maximums and minimums are shown.

TAXONOMIC CONSIDERATIONS

Phytoplankton

Phytoplankton were identified to genus or species, depending on the objectives of the original studies. For many of the plankton, considerable controversy exists as to taxonomy.

Three different identification systems are commonly used for the Cyanophyceae (bluegreen algae), traditional, Drouet and Daily revision (1956), and Rippka et al revision (1979) As the Drouet and Daly revision was taken from extensive field samples and was based on more easily definable and less subjective factors than the traditional classification, it was used in this study (Drouet 1959). However, *Gloeocapsa* was separated from *Anacystis* according to Rippka *et al* (1979). Equivalent genera from the three classifications included the following: *Microcystis* (traditional) = *Anacystis* (Drouet) = *Synechocystis* (Rippka *et al*); and *Aphanothece* (and other genera, traditional) = *Coccochloris* (Drouet) and *Synechococcus* (Rippka *et al*). Because of the difficulty in observing chloroplast structure in very small cells (4 um) under the inverted scope, organisms identified as *Gomphosphaeria* in Haertel (1979) and again encountered in the 1990's were found to be *Botryococcus* and are listed as such in this paper. No *Gomphosphaeria* were encountered in the 1990's. Additional difficulties were present in separating *Aphanizomen* and *Gloeotrichia* and *Anabaena flos-aquae* and *A. spiroides* when only single filaments without heterocysts were present in the water. Finally, Rippka *et al* (1979) consider the different size categories of taxa such as *Synechocystis* (= *Anacystis*) and LPP1 (= *Lyngbya*) as the same species just exposed to better nutrition. However, as at least two distinct size classes of each were consistently present in open water samples in this study, Drouet's 1959 separation into two distinct species was followed.

Bacillariophyceae (diatoms) were originally identified according to Smith (1950), Tiffany and Britton (1971) and Patrick and Reimer (1966, 1975). Round et al (1990) changed the names of some of the genera splitting the genus *Melosira* into *Melosira* and *Aulacoseira*. Consequently only when members of that genus were identified to species in the 1970's could they be assigned to either genus. Thus the term *Melosira/Aulacoseira* is used. Similarly Round *et al* reclassified the controversial diatom *Nitzschia closterium* as *Phaeodactylum tricornutum,* a welcome change as triradiate as well as *Nitzschia*-like forms were common in some of the lakes. Finally, as it is difficult to separate the smaller *Nitzschia* from the smaller *Synedra* in a Sedgewick-Rafter cell, the term *Synedra/Nitzschia* was commonly used, and included *Phaeodactylum*.

Chlorophyceae (green algae) were identified according to Prescott (1951) and Tiffany and Britton (1971). Komarkova-Legnerova (1969) split the genus *Ankistrodesmus* into *Ankistrodesmus* for the colonial forms and *Monoraphidium* for the solitary forms. Both forms were present in the 1970's but were not separately counted so the term *Ankistrodesmus/Monoraphidium* is used. *Monoraphidium* was far more abundant in both decades and was the only form encountered in Bitter Lake. *Schroederia* and *Selenastrum* were combined in the counts because neither was abundant, and both had the same shape and size. No attempt was made to separate solitary round green algae into genera. *Chlamydomonas* was abundant in Lake Cochrane, but was frequently in palmelloid stage when preserved in Lugol's, so it was included in the category "unidentified single cells" in this paper. Also, some of the organisms identified as *Tetraedron* were probably Dinoflagellate cysts--both show a positive starch test preserved in Lugol's and are have the same shape and size.

Dinophyceae were identified according to Prescott (1951), and Tiffany and Britton (1971). Flagellates are almost impossible to identify preserved in Lugol's, and thus many are lumped into categories. Among the Dinoflagellates, *Peridinium, Glenodinium*, and *Gymnodinium* were usually lumped, and *Glenodinium,* and *Gymnodinium* were always lumped. Identification of live samples indicated that all three genera were present in Lake Cochrane.

Chrysophytes were identified according to Prescott (1951), Tiffany and Britton (1971) and Patterson and Larson (1991). Lacking live samples for identification, many categories were lumped into the category "unidentified Chrysophyte-like flagellates" These were mostly small solitary organisms (4-5mu), but were occasionally found in colonial palmellas of *Dinobryon*-sized cells. These palmelloid colonies bore superficial resemblance to the green alga *Kirchneriella obesa,* but never showed a positive test for starch. *Ochromonas* and *Paraphysomonas* were not separated in the 1970's because of the difficulty in observing chloroplasts in very small forms under the inverted microscope, so the term *Ochromonas/Paraphysomonas* was used. Mostly *Paraphysomonas* was encountered in the 1990's. The term *"Mallomonas/Rhizochrysis-like"* was used because I suspected that the same organism was appearing in both rhizopodial and flagellated stages. The flagellated stage resembled *Mallomonas acaroides* and the rhizopodial stage resembled *Rhizochrysis.* They were found together, of identical size (approximately 20 um diameter) and golden-brown pigmentation.

Cryptophyceae and Euglenophyceae were identified according to Prescott 1951. Both *Cryptomonas* and *Chroomonas* were present but were lumped in this database because of difficulty of accurate identification of preserved samples in a Sedgewick-Rafter cell. Among the Euglenophytes, only *Trachelomonas* was sufficiently common to separately list, but *Euglena* and *Phacus* were occassionally encountered in the shallower lakes.

Zooplankton

Most zooplankton were identified to genus or species, depending on the objectives of the original studies, using Edmondson (1959). Groups found in the zooplankton tows that were not identified to genus included copepod nauplii, fish larvae, water mites, amphipods, hemipterans, and other insecta with the exception of *Chaoborus* sp.

Rotifers were sampled with too large a mesh size to retain smaller forms in 1970's so estimates for that decade only include the larger forms.

Cladocerans were routinely identified to species as usually only one species of a genus was present. However, multiple species of *Daphnia* could coexist in a lake and were sometimes separately counted. *D. pulex* was not encountered in Lake Hendricks before 1975, but closely related *D. schodleri* was. In 1975, closely related *D. catawba* replaced *D. pulex* in late summer. Neither *D. catawba* nor *D. schodleri* were ever encountered in later years, or at the same time as *D. pulex.* Since there is controversy considering the taxonomy, the three species are lumped in the data tables as *D. pulex**.

All calanoid copepods found were *Diaptomus,* with both a small and a large species found in most lakes, although the larger species was never abundant in the deeper lakes. The small *Diaptomus* in all the lakes except Bitter was *D. siciloides* and the larger species was *D. clavipes.* In Bitter Lake prior to 1995, *D. nevadensis* was the larger species, and the smaller species was *D. connexus.* Lack of adult stages on the few dates sampled made identification of species impossible after the freshening of Bitter Lake in 1995-1996. Cyclopoid copepods were difficult to speciate in early copepodite stages and were lumped except in seasons where only one species was present in the water column, e.g. early spring for *Cyclops bicuspidatus* and late summer for *C. vernalis. Mesocyclops leuckarti* and *M. edax* were both present, but the species were not separated in routine counting.

RESULTS

Physical factors

Six of the lakes, Pickerel, Enemy Swim, Cochrane, Hendricks, Oak and Bitter were sampled both in the 1970s and the 1990's, making possible comparisons between decades (Table 2). Cochrane, Hendricks and Oak showed little or no change in maximum station depth measured. Increases in maximum station depths in the 1990's in Pickerel and Enemy Swim occurred partly because stations were selected over the deepest part of the lake in the 1990's as opposed to selection of sites for comparison with remote sensing data in the 1970's (Thoreson et al 1976). Bitter Lake almost doubled in maximum station depth in the 1990's because of rising water levels between 1991 and 1995 that also flooded the surrounding countryside, more than doubling its area. Decreases in median and minimum station depths in Bitter Lake in the 1990's reflected sampling closer to shore on windy days.

In the 1970's, greatest water transparency as measured by Secchi depth was found in Pickerel, followed by Enemy Swim (Table 2). In the 1990's, Enemy Swim and Roy both had greater water transparency than Pickerel. High maximum water transparencies recorded in Hendricks (1978), East Oakwood (1994), and Bitter (1995) coincided with high May or June *Daphnia pulex* populations. During both decades, lowest secchi depth readings were found in Bitter. All of the lakes sampled in both decades, except Bitter, showed a decrease in water transparency between the 1970's and the 1990's. Bitter Lake greatly increased in water transparency after it greatly increased in depth.

Turbidity measurements, taken only after 1991, showed Roy to be least turbid, followed by Cochrane, Enemy Swim and Pickerel (Table 2). High turbidity measurements in Pickerel were found at depth over the deepest part of the lake, even though care was taken not to disturb the bottom sediments. Highest median turbidity was measured in Oak and highest maximum turbidity was measured in Bitter.

Maximum water temperatures recorded (Table 2) never exceeded 28ºC in either time period. Minimum water temperatures occurred when sampling immediately after ice-out. Median temperature variation reflected fewer spring and fall samples in some years.

Electrical conductivity (Table 2) was lowest in Enemy Swim, Blue Dog and Pickerel. Hendricks, South Buffalo and Oak were slightly higher, and lakes on the west slope of the Coteau, Roy, Tetonkaha, Round, and East Oakwood, were higher yet. Highest conductivities were found in the lakes with no natural outlet, Cochrane and Bitter. Conductivities in Oak, Hendricks and Cochrane decreased slightly between decades, whereas Enemy Swim and Pickerel increased slightly. Bitter Lake showed a dramatic decrease in conductivity between 1974 and 1995, which probably coincided with the increase in water levels between 1991 and 1995. Conductivity was not measured in Bitter Lake in 1990-1991.

Chemical Factors

Principle cations in Enemy Swim and Pickerel were magnesium and calcium, and bicarbonate was the principle anion (Table 3). Sodium, chloride and sulfate levels were very low especially in Enemy Swim. Bicarbonate levels decreased between the 1970's and the 1990's in both lakes, but because of small sample sizes of other major ions in the 1970's, changes could not be documented. Principle cations in Hendricks and Oak were calcium and magnesium and principle anions were bicarbonate and sulfate. Calcium levels decreased in the 1990's in both lakes. In the 1990's, sulfate and bicarbonate levels decreased in Oak lake, but were not measured in Hendricks. The principle cation in Roy was calcium and the principle anion was sulfate. Magnesium and bicarbonate levels were also high. Only anions were measured in Tetonkaha, East Oakwood, and Round Lakes. Sulfate was the major anion. Bicarbonate levels were lower in those three lakes than all the other lakes in the study. The principle cation in Cochrane was magnesium and the major anion was sulfate. Sodium, potassium and chloride levels were also high. Magnesium and sodium were the major cations and sulfate was the major anion in Bitter Lake in 1975. Potassium and chloride levels were also high. By 1995, levels of all cations and anions except calcium and bicarbonate were almost ten-fold lower. Although only one cation and anion sample is available from Bitter Lake in the 1970's, the change in total cations and anions is supported by the change in conductivity (Table 2).

Total nitrogen levels were lowest in Pickerel and Enemy Swim and highest in Bitter (Table 4). Median levels showed little difference between decades in Pickerel and Enemy Swim, but decreased in the 1990's in Cochrane, Hendricks, Oak and Bitter. Very low levels in Pickerel, Enemy Swim, Cochrane and Hendricks coincided with samples taken immediately after ice-out. High levels recorded in Blue Dog, Hendricks (1970's only), Tetonkaha, East Oakwood, Round and Bitter (1990's only) coincided with blooms of nitrogen-fixing blue-green algae. Nitrate and ammonia were frequently below the limits of detection.

Total phosphorus levels were lowest in Roy and Enemy Swim and highest in Bitter (Table 4). Median levels showed little difference between decades in Enemy Swim and Pickerel but decreased in Cochrane, Hendricks and Bitter, and increased in Oak. Very low levels again coincided with samples taken shortly after ice-out. Maximum levels occured coincident with times of increased runoff or large algal blooms. Soluble reactive phosphorus was frequently below the limits of detection.

Silica levels varied greatly in the lakes with time (Table 5). Lowest median and minimum levels were in Cochrane, Roy and Bitter. Oak showed the highest levels during the 1970's, but the levels were much lower in the 1990's.

Oak and Hendricks were high in iron levels in the 1970's and showed lower levels in the 1990's (Table 5). Iron was frequently below the limits of detection.

Highest manganese levels were found in Cochrane and Bitter lakes in the 1990's (Table 5). Lowest levels were found in Lake Hendricks. Manganese was frequently below the limits of detection, particularly in Lake Hendricks.

Copper was almost never present in detectable levels when measured in Cochrane, Hendricks and Oak (Table 5).

Both median chlorophyll a values and the calculated trophic state index (TSI, Carlson 1977) indicated that the most eutrophic lake was Bitter in the 1970's, and the least eutrophic was Roy. All of the lakes that were shallow enough to have midlake sediments suspended in the water column were hypertrophic (TSI 65 or more) with the exception of Blue Dog, which was borderline. Pickerel, Enemy Swim, Cochrane, Hendricks and Oak increased in both Chlorophyll a and TSI between decades. Bitter decreased.

Dissolved oxygen was always measurable during the open water season except in Lake Cochrane, which could be depleted in the deep water samples (Table 5). Supersaturated levels of oxygen were common during times of algal blooms.

All the lakes had alkaline pH with maximum levels recorded during algal blooms, particularly in Bitter (Table 5).

Weather Variables

Lakes sampled in 1978-1979, Oak, Cochrane, and Hendricks received the greatest amount of wind in the seven days prior to sampling (Table 6). Conversely, rainfall received was much higher in the 1990's for all six lakes sampled in both decades. Highest maximum snow depth was experienced at Lake Cochrane, during the winter of 1993-1994. Solar radiation varied seasonally, but amounts were similar for all seven lakes sampled in the 1970's.

Phytoplankton

Bluegreen algal picoplankton were numerically the most abundant phytoplankton in any of the lakes (Tables 7-15). However, because of their small size, their contribution to the total algal volume in the lake was frequently smaller than the numerically less abundant, but larger bluegreen algae, diatoms, and green algae (Haertel 1996).

Total picoplankton increased between decades in Pickerel and Hendricks, but decreased in Cochrane, Oak and Bitter. Greatest abundance of picoplankton were recorded in the lakes with no outlet, Bitter and Cochrane (Table 7). In 1990-1991, Bitter picoplankton populations were similar to those in 1974 with a median of 22,321.9 cells per microliter and a minimum of 1067.8. At that time all the picoplankters recorded were *Anacystis incerta*. After the increase in water levels by 1995 picoplankton decreased almost a thousand fold to a median of 16.1 and a maximum of 36.2, and *Coccochloris peniocystis* accounted for about 40% of the picoplankters. Lake Cochrane experienced its first picoplankton bloom on June 23, 1971, about two weeks after a cottage owner had bulldozed a hillside into the lake. After that event, picoplankton populations remained high, reaching peak levels September 26, 1976, a year when construction of sediment control dams again resulted in extensive soil erosion into the lake. *C. peniocystis* comprised a larger fraction of the picoplankton in the less eutrophic lakes accounting for about 40% of the median total in Cochrane and about one quarter picoplankton in Enemy Swim, Roy, and South Buffalo and 8% in Pickerel. Median values in most of the more hypertrophic lakes were below the limits of detection.

Anacystis cyanea was the only larger chroococcalean taxon abundant in the lakes. Like *A. incerta,* it was most abundant in Bitter and Cochrane. It decreased in abundance between the 1970's and 1990's in Cochrane (Table 7). In 1990-1991, Bitter populations were similar to 1974 with a median of 3487.8 and a minimum of 19.1. By 1995-1996 populations had decreased one hundred fold with a median of 8.2 and a maximum of 65.0.

Lyngbya spp. were the most abundant filamentous, non-nitrogen fixing bluegreens in these lakes, with largest populations in Tetonkaha, Round, East Oakwood and Oak Lakes (Table 8). *Lyngbya* spp. increased between decades in Pickerel, Enemy Swim, Oak and Bitter and decreased in Cochrane and Hendricks. *L. contorta* was more abundant in Cochrane, Bitter, Pickerel and Oak (1970's), and *L. versicolor* was more abundant in Enemy Swim, Roy, Tetonkaha, Round, East Oakwood and Oak (1990's). *L. birgei* was recorded in small numbers only in Roy, Enemy Swim, and Pickerel Lakes. *Oscillatoria* sp. was abundant in Tetonkaha, East Oakwood, and Round.

Aphanizomenon holsatica was the most abundant nitrogen-fixing bluegreen alga in most of the lakes. It was most abundant in Bitter (after the rise in water levels), East Oakwood, Hendricks, Tetonkaha, Round, Oak (1990's only) and Bluedog (Table 9). It was not recorded from Oak prior to 1990 or from Bitter prior to 1995. *Cylindrospermum musicola,* was present in all of the above lakes except Hendricks and Bluedog, and was the most abundant nitrogen-fixing alga in Oak. It may have been present in Oak in late summer

1978, but was not counted separately from *L. versicolor* (Table 8). *Gloeotrichia echinulata* was recorded from Blue Dog lake on August 23, 1974, when *Aphanizomenon* was absent. However, that was the only date *Gloeotrichia* was present in Blue Dog, and *Aphanizomen* was very abundant both 18 days before and 18 days later. *Anabaena* spp. were present in all of the lakes, reaching greatest abundance in Tetonkaha, Round and East Oakwood. *Anabaena* spp. were also abundant in Pickerel, Hendricks and Oak, and increased in abundance between decades in all three lakes. *A. circinalis* and *A. flos-aquae* were recorded from all of the lakes, and *A. spiroides* only from Enemy Swim. *Nodularia* was most abundant in Bitter, and frequently present in Cochrane. It was recorded from Oak Lake in 1997.

Heterocysts, which indicate nitrogen fixation, were separately counted in the 1990's only (Table 10). The largest numbers of *Aphanizomen* heterocysts were recorded in Bitter and Hendricks, and the largest number of *Cylindrospermum* heterocysts were recorded in Oak. *Nodularia* heterocysts were abundant in Bitter, and *Anabaena* spp. heterocysts in Pickerel and Oak.

Centric diatoms were most abundant in Oak (Table 11) where silica levels were also highest (Table 5). *Cyclotella* spp. were widely distributed. *C. meneghiniana* was present in Pickerel and Enemy Swim and both *C. glomerata* and *C. melosiroides* in Cochrane and Oak. A very small (4-5um) unidentified *Cyclotella* formed early spring blooms in Hendricks. *Cyclotella* spp. were most abundant in Hendricks, Oak (1970's), and Bitter (1990-1991). Cyclotella spp. showed a decrease between decades in Pickerel, Enemy Swim, Cochrane and Oak, but increased in Hendricks and Bitter. *Stephanodiscus niagarae* was widely distributed but abundant only in Hendricks, where it decreased between decades. *Melosira/Aulacoseira* were most abundant in Oak, Tetonkaha, Round and East Oakwood. *Melosira* was identified in Bitter lake only after the rise in water levels (1995-1996). *Chaetoceras,* a marine genus, was abundant in the two lakes with higher salinities, Bitter (1970's and 1990-1991) and Cochrane.

The most abundant and widely distributed pennate diatoms were *Synedra/Nitzschia* spp., *Asterionella formosa* and *Fragilaria crotonensis* (Table 12). Included in the *Synedra/Nitzschia* category was *Phaeodactylum tricornutum,* which was most abundant in Bitter Lake prior to the rise in water levels in the 1990's. Not separately counted in Bitter in the 1970's was a very small *Cymbella* sp. which was abundant when *P. tricornutum* was abundant. It was also abundant in 1990-1991. *N. holsatica* was abundant in Cochrane, and *N. acicularis/S. acus* were abundant in Oak (1970's) *S. ulna* was abundant only in the 1970's in Hendricks, Oak and Cochrane. *Asterionella* was abundant in Pickerel, Enemy Swim, Roy, and Oak (1970's) in the spring. It was present in Bitter only after the rise in water levels. *Fragilaria* was widely distributed and abundant in Oak (1970's), Pickerel, and Enemy Swim. *Navicula* spp. were abundant in the 1970's in Cochrane and Oak. *Entomoneis* sp. was present in Cochrane, Oak, Hendricks and Enemy Swim.

Green algae were most abundant in Bitter Lake before the rise in water levels where the most abundant genus was *Monoraphidium* (Table 13). In Bitter (1995-1996), *Monoraphidium* levels decreased to a median of 0 and a maximum of 0.33. *Monoraphidium* was widely distributed but much less abundant in the other lakes. The less widely distributed *Crucigenia quadrata* was abundant in Cochrane from 1976-1978, during and after the construction of the sediment control dams, and in Oak in 1979, after severe winter fishkill. *Oocystis, Pediastrum* and *Scenedesmus* spp. were widely distributed. They were abundant in Round Lake after an intentional fish kill. They were also abundant in Tetonkaha which was connected to Round Lake, and in Oak in 1978-1979 after natural winter fish kills. Their abundance in Cochrane in the 1970's may have indicated summer fish kill. One was recorded from that lake in 1984 (David German, personal communication) and bottom water oxygen concentrations were sometimes below the limit of detection (Table 5). *Oocystis* was most abundant in the two lakes of highest salinity, Cochrane and Bitter prior to the rise in water levels. *Scenedesmus* was abundant in Pickerel (1990's only). *Chlamydomonas* sp. was present in Cochrane but was frequently in palmella stage and included in the category "unidentified single cells." Unidentified single cells were abundant in Oak after the fish kills in 1978-1979. *Shroederia/Selenastrum, Closteriopsis,* and desmids (*Closterium, Cosmarium,* and *Staurastrum*) were widely distributed, but not abundant.

Botryococcus braunii was widely distributed and most abundant in Oak, Tetonkaha, East Oakwood, Cochrane and Round (Table 13). It decreased between decades in Oak, Cochrane, and Enemy Swim and increased in Pickerel, Hendricks and Bitter.

Flagellates

The most abundant category of flagellates found were very small forms (4-5um long) that were assigned to the category "unidentified Chrysophyta-like" (Table 14). In most cases these lacked chloroplasts. These were very abundant in the spring after winters of heavy snow cover, particularly in the 1990's in Pickerel, Enemy Swim, Cochrane and Oak, and in the 1970's in Oak, Cochrane, and Bitter. *Paraphysomonas* was usually present in smaller numbers at the same time. *Dinobryon sertularia* was more common in the less eutrophic lakes, particularly Enemy Swim. *Mallomonas* and *Mallomonas*-like forms were most abundant in Bitter (1990-1991) and Tetonkaha.

Among dinoflagellates, only *Ceratium hirundinella* was routinely identified to species as other genera were difficult to separate in routine counting. Dinoflagellates were most abundant in Lake Cochrane (Table 15). Occasional empty shells were identified as *Peridinium bipes* and *Glenodinium quadridans*. *Gymnodinium* sp. was identified from live samples. Dinoflagellates were also abundant in Tetonhaka, East Oakwood, Round and Oak, and *Ceratium* was frequently present in Pickeral and Enemy Swim.

Euglenophytes were most abundant in Tetonkaha, East Oakwood, and Bitter (Table 15). *Trachelomonas* spp. were the only frequently encountered form in all of the lakes except Bitter, where *Phacus* sp. was present in 1990.

Zooplankton

Larger numbers of rotifers were collected in the 1990's than in the 1970's in all lakes except Enemy Swim (Table 16). This may have been partially an artifact of sampling with a smaller mesh size in the 1990's. Rotifers were not present in samples from Bitter until 1995-1996, after the rise in water levels, and were never abundant. Rotifers were most abundant in Tetonkaha, East Oakwood, Round, Oak and Cochrane. All of those lakes are located in till (Table 1) or just downstream from till (East Oakwood). *Polyarthra* sp., *Filinia longiseta* and *Brachionus* spp. were widely distributed and abundant in the above lakes. *B. plicatilus* was identified in Cochrane in the 1970's and *B. calyciflorus* in the 1990's. However, *Brachionus* was not identified to species on all dates, or in other lakes. *Keratella* spp. were widely distributed and abundant in the above five lakes and in Enemy Swim (1970's) and Hendricks (1990's). *Asplanchna priodonta* was widely distributed and abundant in the above five lakes and in Pickerel (1970's). *Trichocerca* sp. was widely distributed but not abundant. *Kellicotia* sp. and *Synchaeta* sp. were less widely distributed but abundant in Pickerel (1990's) and Hendricks (1990's), respectively. *Platyias quadricornis* was most abundant in South Buffalo.

Daphnia spp. showed a substantial decline in abundance between decades in Pickerel, Cochrane, Hendricks and Oak, and a slight decline in Enemy Swim (Table 17). The *D. pulex* group was the abundant spring form in all of the lakes except Oak, where *D. parvula* was more abundant and Cochrane, where *D. rosea* was more abundant. *D. pulex* and *rosea* were both abundant in spring in Enemy Swim. *D. galeata* commonly became more abundant in midsummer in all of the lakes except Hendricks and Bitter. *D. similus* (subgenus *Ctenodaphnia*) was abundant in Bitter until the rise in water levels, after which it was replaced by *D. pulex*. Although large daphnids were frequently most abundant in the lakes located in outwash (Table 1), smaller-bodied cladocerans were more abundant in the lakes located in till or immediately downstream from till. *Ceriodaphnia lacustris* was more abundant in Cochrane and *Bosmina longirostris* (often associated with *Diaphanosoma birgei*), was more abundant in Oak, Tetonkaha, Round and East Oakwood. *Ceriodaphnia* declined between decades in Cochrane, and *Diaphanosoma* and *Bosmina* declined between decades in Pickerel, Enemy Swim, Cochrane and Oak. The latter two genera increased between decades in Hendricks. *Chydorus sphaericus* was widely distributed, and often associated with *Aphanizomenon*. It increased between decades in Pickerel, Enemy Swim, and Oak, but decreased in Cochrane and Hendricks. The predatory *Leptodora kindtii* was collected in small numbers from Pickerel, Enemy Swim, Roy and South Buffalo.

Diaptomus spp. showed a decline in numbers between decades in Pickerel, Enemy Swim, Cochrane, Hendricks and Oak (Table 18). *D. nevadensis* increased in Bitter between 1974 and 1990-1991 to a median value of 98.5 individuals per liter, but decreased after the rise in water levels by 1995-1996 to a median value of 0.7 and a maximum value of 5.0. The smaller *Diaptomus* present in Bitter showed little change in numbers between time periods. Cyclopoid copepods also showed a decline in numbers between decades in Pickerel, Enemy Swim, Cochrane, Hendricks, and Oak. *Cyclops bicuspidatus* was the species present in all the lakes in the fall and spring, and was usually replaced in mid-summer by *C. vernalis.* In Pickerel, Enemy Swim and Cochrane, *Mesocyclops* spp. were also present with *M. leuckarti* very abundant in Pickerel in 1975, and *M. edax* present in small numbers in Enemy Swim and Cochrane. After the severe winterkill year of 1978 (Haertel and Jongsma 1980), *C. bicuspidatus* was the only cyclopoid present all summer long in Oak and Hendricks which winterkilled, However, it was replaced by *C. vernalis* in Cochrane which did not winterkill. Copepod nauplii decreased between decades in Pickerel, Enemy Swim and Cochrane and increased in Hendricks, Oak and Bitter. Because the net mesh size used in the 1970's was too large to catch the smaller nauplii, the increase in the latter three lakes may be partially due to sampling gear used.

Ostracods were frequently present in the plankton tows in Pickerel, Enemy Swim, Roy, South Buffalo and Bitter, but were infrequent in the midlake plankton of the southern lakes (Table 18). However, they were abundant in the littoral zones of Lake Cochrane (Haertel, unpublished). They were more abundant in Bitter after the rise in water levels, the maximum number per liter recorded in 1990-1991 was only 0.76.

Abundant planktivorous fish taxa collected in the lakes included Yellow Perch larvae (*Perca flavescens)* in Lake Cochrane and Fathead Minnow (*Pimopheles promelas)* adults and larvae in Oak, Tetonkaha, East Oakwood and Round (Table 19). Fish larvae were never present in plankton tows from Hendricks, Roy or Bitter.

Water mites (Hydracarina) were most abundant in Oak, where three different unidentified taxa were present (Table 19). They were also abundant in Roy and Bitter.

Brine Shrimp (*Artemia* sp.) were abundant in Bitter in the spring, before 1995 (Table 19). They were not collected after the rise in water levels.

Amphipods were collected in small numbers in midlake plankton tows in many of the lakes and were abundant in Bitter after the rise in water levels (Table 19). They were not collected from Bitter before 1995.

Hemipterans, mostly Corixidae, were abundant in Hendricks and in Bitter, before the rise in water levels (Table 19). After the rise in water levels, numbers were two orders of magnitude lower.

Chaoborus sp. (*C. punctipennis* in Cochrane, German and Haertel 1979) was present in plankton tows from all of the lakes except Pickerel, South Buffalo, Hendricks, and East Oakwood (Table 19).

Other Insecta included mostly Diptera larvae other than *Chaoborus.* These were most abundant in Hendricks and Bitter, both before and after the rise in water levels (Table 19).

DISCUSSION

Decreased water transparency and increased Chlorophyll a and resultant TSI point to a decline in water quality between decades in Pickerel, Enemy Swim, Cochrane, Hendricks and Oak. However, the nutrients normally associated with increases in trophic state, nitrogen and phosphorus, have not increased, except for phosphorus in Oak. In three of the other four lakes, phosphorus levels actually decreased slightly, possibly suggesting less erosional inputs in the 1990's than in the 1970's. The lack of increase in nutrients, indicates that the increase in chlorophyll and decrease in water tranparency is a result of biological changes rather than chemical (Hrbacek 1961, Shapiro 1975, Carpenter et al 1985a). Numbers of copepods and cladocerans, have decreased in all of the above lakes. The decline in water transparency may be a response to a decline in filtering of the water by the larger zooplankters, particularly *Daphnia* spp. as zooplankton filtration has been shown to be closely correlated with water transparency (Haney 1973, Haertel 1979, Sommer et al 1986) The simultaneous decline in *Diaptomus,* which, like *Daphnia*, is heavily preyed on by zooplanktivorous fishes, suggests that increased fish predation may be a cause of the decline in larger zooplankton. Increased sport fishing removal of game fish, which prey on zooplanktivorous fishes, may be responsible for an increase in zooplanktivorous fishes and subsequent decline in abundance of larger zooplankton and thus water transparency. Improved sport fishing technology and intensity could contribute to increased game fish removal. At the same time, numbers of rotifers appear to have increased, a common change when competition and predation from larger copepods and cladocerans is decreased by fish predation (Carpenter et al 1985b). Severe winter fish kills in two of the lakes, Hendricks (1978) and Oak (1979) and resultant increases in water clarity and decreases in bluegreen algal populations (Haertel and Jongsma 1982) document the importance of predation by zooplanktivorous fishes. Although those winterkills could have been responsible for the higher water transparencies in the 1970's in those two lakes, Pickerel. Enemy Swim and Cochrane did not winterkill, and also showed much higher water tranparencies in the 1970's.

Increased pesticide usage could also contribute to decreased copepod and cladoceran populations and subsequent water transparency (Hurlburt et al 1972, Shapiro 1980). Pesticide levels have not been studied in the lakes.

Bitter is the only lake showing an increase in water transparency and increases in zooplankton between decades, and in Bitter, the drastic increase in water level and decrease in salinity may be solely responsible for the changes.

Nutrient levels and and zooplankton predation may also influence which algal taxa are present. Different algae are limited by different nutrients; for example, limitation in silica may cause diatoms to be replaced by less beneficial bluegreens (Schelske and Stoermer 1972) even at levels where silica is measurable in the water. Both silica and centric and pennate diatom medians decreased between decades in Cochrane, Hendricks and Oak. Many other nutrients were commonly below the limits of detection, including available forms of nitrogen and phosphorus, total iron, manganese and copper. Any of these nutrients may have selectively limited the growth of some algae. Changes in concentrations of major ions may also influence algal population dynamics. Nutrient bioassay experiments (1993) found enhanced Chlorophyll a with addition of silica in Cochrane and chloride in Enemy Swim (Christine Kraft, personal communication).

Geologic position also influences species composition. Lakes located in till or immediately downstream from till, Oak, Tetonkaha, East Oakwood, and Round had abundant rotifers, *Diaphanosoma, Bosmina, Aulacoseira* spp., *Oocystis, Pediastrum* spp., *Lyngbya* spp., *Cylindrospermum, Anabaena* spp. and *Aphanizomenon.* Among these lakes, Oak lake had unusually high species diversity, also having abundant *Cyclotella, Stephanodiscus, Nitzschia/Synedra* spp., *Botryococcus, Crucigenia, Sphaerocystis*, and *Closterium.*

In lakes located in outwash, *Daphnia* spp. and *Aphanizomen* were abundant frequently accompanied by *Chydorus sphaericus.* Among these lakes, Enemy Swim had the unusually high diversity, also having three species of *Anabaena, Gloeotrichia echinulata, Anacystis* spp., *Coccochloris, Lyngbya* spp., *Melosira/Aulacoseira, Asterionella formosa, Fragilaria crotonensis, Oocystis, Pediastrum* spp., *Dinobryon sertularia, Bosmina* and *Diaphanosoma.*

Lack of an outlet in Cochrane and Bitter resulted in more salt tolerant biotas. The bluegreens *Anacystis* spp. *Nodularia,* the diatom *Chaetoceras* and the green alga *Oocystis* were characteristic of both lakes. Dinoflagellates, the diatom *Nitchia holsatica,* the rotifer *Brachionus plicatilis* and the cladoceran *Ceriodaphnia lacustris* were most abundant in Cochrane. In the slightly saline Tetonkaha, East Oakwood and Round, dinoflagellates, *Ceriodaphnia* and *Brachionus* sp. were also abundant. In Bitter, prior to the rise in water levels, *Phaeodactylum tricornutum, Cymbella sp., Monoraphidium* sp, and a zooplankton community similar to that found in saline lakes in Saskatchewan (Hammer and Hurlbert 1992), including the brine shrimp *Artemia,* the cladoceran *D. similis,* and the copepods *D. Nevadensis* and *connexus* were abundant. After the rise in water levels, less salt-tolerant forms, particularly *Aphanozomenon holsatica* and *D. pulex,* became abundant.

CONCLUSIONS

This study presents a data base for water transparency, nitrogen and phosphorus levels, and zooplankton and phytoplankton populations for six prairie lakes in two different time periods, and for one time period in five other lakes. It presents a data base in two time periods for silica, iron, sodium, magnesium and calcium and bicarbonate in several lakes, and a data base for only one time period for manganese, copper, potassium, sulfur and chloride. More study of trace elements and major ions is needed to document what changes are taking place.

Location in outwash or till, as well as the presence or absence of a natural outlet influence the biota present. The most diverse lake located in outwash is Enemy Swim, and the most diverse lake located in till is Oak. These lakes deserve special protection for their scientific value.

Extensive comparisons of water transparency, water chemistry and cladoceran and copepod populations have documented an alarming decrease in water clarity and larger zooplankton, and an increase in Chlorophyll a, even though nitrogen and phosphorus levels have not increased. As these changes threaten the future recreational value of the prairie lakes, investigation into the reasons for the cladoceran and copepod declines should be of highest priority.

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Table 1. Lake characteristics.

Lake	Pickerel	Enemy Swim	Cochrane	Roy	Blue Dog	South Buffalo	Hendricks	Tetonkaha	East Oakwood	Round	Oak	Bitter
Depth (m)												
Mean	4.9	4.9	3.4	3.3	1.9	18	1.5	1.8	1.5	1.2	1.1	
Maximum	13.2	7.9	8.2	5.6	2.4	3.7	3.0	3.0	2.7	1.8	2.0	
Surface area (km^2)	3.6	8.8	1.5	6.9	6.1	7.2	6.3	4.1	3.8	0.2	1.6	13.1
Geologic Site	Outwash	Outwash	Till, No Outlet	Till	Outwash	Outwash	Outwash	Till	Outwash	Till	Till	Outwash, No Outlet
Approximate Age (yrs)	14,000	14,000	13,000	13,000	14,000	13,000	14,000	14,000	14,000	14,000	14,000	14,000
Side of Prairie Coteau	East	East	East	West	East	East	East	West	West	West	East	East
Latitude (N)	45°30'	45°26'	44°42'	45°42'	45°21'	45°37'	44°29'	44°26'	44°26'	44°26'	44°31'	45°17'
Longitude (W)	97°16'	97°16'	96°28'	97°26'	97°17'	97°16'	96°27'	96°59'	96°58'	96°59'	96°32'	97°17'

Notes: Lake depths and surface areas are taken from South Dakota Department of Game, Fish and Parks maps except for Oak Lake which was mapped by Connelly and Troelstrup (2001), and Bitter Lake, which has not been mapped. Bitter Lake surface area is taken from the U.S. Geological Survey Topographic map and was representative of conditions in 1974 and 1990-1991. Bitter Lake surface area had more than doubled by 1995-1996. Geologic site and age are from Flint 1995 and Mickelson et al., 1983. Tetonkaha, East Oakwood and Round Lake are all part of the Oakwood Lakes system.

Table 2. Measured physical variables.

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	Buffalo	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**90-96**
No. Yrs. Sampled	2	5	2	5	9	6	2	1	1	6	3	1	2	1	3	6	1	4
Station Depth (m)																		
Median	7.2	7.8	5.1	6.5	6.0	6.0	6.0	1.9	3.7	2.7	2.8	1.9	2.3	1.7	2.0	1.8	1.3	0.7
Minimum	7.0	1.0	3.7	3.5	1.0	3.0	5.4	1.4	2.2	1.0	2.3	1.0	0.7	1.4	1.0	1.5	1.0	0.5
Maximum	7.4	12.0	6.8	8.1	8.0	8.0	6.0	2.0	4.5	3.2	3.3	3.2	2.7	2.3	2.0	2.0	1.3	2.5
N	82	86	116	108	493	114	24	61	6	219	33	128	30	22	56	46	66	36
Secchi Depth (m)																		
Median	1.7	1.1	1.6	1.3	1.2	1.1	2.3	0.4	1.5	0.5	0.4	0.3	0.4	0.3	0.5	0.3	0.01	0.10
Minimum	1.0	0.8	0.7	0.5	0.6	0.6	0.9	0.1	1.2	0.2	0.3	0.1	0.1	0.1	0.2	0.1	0.01	0.05
Maximum	5.4	3.0	3.0	4.3	3.6	2.2	3.5	1.0	2.0	2.8	1.0	0.9	2.6	0.6	1.0	1.0	0.20	1.90
N	80	86	116	108	493	114	24	61	6	219	33	128	30	22	51	46	63	36
Turbidity (ntu)																		
Median		7.6		3.7		3.6	2.9		6.2		24.5		8.0			35.9		9.3
Minimum		2.1		0.9		1.4	0.6		1.8		17.8		1.9			6.5		1.8
Maximum		20.5		12.0		11.4	8.1		7.9		30.1		83.5			156.0		178.0
N		34		54		60	20		6		6		6			20		10
Temperature (°C)																		
Median	19.0	21.0	19.0	19.0	20.0	19.0	22.0	18.0	20.0	22.0	21.0	23.5	23.0	25.0	18.5	21.0	15.0	20.0
Minimum	7.0	7.0	6.0	8.0	0.0	10.0	7.0	8.0	13.0	0	9.0	3.0	2.5	3.0	5.0	9.0	8.0	7.0
Maximum	25.0	24.0	25.0	23.0	27.0	28.0	24.0	24.0	24.0	28.0	26.0	28.0	26.0	26.0	26.0	26.0	24.0	28.0
N	80	86	122	108	501	114	24	61	6	222	33	104	26	22	56	46	65	36
Conductivity (µS)																		
Median	398	480	330	398	2873	2312	1200	371	636	695	628	1425	1299		575	520	12,300	3875
Minimum	318	275	250	232	389	1768	825	305	488	244	600	1383	1250	1475	537	340	9800	2400
Maximum	470	612	710	528	3111	3231	1460	440	648	850	720	1484	1410	1493	662	608	19,000	4650
N	42	36	82	58	168	66	24	61	6	135	6	12	6	2	15	22	63	12

Notes: Underscored lakes were sampled in two time periods. Measured lake depths are sometimes deeper than maximum depths mapped by the S. D. Department of Game, Fish & Parks (Table 1). The discrepancy is caused by fluctuating water levels.

Table 3. Measured Cation and Anion Concentration ($mg.1^{-4}$).

	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter	
Time Period	**75**	**90-96**	**75**	**90-96**	**70-79**	**90-97**	**95-96**	**74**	**70-79**	**90-91**	**88**	**88**	**88**	**70-79**	**90-97**	**75**	**95-96**
Sodium																	
Median	8	6	8	8	102	103	26		7					9	6	4200	375
Minimum	8	6	8	8	7	51	18		2					5	5		330
Maximum	8	32	4	8	249	14	24		112					14	16		560
N	4*	24	4*	8*	143	14	24		112					14	16	1*	12
Potassium																	
Median	7	5	9	7	50	54	20		11					13	4	900	92
Minimum	6	4	8	7	4	53	15		1					6	4		80
Maximum	7	5	10	7	105	54	24		23					13	5		108
N	4*	24	4*	8*	108	8*	24		97					5*	12	1*	12
Magnesium																	
Median	44	46	50	49	338	425	92		28	54				44	49	5000	520
Minimum	44	32	49	35	274	420	76		1	40				38	7		410
Maximum	44	77	50	85	380	430	107		91	95				48	66		570
N	4*	24	4*	50	59	8*	24		48	27				5*	36	1*	12
Calcium																	
Median	47	32	30	30	96	90	158		96	60				74	36	24	73
Minimum	46	16	29	16	80	85	117		82	25				73	13		29
Maximum	47	64	30	40	216	93	192		73					82	56		124
N	4*	64	4*	56	59	14	16		48	27				5*	36	1*	10
Chloride																	
Median	4	5	4	4	15	22	30		5		15	14	16	6	6	931	128
Minimum	3	3	4	4	12	21	15		2		11	9	13	3	3		110
Maximum	4	10	4	4	38	22	60		10		18	20	20	10	10		225
N	4*	24	4*	8*	59	8*	24		48		101	18	18	5*	12	1*	12
Sulfate																	
Median	77	78	33	26	1315	1924	400		135		560	486	559	130	120	21,350	3400
Minimum	75	60	33	26	1065	1881	250		96		444	395	450	117	80		1900
Maximum	78	160	33	27	2095	1948	460		188		680	580	680	136	158		4600
N	4*	24	4*	8*	59	8*	24		48		102	18	18	5*	12	1*	12
Bicarbonate																	
Median	249	191	264	235	272	252	253	248	193		136	167	114	219	183	980	404
Minimum	224	152	236	232	88	248	210	224	48		68	89	93	124	145	702	250
Maximum	280	250	296	236	1028	256	300	267	263		208	196	162	259	212	1388	448
N	78	24	118	8*	467	8*	24	62	218		128	24	22	37	12	63	12

Notes: Underscored lakes were sampled in two time periods. Carbonate was rarely present in measurable concentrations. Its weight was added to Bicarbonate on the few dates it was detected. *Data available from only 1 or 2 dates.

Table 4. Measured nitrogen, phosphorus and chlorophyll a concentrations, and calculated trophic state index.

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**94-96**	**74-75**	**92-94**	**70-79**	**92-97**	**95-96**		**70-79**	**94**	**88**	**88-94**	**88**	**70-79**	**94-97**	**74**	**95-96**
Total Nitrogen ($mg.l^{-1}$)																	
Median	0.75	0.75	0.80	0.76	1.49	1.34	1.20	0.84	1.91	1.17	3.34	2.78	3.50	2.26	1.69	8.71	3.20
Minimum	0.11	0.34	0.01	0.53	0.07	0.98	1.03	0.19	0.21	0.94	1.30	1.10	2.04	1.42	0.20	5.42	2.29
Maximum	1.07	1.51	2.33	1.25	4.16	1.71	2.61	8.02	17.19	1.26	7.71	6.51	6.66	4.32	3.20	16.46	42.92
N	74	36	118	60	465	66	24	61	218	6	128	24	22	41	22	63	12
Nitrate-Nitrogen ($mg.l^{-1}$)																	
Median	.020	.010	.020	.001	.000	.028	.040	.040	.090	.080	.083	.073	0.073	.080	.010	.1501	.0900
Minimum	.000	.000	.000	.000	.000	.000	.010	.000	.000	.040	.011	.012	0.024	.000	.000	.080	.010
Maximum	.200	.171	.100	.121	.400	.140	1.390	0.200	1.060	.270	.202	.161	0.171	1.120	.700	.3600	1.190
N	78	36	118	60	465	66	24	61	218	6	128	24	22	41	22	63	12
Ammonia-nitrogen ($mg.l^{-1}$)																	
Median	.000		.000	.000	.000	.000		.000	.120		.005	.030	.040	.300		.000	
Minimum	.000		.000	.000	.000	.000		.000	.120		.005	.030	.000	.300		.000	
Maximum	.130		.430	.175	1.200	.000		.180	1.900		2.670	3.080	3.140	1.200		.040	
N	78		118	24	445	24		61	218		128	24	22	26		63	
Total Phosphorus ($mg.l^{-1}$)																	
Median	.035	.037	.030	.026	.050	.036	.025	.060	.220	.108	.160	.105	.140	.095	.110	.470	.250
Minimum	.000	.010	.010	.017	.000	.014	.020	.040	.091	.072	.050	.050	.080	.020	.058	.260	.080
Maximum	.130	.140	.180	.228	.200	.056	.040	.290	.368	.139	.390	.210	.230	.300	.370	.940	2.770
N	78	36	118	60	297	66	24	61	78	6	128	24	22	26	22	63	12
Soluble Reactive Phosphorus ($mg.1^{-1}$)																	
Median	.000		.000	.004	.010	.007		.010	.165		.010	.010	.010	.010		.110	
Minimum	.000		.000	.000	.000	.001		.000	.000		.000	.000	.000	.000		.040	
Maximum	.060		.030	.008	.410	.016		.030	.410		.040	.030	.020	.090		.440	
N	78		118	24	465	24		61	218		128	24	22	41		63	
Chlorophyll a ($\mu g.l^{-1}$)																	
Median	11.3	15.2	8.2	14.9	11.8	22.4	6.6	10.1	25.3					25.3	39.9	106.5	20.6
Minimum	0.0	8.2	1.4	2.1	0.0	2.3	2.6	3.4	0.0					0.0	13.6	38.3	4.4
Maximum	30.3	29.4	24.1	42.7	43.7	56.9	15.2	778.8	365.1					109.5	141.5	271.3	97.4
N	78	24	109	37	456	32	24	61	216					55	16	63	12
Trophic State Index																	
Median	52.8	56.2	52.3	54.1	57.2	58.5	49.2	64.4	69.8	74.3	75.3	74.5		67.4	72.0	93.3	72.4

Notes: 0.000, 0.0 = below detection limit. Underscored lakes were sampled in two time periods. The Trophic State Index (TSI, Carlson 1977) is calculated as the average of the Chlorophyll a TSI, total phosphorus TSI and Secchi Depth TSI, except for Round '88 and Hendricks '94 where only TP and secchi data were used. 1988 Chlorophyll a TSI values for Tetonkaha and East Oakwood are from German *et al* 1991. The variables shown in this table were not measured in Buffalo Lake.

Table 5. Measured silica, iron, manganese, and oxygen concentrations, and pH measured.

	Pickerel	Enemy Swim	Cochrane		Roy	South Buffalo	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter
Time Period	**94-96**	**92-94**	**70-79**	**92-97**	**95-96**	**94**	**70-79**	**94**	**88**	**88-94**	**88**	**70-79**	**94-97**	**95-96**
Silica ($mg.l^{-1}$)														
Median	6.8	15.0	6.1	8.0	9.0	13.4	17.1	14.6		17.3		19.8	11.5	6.3
Minimum	0.6	7.0	0.2	0.2	0.0	9.7	0.8	5.5		16.0		13.9	0.0	0.1
Maximum	12.0	19.0	20.0	12.0	14.0	16.0	41.2	18.0		19.0		30.0	26.0	10.0
N	38	48	432	62	24	6	182	6		6		41	22	12
Iron ($mg.l^{-1}$)														
Median	.055	.035	.050	.030	.040	.025	.130	.058		.030		.190	.120	.085
Minimum	.000	.000	.000	.000	.020	.020	.000	.045		.004		.070	.010	.000
Maximum	1.000	.100	.910	.195	.250	.050	.930	.120		.040		.260	1.000	.800
N	38	40	59	54	24	6	48	6		6		5*	22	12
Manganese ($mg.l^{-1}$)														
Median	.050		.000	.190	.050		.000					.000	.100	.175
Minimum	.000		.000	.030	.000		.000					.000	.050	.000
Maximum	.500		.150	.260	.150		.050					.100	.250	.300
N	24		59	6	24		48					5*	16	12
Copper ($mg.l^{-1}$)														
Median			0.00				0.00					0.00		
Maximum			0.20				0.20					0.00		
N			60				47					5*		
Dissolved Oxygen ($mg.l^{-1}$)														
Median		8.7	7.5	9.2			7.6		9.2	9.3	8.8	8.3		
Minimum		6.9	0.0	7.0			4.1		6.7	7.2	6.9	6.0		
Maximum		10.7	10.5	10.0			18.2		14.6	14.4	11.0	9.9		
N		32	171	24			138		92	18	16	15		
pH														
Median	8.0	8.1	8.6	8.2	8.3	8.4	8.6	7.9	9.1	8.6	9.4	8.5	8.0	8.5
Minimum	7.5	7.6	8.1	7.7	7.8	8.0	7.6	6.6	8.2	7.9	8.6	7.6	7.4	8.0
Maximum	8.5	8.9	9.0	9.0	8.4	8.5	9.3	9.0	10.0	9.6	9.7	8.7	8.7	11.0
N	84	106	164	109	24	6	132	33	58	14	10	15	46	36

Notes: 0.00, 0.0 = below detection limit. Underscored lakes were sampled in two time periods. *Data available from only 2 dates.

Table 6. Weather conditions prior to sampling dates.

	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	Buffalo	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter	
Years	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**95-96**
Wind Stress																		
Median	0.026	0.024	0.026	0.038	0.086	0.036	0.033	0.024	0.010	0.078	0.013	0.021	0.020	0.017	0.174	0.020	0.026	0.025
Minimum	0.018	0.008	0.001	0.008	0.003	0.008	0.023	0.018	0.008	0.003	0.007	0.009	0.009	0.009	0.017	0.007	0.018	0.008
Maximum	0.050	0.059	0.050	0.104	0.414	0.106	0.051	0.031	0.043	0.414	0.070	0.043	0.043	0.043	0.414	0.059	0.050	0.059
N	21	17	21	17	93	19	6	11	3	64	11	12	15	11	23	19	12	14
Rainfall																		
Median	10	206	10	193	90	224	93	1	25	60	104	213	213	64	50	122	10	239
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	300	1885	300	767	1000	1290	213	61	1885	700	1077	485	1168	191	960	1052	60	767
N	21	17	21	17	94	19	6	11	3	64	11	12	15	11	23	19	12	14
Snow Depth																		
Median		9		8	19	14		13	32	14	10	18		18	16	10	13	9
Minimum	13	4	13	4	14	7	22			9	4		18		14	4		4
Maximum	17	32	17	32	33	61	24			23	29		29		20	30		20
N	2	5	2	5	8	6	2	1	1	6	3	1	2	1	3	6	1	4
Solar Radiation																		
Median	469		463		467			496		466					457		489	
Minimum	325		325		116			325		119					218		325	
Maximum	620		620		828			620		574					581		620	
N	10	0	12	0	94	0	0	11	0	61	0	0	0	0	23	0	10	0

Notes: Rainfall is the total received (cm) during the day of sampling and 6 days prior. Solar Radiation (Langleys) and Wind Stress is the average of the day of sampling and 6 days prior. Wind Stress = 1.1 x 10^{-6} w^2 where w = windspeed in cm·sec^{-1} (Small, 1963). Snow depth is the average maximum monthly depth during the months of Nov. - Apr. of the prior winter. Solar radiation was measured in Brookings, SD (William Lytle, personal communication). Other variables were taken from the nearest National Weather Service monitoring station.

Table 7. Abundance of non-filamentous Cyanophyceae (cell·1⁻⁴) measured in the study lakes.

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak			Bitter
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**78-79**	**90-97**	**74**	**90-96**
N	47	86	48	108	458	108	24	23	6	211	33	157	40	32	40	46	11	36
Chroococcales:																		
Coccochloris_peniocystis																		
Median		8.8		23.5	1.1	54.6	4.2		37.9	0	0	0	0	0	0	9.5		0
Minimum		0		0	0	5.7	0		0	0	0	0	0	0	0	0		0
Maximum		286.7		109.2	372.5	216.5	14.6		125.8	0	65.5	3.9	6.1	0.9	1.8	289.6		26.1
N					285					157					19			
Anacystis incerta																		
Median		109.4		65.9	1055.3	80.7	12.8		164.9	0	351.0	24.9	13.2	44.6	8364.3	585.9		95,57.9
Minimum		3.3		2.6	0	15.3	6.4		92.7	0	31.5	0	0	0	162.6	33.8		4.8
Maximum		531.4		646.2	20,195.9	402.9	46.9		287.6	289.5	2268.4	261.7	199.5	299.3	11,830.7	4190.3		53,371.5
N					285					157					19			
Total picoplankton																		
Median	79.9	125.7	98.0	92.3	965.5	139.0	19.0	75.6	209.0	0	351.0	24.9	34.3	44.6	3898.1	586.2	21,274.3	10,105.0
Minimum	3.7	5.3	8.8	9.1	0.2	41.2	8.7	34.0	112.6	0	31.5	0	0	0	162.6	44.8	2552.4	8.2
Maximum	244.5	713.6	403.0	690.9	20,614.9	492.8	60.4	189.0	439.4	289.5	2268.4	261.9	199.5	299.3	15,779.9	4414.0	76,594.6	68,155.5
Anacystis cyanea																		
Median	4.4	0.2	4.1	0.9	26.3	8.0	1.2	0	2.8	0	0.7	64.5	39.8	41.9	6.6	8.8	1655.3	206.7
Minimum	0	0	0	0	0	0	0.2	0	1.1	0	0	0.9	0	15.4	0	0	180.8	0.3
Maximum	18.1	15.4	33.1	90.9	1358.5	27.2	2.9	73.1	4.2	13.0	29.3	613.9	200.4	212.1	140.9	387.9	4643.1	3587.8
Gloeocapsa sp.																		
Median		0		0	0	0	0		0		0		0		0	0		0
Maximum		0.1		0.2	12.9	1.8	0		0.1		0		0		10.0	0.6		0
N				60	340	60					6							
Total Chroococcales																		
Median	59.8	125.8	93.0	85.7	1027.1	153.8	19.5	76.33	211.4	0	325.8	99.7	39.4	134.4	3920.9	602.7	16,697.1	10,168.6
Minimum	3.7	8.1	6.4	9.5	0.2	42.2	9.8	20.6	114.6	0	35.9	3.3	2.4	48.4	175.7	35.5	2519.6	8.9
Maximum	244.5	713.6	406.6	665.4	20,778.0	504.9	62.8	219.9	442.7	289.5	2272.4	619.8	287.6	340.1	15,779.4	4464.5	83,196.2	68,956.7
N	77		118					60									57	
Chaemisiphonales																		
Stichosiphon sp.																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0.2	0.1	0.2	2.7	0.0	0.4	0	0	0.0	0.1	0.7	0	0	0	1.0		0.2

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.0 = less than 0.05 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified.

Table 8. Measured abundance of non-heterocystous, filamentous Cyanophyceae (Oscillatorineae, cells·ml^{-4}).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**78-79**	**90-97**	**74**	**90-96**
N	77	86	48	108	458	108	24	23	6	211	33	157	40	32	40	46	11	36
Lyngbya spp.																		
Median	0	0.5	0	0.9	6.3	4.2	3.0	0.5	0.5	0	0	645.9	251.7	829.3	63.3	9.3	0	0
Maximum	1.9	30.7	40.3	220.6	1120.0	551.6	157.4	0	3.4	34.4	1.9	8833.8	3778.5	5498.6	322.5	1372.5	0	992.3
L. contorta																		
Median		0		0	6.3	3.3	0		0.2	0	0	85.7	39.7	26.9	50.5	2.8		0
Maximum		30.7		9.3	1120.0	551.6	2.6		0.7	34.3	1.9	2632.6	1596.5	646.6	3201.0	119.8		992.3
N					539					45								
L. versicolor																		
Median		0		0.3	0	0	2.2		0	0	0	465.5	51.3	750.5	4.6	3.4		0
Maximum		10.8		212.1	0	10.3	157.4		2.7	12.8	1.8	6201.2	3723.9	5327.2	735.2	1363.4		2.3
N					539					45								
L. birgei																		
Median		0		0	0	0	0		0	0	0	0	0	0	0	0		0
Maximum		1.7		4.0	0	0	24.4		0	0	0	0	0	0	0	0		0
Oscillatoria sp.																		
Median	0	0	0	0	0	0	0		0	0	0	43.1	50.7	49.8	0	0		0
Maximum	0	0	0	0	27.5	3.2	0		0	0.1	0	1809.8	615.4	252.4	2.0	46.8		0
Spirulina sp.																		
Median	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0
Maximum	0	0	0	0	0	0.0	0		0	0	0	65.7	197.2	0	0	0		6.3
Total Oscillatorineae																		
Median	0	0.5	0	0.9	6.3	4.4	3.0	0	0.5	0	0	892.4	156.1	859.9	54.1	8.2	0	0
Maximum	1.9	30.7	40.3	220.6	1120.0	551.6	157.4	0	3.4	34.4	1.9	8920.1	3982.6	5628.0	322.5	1375.7	0	992.3

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.0 = less than 0.05 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified.

Table 9. Measured abundance of heterocystous Cyanophyceae (Nostochinaeae, ($cells \cdot ml^{-4}$).

	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**78-79**	**90-97**	**74**	**90-96**
N	47	86	48	108	458	108	24	22	6	211	33	157	40	32	40	46	11	36
Anabaena spp.																		
Median	0.3	0.2	0.1	0	0	0	0	1.0	0	0	0	0	0	0	0	1.5	0	0
Maximum	7.1	91.0	4.9	5.8	12.6	0.1	5.2	9.8	0.7	30.9	91.0	351.6	137.4	163.9	21.1	68.3	0	8.7
N	77		118					60									57	
A. circinalis																		
Median		0	0.1	0	0	0	0		0	0	0				0	0		0
Maximum		3.2	0.9	3.1	12.6	0.1	0.5		0	21.6	0				0	39.1		0.8
N			36							81								
*A. flos-aquae**																		
Median		0	0	0	0	0	0		0	0	0				0	0.5		0
Maximum		89.9	1.9	5.0	1.6	0.1	5.2		0.7	11.4	91.0				21.1	29.2		8.7
N			36							81								
Aphanizomenon holsatica																		
Median	0	0	0	0	0	0	0	15.5	0	21.5	2.3	208.2	131.1	137.5	0	5.0	0	0
Maximum	48.8	35.1	32.6	4.9	9.6	2.9	38.6	106.4	0	1894.7	1666.6	1856.4	7065.2	1360.1	0	227.5	0	14,560
N	77		118					60									57	
Cylindrospermum musicola																		
Median	0	0	0	0	0	0	0	0	0	0	0	62.7	10.8	39.8		10.4	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	1662.1	1037.9	1115.1		900.7	0	139.9
Nodularia Harveyensis																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0.1	3.3	0	0	0	0	0	0	0	0	0	0.4	0	222.6
Gleotrichia echinulata																		
Medium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	7.0	4.3	16.1	4.3	0	0.1	9.0	162.3	0	0	0	0	0	0	0	0.9	0	0
Total Nostochineae																		
Medium	0.4	1.6	0.5	0.1	0	0	0	0	0	25.9	45.6	419.5	346.1	333.4	0	20.3	0	0
Minimum	48.8	91.0	33.1	5.8	12.6	3.5	43.8	162.3	0.7	1894.7	1666.6	2353.1	7065.2	2466.4	21.1	907.0	0	14,560

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.0 = less than 0.05 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified. Small numbers of *Anabaena spiroides* in Lake Enemy Swim were included with the count of *A. flos-aqua as* they could not be separated when heterocysts and akinetes were not present.

Table 10. Measured abundance of Heterocysts (cells·ml^{-1}).

Lake	**Pickerel**	**Enemy Swim**	**Cochrane**	**Roy**	**Hendricks**	**Oak**	**Bitter**
Time Period	**90-96**	**90-94**	**90-97**	**95-96**	**90-94**	**90-97**	**90-96**
N	86	108	108	24	33	46	36
Anabaena circinalis							
Median	0	0	0	0	0	0	0
Maximum	0.1	0.1	0	0.0	0	2.6	0.8
A. flos-aqua							
Median	0	0	0	0	0	0	0
Maximum	3.1	0.2	0.0	0.1	0.1	0.3	0
Aphanizomenon holsatica							
Median	0	0	0	0	0.1	0	0
Maximum	0.2	0	0.0	0.4	10.5	2.5	114.6
Cylindrospermum musicola							
Median	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	28.2	19.1
Nodularia harveyensis							
Median	0	0	0	0	0	0	0
Maximum	0	0	0.1	0	0	0.0	12.7
Gloeotrichia echinulata							
Median	0	0	0	0	0	0	0
Maximum	0.1	0	0.1	0	0	0.1	0
Total heterocysts							
Median	0	0	0	0	0.1	0.0	0
Maximum	3.2	0.2	0.1	0.5	10.5	28.2	114.6

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.0 = less than 0.05 measured.

Table 11. Measured abundance of Centric Diatoms (Centrales, $no \cdot ml^{-1}$).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**90-96**
N	47	86	48	108	458	108	24	22	6	211	33	157	40	32	40	46	11	36
Cyclotella spp.																		
Median	0.14	0	0	0.01	0.11	0.03	0	0	0.03	0	0.04	0	0	0	2.68	0.10	0	0
Maximum	3.50	0.43	1.42	0.80	7.60	0.95	0.03	0.13	0.04	29.00	69.64	0	0.01	0	22.23	1.51	0	31.81
Stephanodiscus niagarae																		
Median	0	0.03	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0	0
Maximum	0.31	0.24	0.11	0	1.02	1.02	0.02	0.06	0	2.25	0.16	1.32	1.43	0.66	4.23	4.07	0	6.36
Melosira/Aulacoseira spp.																		
Median	0.22	0.11	0.43	0	0	0	0.18	0	0.03	0	0	6.50	2.91	2.91	0.05	0.17	0	0
Maximum	2.29	2.24	1.69	1.87	1.53	0.25	2.40	0.12	0.39	0.19	2.26	70.52	37.42	41.16	142.25	277.68	0	0.17
M. Varians																		
Median		0		0	0	0	0		0		0				0	0		0
Maximum		1.60		0.96	0	0	0.25		0		2.26				0.01	6.24		0.17
N					162										21			
Aulacoseira spp.																		
Median		0		0	0	0	0.14		0.03		0				0	0.05		0
Maximum		22.3		1.27	0.64	0.25	2.40		0.39		0.02				8.58	9.39		0
N					162										21			
Chaetoceras elmorei																		
Median	0	0	0	0	0.07	0.03	0	0	0	0	0	0	0		0	0	0	0
Maximum	0	0	0	0.31	8.87	0.57	0	0	0	0	0	0	0		0	0	10.86	82.70
Total centrales																		
Median	0.15	0.17	0.48	0.17	0.60	0.11	0.18	0	0.07	0.11	0.06	6.50	3.24	3.58	4.13	0.67	0	0
Minimum	0	0	0.03	0	0	0	0	0	0.02	0	0	0	0	0	8	0	0	0
Maximum	3.60	2.30	1.71	1.89	11.63	0.95	2.40	0.18	0.42	29.00	69.64	70.52	37.42	41.16	147.88	279.40	10.86	89.06

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.0 = less than 0.005 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified.

Table 12. Measured abundance of Pennate Diatoms (Pennales, no·ml⁻¹).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**90-96**
N	36	86	48	108	458	108	24	22	6	211	33	157	40	32	40	46	11	36
Asterionella formosa																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	8.58	19.39	3.23	6.90	0.85	0.77	3.84	0.26	0	0.02	0.93	0	0	0	3.07	0.05	0	0.68
N	77		118					60									57	
Fragilaria crotonensis																		
Median	0.19	0.04	0.29	0.29	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0
Maximum	9.62	5.27	2.16	6.40	8.19	0.17	1.38	0.19	0.27	1.40	0.43	3.95	2.71	1.73	33.80	3.25	0	0.17
N	77		118					60									57	
Tabellaria fenestrata																		
Median	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0
Mcaximum	0	0	0	0	1.80	0	0.01		0	0.76	0	0	0	0	0.46	0.01		0
Synedra/Nitzchia spp.																		
Median	0	0	0	0.01	0	0.03	0		0.04	0	0	0	0	0	1.55	0.09		19.26
Maximum	2.85	1.81	0.77	1.35	4.34	5.03	0.21		0.10	1.78	0.06	12.18	3.86	4.50	45.06	3.52		566.16
N	36																	
S. ulna																		
Median		0		0	0	0	0		0	0	0				0	0		0
Maximum		0.04		0.04	1.09	0.09	0		0.02	1.78	0.01				13.00	0.08		0
N					279													
N. acicularis / S. acus																		
Median		0		0	0	0	0		0.01	0	0				0	0		0
Maximum		0.13		0.13	0.01	0.31	0.21		0.03	0.35	0.03				16.90	0.60		0.12
N					73													
N. holsatica																		
Median		0		0	0	0	0		0	0	0				0	0		
Maximum		1.81		1.33	3.38	4.95	0		0.03	0	0.04				0	0.21		
N					260													
Phaeodactylum tricornutum																		
Median		0		0	0	0	0		0.01	0	0				0	0		19.26
Maximum		0.13		0.21	4.08	0.13	0.03		0.08	0.18	0				27.36	0.49		566.12
Navicula spp																		
Median		0		0	0	0	0		0	0	0				0	0		0
Maximum		0		0.40	3.38	0.08	0.02		0	0.14	0				6.89	0.01		0
Entomoneis sp																		
Median	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0
Maximum	0	0	0	0.01	0.99	0.07	0		0	0.01	0.50	0	0	0	0.63	0.05		0
Total Pennales																		
Median	0.07	0.25	0.49	0.63	0.11	0.08	0.22	0	0.19	0	0	0.63	0.44	0.27	4.33	0.19	28.00	566.45
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.60	0
Maximum	3.15	20.57	4.39	12.89	13.33	10.05	5.10	0.64	0.58	3.56	1.00	12.18	4.07	5.54	80.47	3.93	99.90	1164.12
N	77		118					60									57	

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.00 = less than 0.005 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified. *Synedra/Nitzschia* spp. also includes *Phaeodactylum tricornutum* which was originally identified as *Nitzschia closteriun.*

Table 13. Measured abundance of green algae (Chlorophyceae) and *Botryococcus braunii* ($no \cdot ml^{-1}$).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-74**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**95**
N	47	86	48	108	458	108	24	22	6	211	33	157	40	32	40	46	11	36
Sphaerocystis schroeteri																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0.22	0	0.80	70.60	0.57	1.91	0	0.22	2.64	0.09	0	0	0	50.70	1.11	0	0
Crucigenia quadrata																		
Median	0	0	0	0	0.16	0.06	0	0	0	0	0	0	0	0	1.86	0	0	0
Maximum	0	0.20	0	1.23	289.58	14.24	0	0	0	10.03	0	0	0	0	161.21	2.35	0	0.16
Oocystis spp.																		
Median	0	0	0	0.12	0	0.05	0	0	0.12	0	0	0	0	0	0	0.03	0	0
Maximum	0.46	0.59	0.62	0.97	24.70	1.71	0	0.18	0.33	0.37	0.03	27.61	1.80	33.63	10.81	1.84	47.66	165.39
Pediastrum spp.																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0.12	0	0
Maximum	9.89	0.71	14.16	1.33	9.26	0.48	0.85	1.73	0.24	0.70	0.43	80.88	18.91	207.98	72.43	2.40	0	0.28
P. boryanum																		
Median		0		0	0	0	0		0	0	0				0	0		0
Maximum		0.71		0.63	7.63	0.48	0.85		0.24	0.70	0.43				72.43	0.64		0
N					216					175								
P. duplex																		
Median		0		0	0	0	0		0	0	0				0	0		0
Maximum		0.61		1.33	1.07	0.43	0.19		0	0.52	0				42.25	2.21		0.28
N					216					175								
Scenedesmus spp.																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0.11	15.91	0.18	0.55	7.32	0.27	0	0	0.04	1.59	0	0.73	0.07	26.05	8.43	0.20	0	0
Schroederia/Selenastrum spp.																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0.01	0.07	0.04	0.02	2.57	0	0	0	9.58	0.01	2.88	0.94	0.35	0	0.01	7.52	0
Ankistrodesmus/Monoraphidium spp.																		
Median	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	91.57	6.53
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.64	0
Maximum	0.38	0.08	0.12	0.14	2.77	0.57	0.01	0.22	0.01	5.90	0.22	2.39	5.84	1.83	0	0.55	246.98	547.07

Table 13 continued. Measured abundance of green algae (Chlorophyceae) and *Botryococcus braunii* ($no \cdot ml^{-1}$).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-74**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**95**
N	47	86	48	108	458	108	24	22	6	211	33	157	40	32	40	46	11	36
Tetraedron																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0.01	2.25	0	0	0	0	0.08	0	0	0	0	0	0.03	0	0
Closteriopsis sp.																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0	0
Maximum	0	0.03	0	0.01	0	0	0	0	0	0	0.13	1.41	0.39	1.01	2.82	1.69	0	6.36
Closterium spp.																		
Median	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0
Maximum	0.19	0.10	0.03	0.01	0.10	0	0.19	0	0	0.03	0	0	0	0	8.45	0.35	0	0.08
Cosmarium spp.																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0.05	0.02	0.07	1.42	0.21	0.01	0	0.06	0.00	0	0	0	0.37	1.12	0.02	0	0
Staurastrum																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0.03	0	0.02	0	0	0.04	0	0	0.03	0.03	0.66	0.68	0.69	0.07	0.18	0	0
Unidentified single cells																		
Median	0	0	0	0	0	0	0	0	0	0	0	0.66	0.22	0.66	0.75	0	0	0
Maximum	0	0.08	0.08	0.87	22.72	2.01	0	0.01	0.17	0	0.08	4.60	3.59	3.95	41.05	0.47	0	0
Total Chlorophyceae																		
Median	0.12	0.09	0	0.34	3.42	0.54	0.04	0.04	0.26	0	0.01	1.97	1.26	1	28.23	0.97	108.64	6.5
Minimum	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0.02	1.64	0
Maximum	9.89	16.06	14.22	3.32	294.40	14.35	1.91	1.73	0.48	10.03	0.52	83.80	22.49	244.95	176.81	4.35	259.54	712.5
Botryococcus braunii																		
Median	0	0.64	0	1.61	18.92	4.79	0	0	4.01	0	0	12.57	2.66	41.49	2.5	1.14	0	0
Maximum	9.30	28.81	93.60	19.21	344.77	31.42	0.39	0	6.97	0.91	7.84	1936.01	355.59	248.92	5910.52	79.40	0	2.73

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.00 = less than 0.005 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified.

Table 14. Measured abundance of Chrysophyta-like flagellates (no·ml^{-1}).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**78-79**	**90-97**	**74**	**90-96**
N	47	86	48	108	458	108	24	22	6	211	33	157	40	32	40	46	11	36
Ochromonas/Paraphysomonas																		
Median	0	0	0	0	0	0	0	0	0.01	0	0.01	0	0	0	0	0	0	0
Maximum	0	0.36	0.47	0.50	1.04	0.19	0.13	0.33	0.12	0.34	0.26	1.01	1.00	0	0	1.75	0	0
Dinobryon sertularia																		
Median	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0.17	0.56	0.55	0.62	0.03	1.70	0.33	0.16	0.04	0	0.05	0	0	0	0	0.48	0	0
D. calciformus																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0.00	0	0	0	0	0.01	0	0.09	0	0	0	0	0	0	0	0	4.91	0
Mallomonas/Rhizo-chrysis-like																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0.02	0.08	0.02	0.10	0.35	0.05	0	0.06	0	0	0.05	3.63	0.08	0.80	0.01	0.02	0	6.36
Unidentified Chrysophyte-like																		
Median	0.02	0	0	0	0	0	0	0	0.06	0	0	0	0	0	0.13	0	5.32	0
Minimum	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.41	0
Maximum	2.00	37.55	0.08	22.45	11.93	14.44	0	0.85	3.27	1.28	2.90	4.93	2.19	0.55	25.62	33.27	15.43	37.55
Total Chrysophyta-like																		
Median	0.04	0.05	0.04	0.02	0	0	0	0.05	0.16	0	0.03	0	0	0	0.13	0.03	5.32	0
Minimum	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0.41	0
Maximum	0.62	37.67	0.65	22.49	11.93	16.23	0.33	0.85	3.27	1.28	3.19	5.40	2.19	0.80	25.62	33.46	15.43	6.36

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured. Sample size (N) is the number given at the top of each column, if not otherwise specified.

Table 15. Measured abundance of Dinoflagellates (Dinophyceae), Cryptophyceae) and Euglenophytes (Euglenophyceae (no·ml⁻¹).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	Blue Dog	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**94**	**70-79**	**90-94**	**88**	**88**	**88**	**70-79**	**90-97**	**74**	**90-96**
N	47	86	48	108	458	108	24	22	6	211	33	157	40	32	40	46	11	36
Peridinium/ Glenedinium/ Gymnodinium spp.																		
Median	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0.02	0.03	0.01	0.13	2.24	1.16	0.30	0	0.10	0.10	0.12	1.32	0.60	0.66	0.34	0.41	0	0.02
Peridinium sp.																		
Median		0			0	0	0	0				0	0	0		0		0
Maximum		0.03			2.24	0.28	0.15	0				0.73	0.60	0.66		0.22		0
N		24			206	6										16		12
Glenodinium/ Gymnodinium spp.																		
Median		0			0	0	0	0				0	0	0		0		0
Maximum		0			1.29	0.03	0.15	0				1.32	0	0.66		0.05		0.02
N		24			206	6										16		12
Ceratium hirundinella																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0.10	0.21	0.17	0.04	0.35	0.04	0.01	0	0	0	0.02	0.66	0.66	0.44	0	0.01	0	0
Total Dinophyceae																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0.10	0.22	0.17	0.13	2.24	1.17	0.30	0	0.10	0.10	0.12	1.32	0.66	0.66	0.34	0.41	0	0.02
Total Cryptophyceae																		
Median	0	0.03	0	0.01	0	0.03	0.13	0	0.15	0	0.01	3.51	1.53	2.07	0	0.05	0	0
Minimum	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0
Maximum	13.09	1.67	1.43	0.27	1.63	0.56	0.99	0	0.48	4.41	0.40	64.55	78.17	45.15	0	0.29	0	0.59
Trachelomonas spp.																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0.04	0	0.02	0	0	0	0.64	0.02	5.40	5.38	0.73	0	0.08	0	0
Total Euglenophyta																		
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0
Maximum	0	0.01	0	0.04	0.04	0.03	0.01	0	0.07	0.64	0.02	5.40	5.38	0.73	0.02	0.10	0	6.36

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.00 = less than 0.005 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified.

Table 16. Measured abundance of Rotifers (Rotifera, no·ml^{-1}).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	South Buffalo	Hendricks		Teton-kana	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**90**
N	39	42	34	54	344	66	12	6	167	33	158	41	33	40	46	23	36
Filinia longiseta																	
Median	0	0	0	0.1	0	7.5	0	0	0	0	5.0	2.0	13.7	0	0	0	0
Maximum	2.1	9.9	62.9	10.4	550.0	78.6	0.5	1.3	8.5	1.7	579.4	447.9	571.2	6.5	81.4	0	21.6
Asplanchna sp.																	
Median	0.1	0.0	0.8	2.9	1.8	1.1	0.3	5.0	0	0	1.8	2.6	2.6	9.2	4.0	0	0
Minimum	0	0	0	0	0	0	0	1.4	0	0	0	0	0	0	0	0	0
Maximum	190.3	10.0	17.1	37.2	322.2	57.0	4.3	14.2	38.6	5.7	72.2	145.7	78.6	369.0	91.9	0	59.0
Brachionus spp.																	
Median	0	0	0	0	0	1.1	0	1.9	0	0	8.8	3.1	24.5	0.1	0	0	0
Maximum	0	1.0	0	1.4	110.0	1285.4	0	4.3	93.1	1.4	942.6	589.4	1311.8	8.3	25.6	0	0
Keratella spp.																	
Median	0	7.5	1.0	3.2	0	2.4	2.2	18.4	0	63.1	6.3	5.0	5.8	0	13.1	0	0.5
Minimum	0	0	0	0	0	0	1.1	12.1	0	0.6	0	0	0	0	0	0	0
Maximum	19.9	37.2	108.3	50.0	281.8	194.5	6.3	48.6	63.3	312.3	3561.6	4243.6	1532.4	12.9	838.0	0	43.9
K. quadrata																	
Median	0	0.2	0	0		1.9			0	1.2					0		
Maximum	11.0	1.4	2.7	1.4		194.5			15.8	165.0					7.1		
N		9	17	35		56			9	27					28		
K. cochlearis																	
Median	0	16.5	0	2.9		0			0	22.8					2.7		
Minimum	0	5.0	0	0		0			0	0					0		
Maximum	12.7	28.7	14.2	37.2		7.6			0.9	224.4					838.0		
N		9	17	35		56			9	27					28		
Kellicotia longispina																	
Median		0		0		0	0	0		0	0	0	0		0		0
Maximum		70.2		0		0	81.1	0		0	4.8	0	0		274.3		0.4
Platyias quadricornis																	
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0.2	0.5	14.1	0	29.1	0	0	0	0	0	0	20.0	0	0
Polyarthra sp.																	
Median		0		0		0	0	1.2		0	5.3	0	0		0		0
Maximum		20.6		63.8		0	0	11.3		24.5	10,129.3	2752.9	523.8		111.8		0

Table 16 continued. Measured abundance of Rotifers (Rotifera, no·ml^{-4}).

Lake	Pickerel		Enemy Swim		Cochrane		Roy	South Buffalo	Hendricks		Teton-kana	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**94**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**90**
Synchaeta sp.																	
Median		0		0		0	0	0		0	0	0	0		0		0
Maximum		0		0		0	0	0		290.4	0	4.0	0		25.5		0
Trichocerca sp.																	
Median		0		0		0	0	0		0	0	0	0		0		0
Maximum		4.1		0.6		1.7	0	16.5		0	84.4	79.2	15.6		45.7		0
Total Rotifers																	
Median	0.0	15.0	3.9	3.8	2.7	48.6	3.8	41.2	0	63.1	152.3	103.0	147.9	9.9	66.0	0	5.0
Minimum	0	0	0	0	0	0.3	2.3	22.0	0	1.7	0	0	0	0	0	0	0
Maximum	200.4	722.0	108.3	41.6	725.0	1363.2	87.4	53.7	199.3	312.3	10,238.5	4332.0	2484.3	369.0	1676.1	0	62.7

Notes: Zooplankton were sampled with a 153 µm mesh in 1970-79 and a 80 µm mesh in 1990-97, so smaller genera and taxa were more reliably retained in 1990-97.

Table 17. Measured abundance of Cladocerans (Cladocera, no·ml^{-4}).

	Pickerel		Enemy Swim		Cochrane		Roy	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**90-96**
N	39	42	31	54	334	66	12	6	167	33	158	41	33	40	46	23	36
Daphnia (subgenus *Ctenodaphnia*) spp.																	
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2	1.8
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0	20.9	224.4
Daphnia spp																	
Median	7.6	4.7	4.1	3.2	1.6	1.2	26.9	0.2	45.9	18.2	2.9	1.9	5.9	0.1	4.2	0	0
Minimum	0	0	0	0	0	0	6.3	0	4.3	0	0	0	0	0	0	0	0
Maximum	364.5	25.0	94.8	85.5	1152.1	73.1	42.9	21.3	734.7	378.4	149.1	104.0	184.2	1709.5	171.4	0	871.3
*D. pulex**																	
Median	0	0.5		0.7	0	0	26.9		45.8	20.7	0	0	0	0	0		0
Minimum	0	0		0	0	0	3.1		4.3	0	0	0	0	0	0		0
Maximum	175.1	25.0		19.0	0.8	0	42.9		734.7	378.4	145.2	79.2	184.2	17.2	14.4		871.3
N	18	36		48	315	60				27		35					
D. galeata																	
Median	1.4	1.4		0.6	0.1	0	0		0	0	0	0	0	0	0		0
Maximum	182.3	22.4		77.8	85.8	36.5	3.1		0	0	87.3	39.8	60.1	31.0	7.1		0
N	18	36		48	315	60				27		35					
D. rosea																	
Median	0	0		7.2	0.5	0	0		0	0	0	0	0	0	0		0
Maximum	0	0		42.3	1152.1	36.5	0		45.5	76.9	3.1	0	0	10.0	31.8		0
N	18	36		48	315	60				27		35					
D. parvula																	
Median	0	0		0	0	0	0		0	0	0	0	0	0	3.5		0
Maximum	0	0		0	0	0	0		0	0	11.6	2.7	0.7	1709.5	169.7		3.1
Ceriodaphnia lacustris																	
Median	0	0	0	0	35.4	21.2	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0.6	0	0	2011.1	184.2	0	0	29.0	0	95.0	165.0	238.7	11.9	36.1	0	0
Diaphanosoma birgei																	
Median	0	0	0	0.2	0	0	0	0	0	0	6.6	2.0	5.7	18.6	2.1	0	0
Maximum	25.8	19.7	27.0	14.8	2.8	0	8.0	0.5	46.9	126.4	161.4	112.9	70.1	808.0	137.3	0	0

Table 17 continued. Measured abundance of Cladocerans (Cladocera, no·ml-4).

	Pickerel		Enemy Swim		Cochrane		Roy	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-94**	**70-79**	**90-97**	**95-96**	**74**	**70-79**	**90-94**	**88**	**88-94**	**88**	**70-79**	**90-97**	**74**	**90-96**
Bosmina longirostris																	
Median	0	0	0.7	0.1	0	0	0	23.8	0	0	61.0	48.6	94.0	9.4	69.3	0	0
Minimum	0	0	0	0	0	0	0	3.1	0	0	0	0	0	0	0	0	0
Maximum	0.9	3.0	15.7	12.0	16.8	2.1	3.7	72.3	6.3	16.0	1431.6	719.1	943.4	3040.0	821.5	0.2	27.0
Chydorus sphaericus																	
Median	0.1	0.1	0.8	0.0	0	0	0		5.3	0	0	0	0	0	0	0	0
Maximum	8.4	12.0	5.3	6.1	13.9	4.4	0		328.7	0.1	0	0	0	0.1	54.3	0	0
Leptodora kindtii																	
Median	0	0.0	0	0.0	0	0	0	0.0	0	0	0	0	0	0	0	0	0
Maximum	2.6	0.5	6.7	0.7	0	0	0.0	0.1	0	0	0	0	0	0	0	0	0
Total Cladocera																	
Median	8.4	7.6	10.3	8.5	38.4	41.0	27.2	25.0	63.4	30.4	108.5	100.3	178.2	29.9	106.6	1.2	12.0
Minimum	0	0.7	0.4	0.4	0	0.1	16.9	3.6	7.3	1.5	0	0	5.2	0.1	0.8	0	0
Maximum	364.5	26.6	101.8	94.3	2100.0	197.6	42.9	93.6	1092.4	498.6	1468.8	966.6	1018.7	387.2	950.5	20.9	871.3

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.0 = less than 0.05 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified. *D. pulex** includes *D. schodleri* from Lake Hendricks (1970-1972, only) and *D. catawba* from Lake Hendricks (1975, only). *D.*

Table 18. Measured abundance of Copepods (Copepoda) and Ostracods (Ostrocoda, no·ml^{-4}).

	Pickerel		Enemy Swim		Cochrane		Roy	South Buffalo	Hendricks		Teton-kaha	East Oakwood	Round	Oak		Bitter	
Time Period	**74-75**	**90-96**	**74-75**	**90-96**	**74-75**	**90-97**	**95-96**	**74**	**70-79**	**90-91**	**88**	**88**	**88**	**70-79**	**90-97**	**74**	**90-96**
N	39	42	34	54	334	66	12	6	163	33	158	41	33	40	46	23	36
Diaptomus spp.																	
Median	13.3	10.2	18.1	11.0	21.7	22.2	13.3	1.4	20.3	25.8	20.4	14.9	21.9	12.2	44.6	26.0	72.7
Minimum	0	0	0.4	0	0.2	0.2	1.1	0	0	0	0	0	0	0	0.9	3.7	0
Maximum	324.8	29.6	237.5	61.7	616.7	98.1	58.5	2.8	1027.5	186.7	114.6	84.5	94.9	671.2	232.6	88.7	758.1
D. siciloides /D. connexus																	
Median	13.3	10.2	18.1	11.0	21.5	22.2	13.3	1.4	17.1	20.1	20.4	14.9	21.9	20.5	43.1	24.7	41.0
Minimum	0	0	0.4	0	0	0.2	1.1	0	0	0	0	0	0	0	0.9	0	0
Maximum	324.8	29.6	237.5	61.7	616.7	98.1	58.5	2.8	1020.0	186.7	114.6	84.5	94.9	613.5	232.6	84.7	150.9
D. clavipes /D. nevadensis																	
Median	0	0	0	0	0	0	0	0	2.0	0	0	0	0	0	0	2.5	10.7
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0
Maximum	0.7	0	0	0	1.6	0.0	0	0	77.1	27.7	0	0	0	63.2	32.8	7.6	607.3
Total Cyclopoida																	
Median	17.5	7.8	19.3	7.4	8.2	9.5	16.2	1.9	7.9	3.5	106.1	86.3	152.0	57.9	27.2	0	0
Minimum	0.5	1.4	2.4	0	0	0	8.6	0.5	0	0	0	2.8	14.7	0.0	1.1	0	0
Maximum	103.4	65.4	302.0	93.0	221.4	181.1	39.0	49.6	456.8	226.3	1030.4	400.2	1028.7	586.6	133.4	0.1	26.9
Cyclops bicuspidatus																	
Median	0	0		0.5	0	0	8.0		6.1	0	0	0	0	73.2	0		0
Minimum	0	0		0	0	0	0		0	0	0	0	0	2.4	0		0
Maximum	45.6	65.4		93.0	1.3	181.1	39.0		85.3	9.7	1030.4	389.0	1028.7	510.9	133.4		5.7
N	16	31		48	21	45			30	15		35		20	31		
C. vernalis																	
Median	0	0.7		0.0	1.8	3.3	4.8		0	0.7	39.3	29.0	26.7	0	14.5		0
Maximum	3.5	11.9		28.3	9.7	38.5	15.8		32.5	28.3	344.0	347.2	273.0	0	126.2		27.0
N	16	31		48	21	45			30	15		35		20	31		
Mesocyclops spp.																	
Median	3.5	0		0	0	0	0		0	0	0	0	0	0	0		0
Maximum	56.2	8.6		11.1	0	5.7	0		0	0	0	0	0	0	0		0
N	18	31		48	21	45			30	15		35		20	31		
Total nauplii																	
Median	14.5	11.1	18.4	12.2	5.0	24.7	26.9	7.8	5.3	49.5	240.4	103.1	255.3	9.4	64.7	0.1	36.2
Minimum	0	1.4	0.3	0	0	0	19.5	5.7	0	0	0	9.9	18.4	0	0	0	0
Maximum	143.9	44.7	178.7	90.2	360.7	163.2	35.7	8.5	158.9	448.1	1495.6	775.4	925.0	222.6	398.9	55.4	350.8
Total Copepoda																	
Median	46.2	30.2	71.0	28.6	42.2	63.6	60.5	10.9	44.7	89.6	408.0	326.0	460.4	82.0	141.4	26.0	93.5
Minimum	5.0	4.1	4.4	4.6	0.4	12.0	46.3	6.8	1.4	2.0	0	49.1	44.5	2.1	14.6	3.7	0
Maximum	486.2	103.0	612.5	193.9	788.9	392.7	105.5	65.2	1080.0	681.2	2017.2	1157.6	1235.7	952.0	619.9	88.7	1108.9
Total Ostracoda																	
Median	0	0.24	0	0.34	0	0	0	3.15	0	0	0	0	0	0	0	0	0
Maximum	24.49	4.65	4.67	34.3	1.45	0.75	7.44	6.22	4.55	4.72	0	2.02	0	0	0	0	5.83

Notes: Underscored lakes were sampled in two time periods. Minimum values measured are 0 when not given. 0 = none measured, 0.0 = less than 0.05 measured. Sample size (N) is the number given at the top of each column, if not otherwise specified. *Diaptomus, connexus* and *Nevadensis* were only found in Bitter Lake, and were the only *Diaptomus* species found there prior to the rise in water levels in the mid 1990s.

Table 19. Larger organisms caught in horizontal plankton tows (individuals per m^3).

	Pickerel	Enemy Swim	Cochrane		Roy	Buffalo	Hendricks		Tetonkaha	East Oakwood	Round	Oak		Bitter	
Years	**90-96**	**90-94**	**76-79**	**90-96**	**95-96**	**94**	**78-79**	**90-94**	**88**	**88-94**	**88**	**78-79**	**90-96**	**74**	**90-96**
N	42	54	97	60	12	6	37	33	156	41	33	24	42	23	36
Fish Larvae/Minnows															
Median	0	0	0.54	0	0	0	0	0	0.01	0.06	0	*	0.20		0
Maximum	0.27	0.30	8.00	35.17	0	0.71	0	0	6.82	4.24	0.08	*	8.51		0
Hydracarina															
Median	0	0	0	0	7.68	0.48	0	0	0	0	0	2.24	0.48		0
Maximum	4.95	1.67	0.50	9.00	15.56	1.41	1.02	1.06	0	3.71	0	99.99	159.04		13.48
Artemia sp.															
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	5.08	43.68
Amphipoda															
Median	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Maximum	0	0.26	0	0.13	0	0.71	0	0	0.01	0	0	0	0		229.74
Hemiptera															
Median	0	0	0	0	0	0	0	0	0.01	0	0	0	0		11.14
Maximum	0.35	0.71	0	0.02	0	0	*	4.24	1.39	0.11	0.10	0	1.41		334.7
Chaoborus															
Median	0	0	0	0	0	0	0	0	0	0	0	0.19	0		0
Maximum	0	4.24	0.67	3.39	0.71	0	0	0	0.17	0	0.04	2.52	2.13		22.09
Other Insecta															
Median	0	0	0	0	0	0.17	0	0	0	0	0	0	0		0.99
Maximum	0.71	2.27	0	1.41	14.10	2.12	460.50	2.13	0.01	1.59	0	0.02	86.52		82.26

Notes: Underscored lakes were sampled in two time periods. Hemiptera in Hendricks and fish larvae in Oak (1978-1979) were abundant but were not counted. *The estimate for *Artemia* (Bitter Lake, 1974) was taken from Clarke-Bumpus zooplankton tows.

MENINGEAL WORM IN A MULE DEER IN SOUTH DAKOTA

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ABSTRACT

A 3.5-year old male mule deer *(Odocoileus hemionus)* collected in February 2001 from Charles Mix County, South Dakota by South Dakota Department of Game, Fish and Parks (SDGFP) personnel was delivered to the Animal Disease Research and Diagnostics Laboratory (ADRDL), South Dakota State University, for examination. Four adult parasites identified as meningeal worm *(Parelaphostrongylus tenuis)* were collected from a section of cerebellum tissue from this deer. Occurrence of meningeal worm in this deer likely represents an isolated case in free ranging mule deer populations in the state. This description represents the first documented occurrence of this parasite in mule deer in South Dakota.

Keywords

Meningeal worm, mule deer, *O. virginianus, Parelaphostrongylus tenuis,* South Dakota, white-tailed deer.

INTRODUCTION

Meningeal worm (*Parelaphostrongylus tenuis*) is a common parasitic nematode of white-tailed deer (*O. virginianus*) that occurs throughout the deciduous mixed-hardwood forests of eastern North America (Lankester 2001). The parasite has been reported as far west as western Manitoba (Bindernagel and Anderson 1972) in Canada and western Nebraska in the United States (Oates et al. 2000). *Parelaphostrongylus tenuis* has not been found in areas having sandy soils and pine dominated forests (Kocan et al. 1982) in the United States or the boreal mixed-wood forest of northcentral and western Canada (Wasel et al. 2003).

Although meningeal worm is generally not pathogenic to white-tailed deer, its definitive host, significant mortality in other cervids is well documented. Meningeal worm has been implicated as contributing to the local decline of North American caribou *(Rangifer tarandus)* (Samuel 1991), moose *(Alces alces)* (Lankester and Samuel 1997), and elk *(Cervus elaphus nelsoni)* (Raskevitz et al. 1991) populations. Although Tyler et al. (1980) documented severe neurologic disease in mule deer following experimental infection with meningeal worm, natural infection in this species is poorly documented. To our knowledge, Oates et al. (2000) documented the first naturally occurring infection of *P. tenuis* in a free-ranging mule deer from the north-central Great Plains (Nebraska). Our paper describes a mule deer from South Dakota that was infected with meningeal worm. This description represents the first documented occurrence of this parasite in mule deer in South Dakota.

After being observed with ataxia and seemingly unaware of its surroundings, a 3.5-year old male mule deer was euthanized by South Dakota Department of Game, Fish and Parks (SDGFP) personnel on 4 February 2001 in Charles Mix County, South Dakota. On 5 February 2001, the animal was delivered to the Animal Disease Research and Diagnostics Laboratory (ADRDL), South Dakota State University (SDSU), for examination. Four adult parasites identified as *P. tenuis* were collected from beneath the brain meninges from a section of cerebellum tissue, however, inflammation in surrounding brain tissue was not evident.

Distribution of meningeal worm in white-tailed deer populations in Nebraska, North Dakota, and South Dakota is well documented. Oates (1999) documented an overall prevalence of infection with meningeal worm for all white-tailed deer sampled in Nebraska of 7% while Wasel et al. (2003) documented an overall prevalence of infection of 8.2% for all white-tailed deer sampled in North Dakota. Jacques (2001) documented an overall prevalence of infection of 20.3% (n = 2,848) for white-tailed deer sampled in South Dakota. Furthermore, 215 mule deer harvested in South Dakota from 1997-1999 also were examined for meningeal worm, however, none were found to be infected with the parasite (Jacques 2001). Because the *P. tenuis* infected deer we described was the first of 216 mule deer examined from South Dakota infected with the parasite, it seems unlikely that the parasite is established in free ranging mule deer populations in the state. Occurrence of meningeal worm in this deer likely represents an isolated occurrence in mule deer populations in South Dakota. However, Samuel and Holmes (1974) expressed concern that the range of the parasite might be expanding westward through the Aspen Parkland Ecoregion, eventually arriving in western North America where white-tailed deer occur sympatrically with susceptible ungulate populations. It should be noted that white-tailed deer occur sympatrically with elk and mule deer populations in South Dakota. Hence, to minimize the potential westward expansion of this parasite into uninfected ungulate populations inhabiting western South Dakota, intrastate movements of white-tailed deer is discouraged.

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PLANT COMMUNITY TYPES AND BIODIVERSITY ON A MILITARY INSTALLATION

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ABSTRACT

The U.S. Army is responsible for preparing a well-trained combat force while maintaining the ecological diversity and integrity of the lands it manages. To help ensure that the dual goals of military training and land stewardship are met on an army-wide basis, a 3-year experiment to delineate and describe the plant communities as related to soil characteristics, and determine the existing health and biodiversity of the plant communities was developed .

Reconnaissance of the study area was conducted over several months during the summers of 1993-1995. Forty-five 100 m transects were randomly positioned on a native prairie during the springs of 1995-1997 (15 per year), using the IDRISI software program and located with a hand held global positioning system (GPS).

Three community types were verified at Camp Grafton (South Unit) based on floristic composition and soil data. These included upland, midland, and lowland prairie communities. This study found graminoid alpha (intracommunity) diversity greater ($P<0.05$) on the upland sites versus the lowland sites. Alpha diversity for forb species were not different ($P>0.05$) between sites. Beta diversity did not differ ($P>0.05$) between upland, midland, or lowland communities. No differences in mosaic diversity were found between upland, midland, or lowland communities ($P>0.05$). Although this transitional zone in Eddy County, North Dakota has excellent areas of native vegetation, it is clear that more management inputs, (eg., rotational grazing, prescribed burning, re-seeding) are needed to maintain the ecological diversity of plant species at CGS.

INTRODUCTION

The U.S. Army is responsible for managing nearly 5.1 million hectares of land on 186 major installations worldwide (U.S. Dept. of Army 1989). As a result of the limited land available and a dramatic increase in the area needed for military training and modern weapons testing, these areas have become important land bases for high military training use (U.S. Dept. of Army 1989). With increased land use comes the risk of deterioration in land condition, including accelerated soil erosion and reduced vegetative cover (Barker et al. 1998). Military lands must be carefully managed to preserve the functional and structural integrity of the natural communities, ensure long-term sustainability for future training needs, and to provide a realistic training environment. In addition to its responsibility for preparing a well-trained combat force, the U.S. Army must maintain the ecological diversity and viability of the lands in its care. While many of these lands are intensively used for a variety of military training activities, they are also managed for non-military values such as fish and wildlife, recreation, and agriculture. Additionally, the National Environmental Policy Act of 1969 and Army Regulation 200-2 require the Army to minimize any significant short-term and long-term environmental impacts on natural resources (Goran et al. 1983). Furthermore, rare and endangered species, and the habitat necessary to maintain those species on army land, are protected by the Threatened and Endangered Species Act (U.S. Dept. of Interior 1973). Recent legislative trends in environmental impact analysis require quantification of impact estimates. Thus, there is a need to establish cause-effect relationships between Army activities and environmental impacts. Knowledge about these impacts and their short and long-term effects will help Army personnel plan training programs that minimize adverse effects on local ecosystems.

Gilbert C. Grafton (South Unit) (CGS) was developed in 1983 to support the training needs of the North Dakota Army National Guard (NDARNG). Gilbert C. Grafton (South Unit) is located in Eddy County, approximately 56 km southwest of Devils Lake, and has an area of approximately 3,470 ha (Barker et al. 1998) (Fig. 1). This training site is also used by the North Dakota Air National Guard; Army National Guard units from other states; the U.S. Army Reserve; various Reserve Offi-

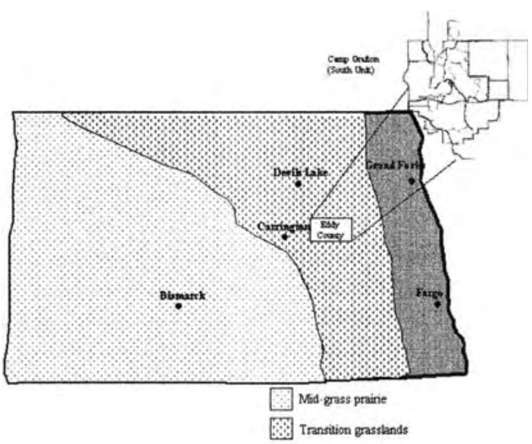

Figure 1. Location of Camp Grafton (South Unit), with respect to Eddy County, North Dakota.

cer Training Corps units; and active component units of the U.S. Army, Navy, and Air Force. The North Dakota Army National Guard recently introduced tracked vehicles to some of its land units ("mechanized units"). These vehicles have the potential to negatively affect the natural environment, posing new management challenges to the training site. With the addition of tracked vehicles, vegetation and soil properties need to be monitored on these installations to ensure that no irreparable harm will occur to the sites' natural resources. Measuring environmental impact involves inventory of natural resources and monitoring for those resources over time to determine whether ecological changes have occurred. Gilbert C. Grafton (South Unit) occurs in an area known as the Transitional Grasslands. These grasslands once encompassed approximately 9.325 million ha in North and South Dakota, Nebraska, Manitoba and Saskatchewan (Barker and Whitman 1989). Today, North Dakota has the largest area of transitional grasslands in relation to other plant community types, comprising approximately 30% percent of the grasslands (Barker and Whitman 1989). Transitional Grasslands has been converted to cropland throughout the Northern Great Plains region with approximately 32% of the original grasslands remaining (USDA NASS 2000). Thus, the ecological integrity of the CGS is a primary concern for the North Dakota Army National Guard. The description and geographic delineation of the remaining native vegetation of the transitional grasslands are prerequisite to generating baseline information regarding their ecological diversity and subsequent impacts from different management practices, including military training activities.

Without proper management, lands that receive intense use are susceptible to reduced vegetative cover and accelerated soil erosion. Proper management is necessary to (1) preserve the functional and structural integrity of the natural communities, long term sustainability, and (2) preserve the natural community to provide a more "realistic" training environment and the necessary camouflage for troops, vehicles, etc. which led to this study.

The objectives of this study were to 1) delineate and describe the vegetation types on the Transitional Grasslands at CGS; 2) determine alpha, beta, and mosaic diversities of the plant community types found within the Transitional Grasslands found at CGS and 3) determine the existing status of plant communities and seral stages associated with those communities at CGS. The results from this study will allow land managers and installation officials to understand the ecological processes and impacts that military training have on the land base and adjust their training appropriately.

METHODS

Study Area

The study was conducted in the southeastern corner of Eddy County, North Dakota, between 47°40N to 47°45N N Lat and 98°35N to 98°43N W Long, in the Drift Prairie physiographic region and the Transitional Grasslands prairie region (Barker and Whitman 1989) (Fig. 1). Vegetation in these transitional grasslands is a combination of mixed-grass and tallgrass prairie plants (Whitman and Wali 1975, Barker and Whitman 1989). Küchler (1964) classified the potential natural vegetation of this northern prairie as a moderately dense, Wheatgrass-Bluestem-Needlegrass *(Agropyron-Andropogon-Stipa)* association. The Transitional Grassland type lies between the Bluestem prairie to the east and the drier Wheatgrass-Needlegrass association to the west. The study area is administered by the North Dakota Army National Guard and has been grazed by cattle for many years.

Dix and Smeins (1967) described the prairie environment of neighboring Nelson County, North Dakota, in terms of the location and drainage of different types of soils and the plant species that were prominent constituents in these areas (Fig. 2). For the present study, the vegetative plant communities were designated by high, mid and low prairies based on topography and drainage. The high prairies (uplands) were classified as steep shoulder slopes and tops of knolls that lose most of their moisture to runoff. The mid prairies (midlands) were classified as back slopes with moderate infiltration. The low prairies (lowlands) were classified as footslope and toeslope positions. A visible zonation of plant communities occurred across these three topographic situations.

Average annual precipitation (29-year average) at the McHenry weather station was 47.3 cm per year (NOAA, 1995-1997). Annual precipitation was 63.2 cm, 47.5 cm, and 29.4 cm for 1995, 1996, and 1997, respectively. The 29-year average precipitation was 8.7 cm in June, 6.7 cm in July, and 6.9 cm in August. Precipitation was below the 29-year average for June and above the average for July for all three years. Precipitation was below the 29-year average for August with 5.5 cm, 3.1 cm, and 3.5 cm for 1995, 1996, and 1997, respectively.

Sampling Methods

Forty-five, 100 m transects were randomly positioned on native prairie at CGS during the springs of 1995-1997 (15 per year) using the GIS software pro-

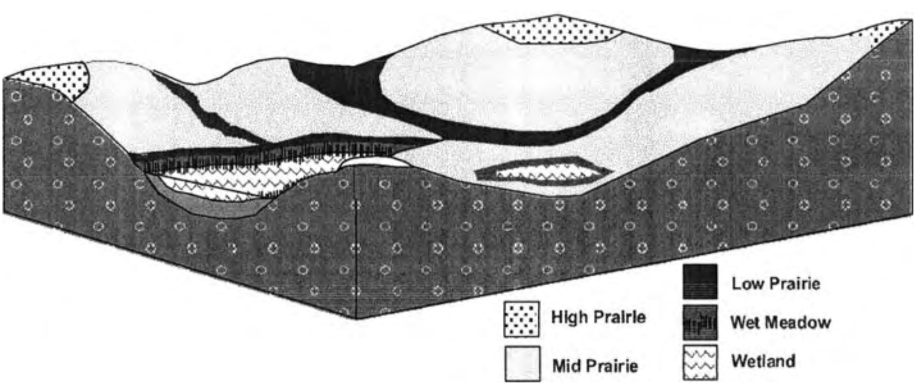

Figure 2. Hypothetical block diagram of Camp Grafton (South Unit), modified from Dix and Smeins (1967).

gram IDRISI. The transects were located in the field with a hand-held global positioning system (GPS) receiver. The transects were proportionately allocated, using the relative areas within the upland, midland and lowland communities. Quadrat data were used to detect the frequencies of graminoid and forb species. Quadrats were sampled every 5 m along the 100 m transects using a 0.25 m2 frame for forb frequency and within the 0.25 m^2 frame, a 0.1 m^2 frame to determine frequency of graminoid species, after Biondini et al. (1989), Stohlgren et al. (1998) and Daubenmire (1959). The larger 0.25 m^2 frame was used to determine presence/absence data for forbs, due to the inherent spatial patchiness of forb species (Biondini et al. 1989). In this study we evaluated 3 plant communities, upland, midland, and lowland plant communities with 18, 17, and 10 transects, respectively. Plant species nomenclature follows the Great Plains Flora (Great Plains Flora Association 1986).

Soil cores were taken approximately 1 m from the line transect at 25 m intervals along each of the 45 transects. A soil core comprised approximately 0.2 liters of the A-horizon on the lowland and midland sites. On the upland sites, a soil core contained both the A and B-horizons due to the shallow depth of the A horizon. Samples were analyzed for soil texture (Bouyoucos 1936), pH, electrical conductivity (EC) and organic matter (OM). The electrical conductance was determined following procedures described by Jackson (1958). Organic matter was determined following procedures described by Schulte (1988). Soils of each transect were classified to Series. These data were used in soil interpretation rating guides as predictors of soil behavior and environmental assessment.

Data Analysis

Alpha diversity using frequency data was calculated using the Shannon-Weiner index (Shannon and Weaver 1973). Beta and mosaic diversity were estimated from the presence/absence data with the use of affinity analysis (Scheiner and Istock 1987). Alpha, beta, and mosaic values among plant communities were compared using the Kruskall-Wallis test (Mosteller and Rourke 1983). Mosaic diversity values were standardized and analyzed using the bootstrap technique outlined by Scheiner and Istock (1987). Three standard deviations were used as a conservative test to determine whether mosaic diversity of the landscape was different from the random expectation. Diversity indice values were calculated by type of prairie, (i.e., high, mid, and lowland prairie).

Vegetation data were subjected to Two-Way Indicator Species Analysis (TWINSPAN) classification and Detrended Correspondence Analysis (DCA) ordination to rank dominant species within the plant community (Hill 1979). TWINSPAN is a numerical classification technique developed specifically for hierarchical classification of community data. The technique is based on the concept that a group of samples which constitute a community type will have a corresponding group of species that characterize that type (indicator species). The process is hierarchical, and so each of the new groups then undergoes the same process, until either a certain number of divisions have been reached or a group is too small to subdivide further. Once all the samples have thus been classified, the species are classified according to their overall fidelity to the groups, and a sorted table is produced. Default options were used with DCA when performing ordination of vegetation (Hill 1979). Ordination results are displayed as a graph where sites with similar species composition are nearby and dissimilar sites are far apart. The relationships between axis scores and soil variables were analyzed with Spearman rank correlation to determine if multiple gradients existed. Principal component analysis was conducted to determine if gradients existed between plant species and the associated soil characteristics from the upland, midland and lowland community types.

RESULTS

Principal Component Analysis for Soils

The first three components, clay, EC, and OM explained 87 percent of the variation in the soil data (Table 1). Examination of the communalities showed that clay and sand were both greater than 0.9 and explained the highest amount of variation in the data set. The first component is labeled a clay-OM component and explains 67 percent of the total variation. Component two is a silt component. Component three is an EC component and represents 21 percent of the variation. Dix and Smeins (1967) found the largest positive correlation between the drainage regime gradient and clay fraction, and the largest negative correlation with the sand fraction. This indicates that coarse particles tend to stay at high slope positions while finer particles tend to be transported down through the landscape. Principal component analysis showed a strong correlation between the upland prairie community and the sand component while the lowland community type was correlated with the clay component ($r=.786$, $p<0.001$; $r=.925$, $p<0.001$, respectively). Dix and Smeins (1967) suggested that soil salinity does not control the general species composition in the Transitional Grasslands. However, salinity does play an important role in determining species composition of some stands, particularly marshes (Dix and Smeins 1967).

Vegetation Ordination

The correlation between DCA axis scores and soil variables is presented in Table 2. Axis one is negatively correlated with pH, sand and silt, and positively correlated with clay and OM. Axis one represents a gradient starting with an upland prairie that moves down through the landscape to lowland prairie, and represents the topographic relationships and gradient divisions between upland and lowland communities. Axis two had no significant correlation with any soil variable or vegetation components. Axis three represents a negative correlation between EC and pH with silt. Figure 3 summarizes the results of the DCA analysis showing the positioning of upland, midland, and lowland plant communities along a sand to clay gradient within the coordinate axis system. DCA axis 1 and 2 explained 49.6 and 20.5% of the variability, respectively.

Diversity Indices

Diversity values were calculated for each community as described by Dix and Smeins (1967). This study found graminoid alpha (intracommunity) diversity greater (P<0.05) on the upland sites versus the lowland sites (Fig. 4). Alpha diversity for forb species were not different (P>0.05) between sites. Beta (intercommunity) diversity is a reflection of dissimilarity (1-similarity) in plant composition within a gradient (Fig. 4) (Wilson and Mohler 1983). Gradients in plant communities are enhanced by changes in topography across a landscape. Topography plays a large role in redistributing soil moisture, which is a key element influencing plant composition in arid and semiarid grasslands (Wollenhaupt and Richardson 1982). Beta diversity did not differ (P>0.05) between upland, midland, or lowland communities (Fig. 4). Glenn et al. (1992) reported that differences in slope, aspect, elevation, or grazing pressure showed no relationship with beta diversity in Kansas. Mosaic diversity did not differ from that of a random distribution of species across the landscape (Fig. 4). No differences in mosaic diversity were found between upland, midland, or lowland communities (P>0.05) and thus our hypothesis was rejected. The invasion or naturalization of *Poa pratensis* as well as previous land use of this landscape may explain why no differences were noted. *Poa pratensis* was well represented in virtually every stand at CGS. The intermediate disturbance hypothesis (Grime 1973, Connel 1978) predicts that plant species richness will be highest in communities with moderate levels of disturbance and at intermediate time spans following disturbance. One assumption of the intermediate disturbance hypothesis is that a trade-off exists between the ability of a species to tolerate disturbance and its ability to compete.

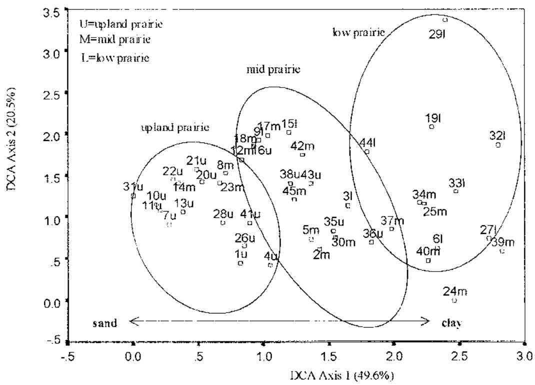

Figure 3. Axis 1 and 2 from DCA ordination of all transects.

Plant Community Description

Upland Prairie Community. TWINSPAN identified four different vegetative delineations of the upland plant community, which were described by seral stage using a sequence of late to early seral conditions using indicator plant species as defined by the USDA-SCS (1984). The four seral stages described were: 1) *Calamovilfa longifolia-Stipa comata-Poa pratensis-Bouteloua gracilis,* 2) *Stipa comata-Poa pratensis-Bouteloua gracilis-Schyzachrium scoparium,* 3)

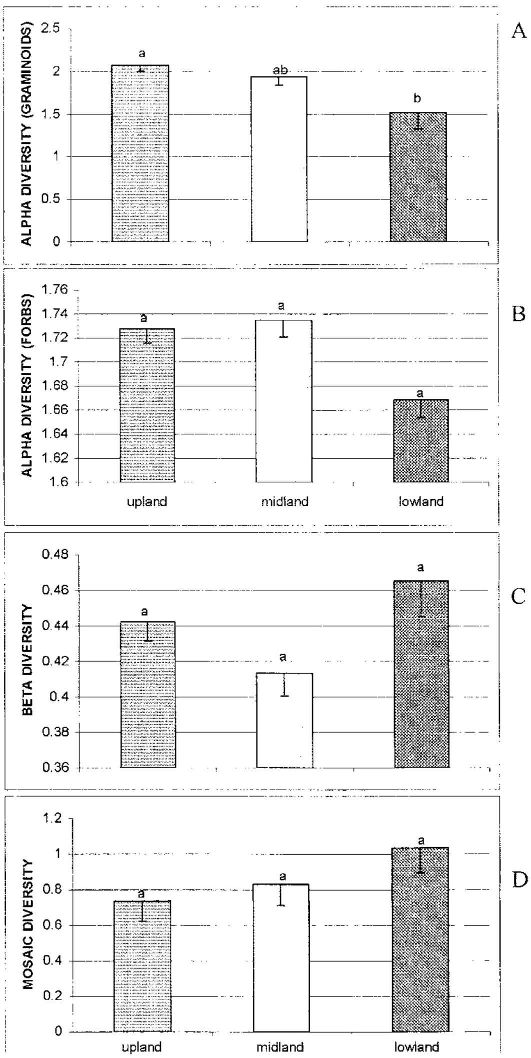

Fig. 4. (A) Mosaic diversity; (B) Beta diversity (estimated as average dissimiliarity); (C) Alpha diversity for graminoids (Shannon-Weiner index); (D) Alpha diversity for forbs . Standard error bars are given for each value.

Poa pratensis-Calamovilfa longifolia-Stipa viridula, and 4) *Poa pratensis-Bouteloua gracilis-Carex* spp.-*Koeleria pyramidata*. According to the USDA-SCS (1984), *Stipa comata* and *Calamovilfa longifolia* should comprise approximately 50 percent of the species composition by weight in high seral stage near climax development. *Stipa comata* and *Calamovilfa longifolia* were considered indicator species of a late seral stage, and exotic species such as *Bromus inermis* and *Poa pratensis* were indicative of an early seral stage. The *Calamovilfa longifolia-Stipa comata-Poa pratensis-Bouteloua gracilis* seral stage represented the highest level of plant succession (Table 3.). This seral stage had a high number of forb species compared to the other seral stages of the upland community.

The soils occupying this topographic area (summit and shoulder slopes) were primarily the Serden, Sioux, and Heimdal series. These soils are excessively drained with a high sand content and are leached with little organic matter (Fig. 5). The high sand content is negatively correlated with organic matter and positively correlated with pH. The plant species located on the high prairie are generally characteristic of the western Mixed Grass Prairie that have a high tolerance for dry conditions with dominant grass species including *Calamovilfa longifolia* and *Bouteloua gracilis*. In the second seral stage, *Stipa comata* ranked first; however, *Poa pratensis* had increased in frequency and ranked second, suggesting deterioration due to some form of disturbance. CGS is used by various military units from within the state and from throughout the United States. The training varies in duration and intensity, therefore having varying degrees of impact or disturbance. *Calamovilfa longifolia* was no longer present, suggesting a lower seral stage than the previous seral stage described. The third seral stage was dominated by *Poa pratensis,* indicating a clear displacement of native species. Indicator grass species of the late seral stage were absent and short grasses and sedges were common. The earliest seral stage was classified as a *Poa pratensis,* short grass, sedge plant community. Indicator climax plant species were no longer present. *Poa pratensis* and *Bromus inermis* comprised 29% of the species composition.

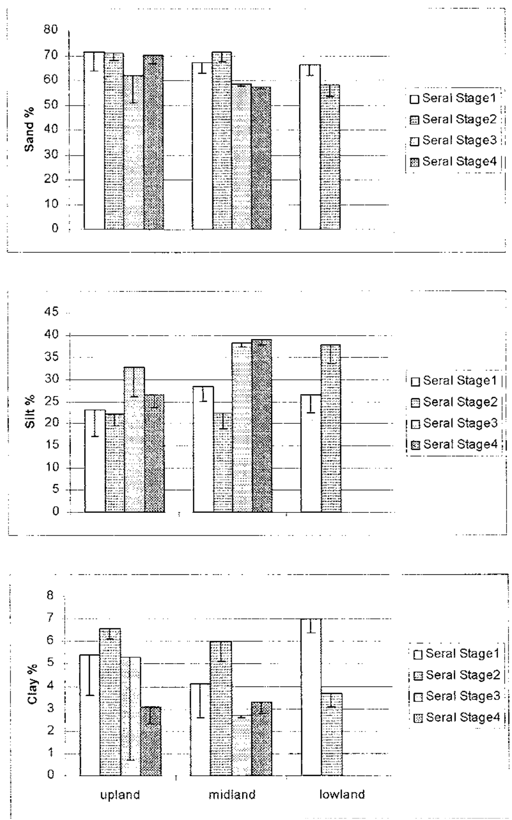

Figure 5. (A) Sand (%); (B) Silt (%); (C) Clay (%); for upland, midland and lowland communities.

Midland Prairie Community. TWINSPAN identified four different vegetative delineations of the midland plant community, described by seral stage using a sequence of late to early seral condition using indicator plant species as defined by the USDA-SCS (1984). These seral stages, in sequence of late to early climax development were 1) *Poa pratensis-Calamovilfa longifolia-Stipa comata-Stipa spartea,* 2) *Poa pratensis-Stipa spartea-Andropogon gerardii-Calamovilfa longifolia,* 3) *Poa pratensis-Agropyron cristatum-Carex heliophila-Stipa comata,* and 4) *Poa pratensis-Bromus inermis-Stipa viridula* (Table 4).

Kentucky bluegrass *(Poa pratensis)* was dominant in all midland communities located at CGS. Considerable accumulation of litter on the midland prairie appears to have reduced the competitiveness of other species physiologically adapted to the site. The highest seral stage was dominated by *Poa pratensis, Calamovilfa longifolia, Stipa comata, Stipa spartea, and Symphoricarpos occidentalis* with a *Carex* spp. understory. Across all 3 communities, this seral stage had the highest number of forb species with 51 species observed.

The second seral stage was dominated by *Poa pratensis*. *Stipa comata,* was no longer present and was replaced by *Boutleoua gracilis,* a short grass species. *Stipa spartea, Carex heliophila* and *Calomovilfa longifolia* remained as dominant species.

The third seral stage remained dominated by *Poa pratensis* with high seral stage indicator species absent. *Poa pratensis* and *Agropyron cristatum* comprised 46% of the species composition while short grasses and sedges comprised 21% of the species composition. The fourth seral stage was dominated by *Poa pratensis, Bromus inermis, Stipa viridula* and *Carex heliophila.* This seral stage ranked farthest from climax on the midland community. This seral stage was classified as a *Poa pratensis, Bromus inermis* plant community with *Stipa viridula* as the only climax plant species present. *Poa pratensis* and *Bromus inermis* comprised 60.3% of the species composition. It appears that this seral stage of plant community development has deteriorated due to the dominance of exotic species and lack of desirable native plant species.

The soils occupying this landscape area were primarily of the Maddock, Hecla, Egeland, Embden series. These soils are fine and very fine sands and are well-drained (Fig. 5). These soils have a thicker A-horizon due to the additional runoff from the surrounding landscape and water movement through the soil. The midland prairie exhibited species composition characteristics of both the upland and lowland prairie communities. Dix and Smeins (1967) found the midland prairie to occur on all soil textures, and species composition appeared to be little influenced by this factor. Hirsch (1985) reported *Stipa comata* as a dominant grass species on midland sites with *Carex* spp., *Bouteloua gracilis, Agropyron smithii,* and *Calamovilfa longifolia* comprising the midland community in southwestern North Dakota.

Lowland Prairie Community. TWINSPAN identified two different vegetative delineations of the lowland plant community, described by seral stage using indicator plant species as defined by the USDA-SCS (1984). According to the USDA-SCS (1984), *Andropogon gerardii, Stipa viridula* and *Stipa spartea* should comprise 40 percent of the species composition by weight in the late seral stage of development. Deterioration or disturbance of the native range resulting in an earlier seral stage creates a plant community with exotic species such as *Poa pratensis* and *Bromus inermis* (USDA-SCS 1984). The seral stages identified in sequence of late to early seral development were *Poa pratensis-Stipa spartea-Andropogon gerardii* and *Poa pratensis-Stipa spartea* (Table 5). The *Poa pratensis-Stipa spartea-Andropogon gerardii* seral stage represented the higher level of climax plant succession, and contained the highest number of forb species with 31 species observed. The soils occupying this topographic area were primarily the Hecla and Embden series. Soils are well-drained with fine sandy loams (Fig. 5). These soils have a thicker A-horizon than the midland prairie due to the additional runoff from the surrounding landscape and water movement through the soil. The lowland prairie was the lowest level of the landscape and exhibited species composition characteristics common to the eastern Tall Grass Prairie.

CONCLUSION

DECORANA verified three community types at Camp Grafton (South Unit) based on floristic composition and soil data. These included upland, midland, and lowland prairie communities. TWINSPAN recognized four seral stages of successional development on the upland prairie community. The *Calamovilfa longifolia-Stipa comata-Poa pratensis-Bouteloua gracilis* seral stage represented the highest level of climax plant succession. In addition, this seral stage had a high number of forb species compared to the other seral stages of the upland prairie community

TWINSPAN recognized four seral stages of successional development on the midland prairie community. The *Poa pratensis-Calamovilfa longifolia-Stipa comata-Stipa spartea* seral stage represented the highest level of climax plant succession. The plant species located on the midland prairie are characteristic of the western Mixed Grass Prairie and the eastern tallgrass prairie. Dix and Smeins (1967) found *Andropogon gerardii, Sorghastrum nutans,* and *Spartina pectinata* as species transitional to the lowland prairie but retained in the midland prairie. In the present study, *Andropogon gerardii* was only present in the late seral stage of the lowland prairie, while *Stipa spartea* was more prevalent in the lowland prairie than the midland prairie.

TWINSPAN recognized two seral stages of successional development on the lowland prairie community. The lowland prairie was the lowest level of the landscape and exhibited species composition characteristics common to the eastern Tall Grass Prairie.

Poa pratensis was dominant in all communities located at CGS. The presence of this graminoid species has had a homogenizing effect on the vegetation within this landscape through considerable accumulation of litter which reduces the competitiveness of other species physiologically adapted to the site. Whisenant (1990) found *Bromus japonicus,* in the northern mixed grass prairie, to increase litter buildup and decreases soil evaporation which favors its germination and establishment. This situation is occurring in these transitional and tall-grass prairie ecosystems. It may become increasingly important to maintain natural disturbance regimes such as fire. Invasion by exotic species either has already occurred or is inevitable in such systems. Maximizing the diversity and level of native species may depend on maintaining some level of natural disturbance (Connel 1978).

Pre-settlement disturbances, such as fire and grazing by native ungulates, affected the landscape of the North American grassland and have been discussed by many (Gleason 1923, Day 1953, Dix 1964). In addition, the imposition of European culture in the transitional grassland of North Dakota brought about significant changes in the native vegetation. Such changes are obvious where the vegetation has been destroyed by cultivation or heavy grazing. Today, disturbances such as lack of fire, grazing, invasions of exotic noxious weeds, military training, (eg., bivouac sites, personnel carriers, and tank training impact,) and introduced grass species are evident on (CGS), but it is difficult to assess which disturbance factor is the most critical in affecting the vegetation composition in each community. Although this transitional zone in Eddy County, North Dakota has excellent areas of native vegetation, it is clear that more management inputs, (eg., rotational grazing, prescribed burning, re-seeding) are needed to maintain the ecological diversity of plant species at CGS.

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Table 1. Component matrix for soil variables at Camp Grafton (South Unit), North Dakota, 1995-1997.

	Soil Factor (49.6%)	OM Factor (20.5%)	Silt Factor (17.0%)	Communalities
CLAY	.944	-.120	.047	.906
EC	.095	-.026	.970	.181
OM	.894	.998	.103	.821
PH	-.574	.520	.322	.695
SAND	-.960	-.103	-.028	.929

Table 2. Correlation between DCA axis scores and mean soil variables at Camp Grafton (South Unit), North Dakota, 1995-1997.

	AXIS 1	AXIS 2	AXIS 3	CLAY	EC	OM	PH
AXIS 1	1.00	–	–	–	–	–	–
AXIS 2	-.164	1.00	–	–	–	–	–
AXIS 3	-.015	.110	1.00	–	–	–	–
CLAY	.682**	-.014	.056	1.00	–	–	–
EC	-.073	.184	-.348*	.237	1.00	–	–
OM	.389**	.200	.189	.718**	.279	1.00	–
PH	-.652**	-.076	-.364*	-.467**	.172	-.445*	1.00
SAND	-.558**	-.042	-.157	-.958**	-.241	-.730**	.388**
SILT	-.406**	.240	.356*	-.093	-.071	.167	.214

* Denotes significance at 0.01
** Denotes significance at 0.001

Table 3. Percent composition of graminoid species in relation to successional stage for the upland community.

Successional Stage	Late	Mid-late	Mid	Early
Species	**%**	**%**	**%**	**%**
Calamovilfa longifolia	7.6	--	--	--
Stipa comata	17.9	16.9	--	--
Poa pratensis	11.9	16.3	24.1	17.6
Bouteloua gracilis	10.7	11.8	12.5	13.9
Carex heliophila	13.8	10.6	11.1	11.5
Schyzachrium scoparium	--	9.3	--	--
Stipa viridula	--	--	20.2	--
Bromus inermis	--	--	--	11.7
Koeleria pyramidata	--	–	--	11.0

Table 4. Percent composition of graminoid species in relation to successional stage for the midland community.

Successional Stage	Late	Mid-late	Mid	Early
Species	%	%	%	%
Carex heliophila	18.5	13.4	10.9	12.0
Poa pratensis	18.4	20.2	34.4	38.2
Calamovilfa longifolia	10.3	8.4	--	--
Stipa spartea	8.6	12.8	--	--
Stipa comata	8.1	--	--	--
Bouteloua gracilis	--	6.3	--	--
Agropyron cristatum	--	--	11.6	--
Muhlenbergia cuspidata	--	--	10.6	--
Bromus inermis	--	--	--	22.1
Stipa viridula	--	--	--	16.7

Table 5. Percent composition of graminoid species in relation to successional stage for the lowland community.

Successsional Stage	Late	Early
Species	%	%
Poa pratensis	29.4	42.0
Stipa spartea	20.6	29.6
Andropogon gerardii	11.0	--
Carex heliophila	5.9	--
Agropyron caninum	--	10.5
Stipa viridula	--	9.4

A BISON CRANIUM FROM THE MISSOURI RIVER FLOOD PLAIN, JUST SOUTH OF OLD FT. PIERRE, STANLEY COUNTY, SOUTH DAKOTA

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ABSTRACT

In October, 2002, a bison cranium was found during construction activities in the terrace fill of the Missouri River flood plain, approximately three meters below the surface in a succession of homogeneous black claystone. The cranium lay face-up, and measurements indicated a relatively large individual with a tip-to-tip horn core distance of 65 cm. Following preparation, cheek tooth wear indicated a very old individual and horn core burrs suggest the cranium is that of a male, explaining the relatively large size of the individual. Cranial measurements indicate the individual represents a member of the extant species, *Bison bison.* This assessment is reinforced by radiocarbon dating of the cranium that resulted in an age of 720 ± 40 years before present. Interestingly, the skull is of the approximate same size and age (710 ± 40 years B.P.) as one collected during 1998 to the south in Lyman County, SD.

INTRODUCTION

In the Fall, 2002, I was contacted by Mr. Brad Lawrence, City of Ft. Pierre, who reported a bison cranium had been found during construction for the Wakpa Sica Historical Center just south of the original site of Ft. Pierre Choteau. Mr. Tony Woodraska encountered the skull while digging a trench. The face of the specimen had been destroyed by the backhoe, but the remainder was well preserved, including the dentition. Amazingly, the cranium was found perfectly centered in the backhoe trench but was not destroyed.

On October 21, 2002, Lena Martin and I arrived to excavate the specimen in order not to delay construction. Unfortunately, the weather was cold with light snow, making field collection difficult. Nevertheless, with the volunteer help of Ms. Martin and Mr. Gene Blue Arm, the cranium was jacketed in plaster and burlap and lifted into my pickup by 1700 hours. The bison was transported to my office in Sturgis where it was prepared and conserved, and was then curated into the systematic collections at the Museum of Geology, SD School of Mines and Technology (SDSM).

The cranium was found just south of the original site of old Ft. Pierre in the NW¼, SW¼, NW¼, Sec. 21, T.5N., R.31E., Stanley County, South Dakota. The area lies on the Recent flood plain of the Missouri River, approximately

.8km west of the present river channel. Geologically, the specimen was located approximately 3 meters below the current surface. The top was sod-covered, but below the cover, the section was comprised of homogeneous grayish black claystone. The relatively impermeable clay provided an ideal setting for preservation of the bison. The occurrence in the terrace fill of the modern flood plain suggested a Holocene age, but resolution within the Holocene could not be determined.

During excavation, the relative large size of the cranium, relative depth of the occurrence, and lack of associated archaeological evidence sparked interest in the antiquity of the specimen. Some of these questions were resolved after preparation and when radiometric dating was employed to provide a precise date of when this animal existed.

DESCRIPTION/TAXONOMY

SDSM 61767 is represented by most of the cranium, missing the frontal area due to excavation and teeth that had fallen from their alveoli before final burial; neither dentary was associated. The dentition is exceedingly worn on the occlusal surfaces indicating a very old individual. Horn burrs and large horn cores suggest a male of the species. Some remnant of the horn sheath remains and obscures the horn tip. The remainder of the cranium is likewise well preserved, including delicate processes, indicating the cranium underwent relatively little transport before burial, but enough to lose many of the teeth, although some may have been lost during life. Only the posterior two molars are preserved on the right side, whereas all three molars occur on the left. The left fourth premolar was found in the surrounding matrix about 10 cm from its alveolus.

Determination of the taxonomic identity of SDSM 61767 was made based upon morphometrics. Bison species are differentiated on the basis of cranial morphology, but most morphological characters are based upon relative size differences because a general size deterioration occurs from the Pleistocene through the Holocene. Therefore, comparison with known species measurements is imperative. Grandstaff *et al.* (2000) tabulated differential measurements and characters states of bison species based upon those of Skinner and Kaisen (1947) and McDonald (1981). SDSM 61767 is compared in Table 1. One must keep in mind that SDSM 61767 was ontogenetically a very old male at death, so measurements should represent the larger dimensions of an old male of the species. For example, the tip to tip horn core measurement of 650mm lies within the range of both *Bison antiquus occidentalis* and *Bison bison bison,* but lies at the upper end of the range of *Bison bison bison.* A similar situation occurs with other measurements such as occipital condyle width or depth of cranium to foramen magnum. Measurements of SDSM 61767 compare most favorably with those of *Bison antiquus occidentalis* and *Bison bison bison.* However, the molar row length compares most favorably with that of *Bison bison bison.*

DISCUSSION

The distribution, evolution, and taxonomy of Holocene bison was discussed in Grandstaff, Parris, and Martin (2000) and is only summarized here. McDonald (1981) noted that *Bison alaskensis* and *Bison priscus* are immigrants that became extinct in North America about 20,000 years ago. *Bison antiquus,* separated into subspecies *B. antiquus antiquus* and *B. antiquus occidentalis* by some authors, represents the ancester from which extant species were derived. The two extant subspecies of bison appear to have differentiated from *Bison antiquus* approximately 5000 years ago and include: *Bison bison bison,* found principally in open plains environments, and *Bison bison athabascae,* the Wood bison, found in more wooded and upland environments.

Based upon cranial and dental dimensions, SDSM 61767 is assigned to *Bison bison bison*, the living bison adapted to a prairie habitat. This assignment is reinforced by the geographic source of the specimen in the Northern Great Plains.

Because morphology alone could not determine the precise age when the bull existed, other than within the last 5000 years or so, radiometry was utilized. Care was taken to select a sample of the skull that was unaltered during preparation and would not impact the aesthetics of the cranium (although the entire frontal-nasal area was already destroyed). Beta Analytic Inc. analyzed the sample (Beta-172819), and based upon bone collagen, derived a radiocarbon date of 720 ± 40 years before present.

CONCLUSIONS

A large male bison cranium (SDSM 61767) was found in the Recent terrace fill of the Missouri River, buried three meters below the surface, just south of old Ft. Pierre Choteau. The relatively large size of the cranium and depth of burial in a relatively homogeneous matrix made temporal designation questionable. Upon preparation, the well-worn dentition indicated an elderly individual that probably died of old age. No archaeological association was noted, and only the cranium was encountered, suggesting normal flood plain deposition. Based upon measurements, the cranium appears to be that of *Bison bison bison.* This contention was reinforced by a radiocarbon date of 720 ± 40 years before present.

The specimen was of the same relative age (710 ± 40 years B.P.) as another bison specimen found south of Chamberlain in Lyman County, SD (Grandstaff *et al.,* 2000). This specimen was also found over 2 meters below the surface. The synchronicity and depth of occurrences may indicate a time of extensive flooding of the Missouri River Basin just over seven hundred years ago, a contention that must be tested when additional datable remains are found. Also, this occurrence proves that deep burial in a homogeneous clay, parameters often promoted as indicative of great age, do not necessarily indicate great antiquity.

ACKNOWLEDGMENTS

I wish to thank Mr. Brad Lawrence, City of Ft. Pierre, for contacting the Museum of Geology, aiding in funding for dates and field work, and for gaining permission to collect and preserve the cranium at the Museum of Geology. His excitement insured preservation of this important specimen. Ms. Stacey LaCompte, Executive Assistant, Wakpa Sica Historical Society supported our investigation. Mr. Gene Blue Arm, Eagle Butte, SD, and Ms. Lena A. Martin kindly volunteered during field recovery. The cranium was found by Mr. Tony Woodraska, and the scientific community thanks him for reporting the occurrence.

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Table 1. Cranial and Horn Core Dimensions (mm) of SDSM 61767 and male *Bison* (See Grandstaff, *et al,* 2000). *B.a.a=Bison antiquus antiquus, B.a.o.=Bison antiquus occidentalis, B.b.b.=Bison bison bison, B.b.at.=Bison bison athabascae, B.p.=Bison priscus, B.al.=Bison alaskensis.*

	B.a.a.	*B.a.o*	*B.b.b.*	SDSM	*B.b.at*	*B.p.*	*B.al.*
Total cranial length	629	511-606	500-583	530	562-604	-	602-676
Tip-Tip core width	765-1067	626-1055	510-778	650	542-848	751-1064	800-1540
D-v diam. core base	81-126	70-114	69-99	85	81-106	84-116	100-153
A-p diam. core base	76-129	77-120	67-103	83	83-109	98-130	122-171
Width btwn. aud. meat.	251-318	238-294	220-270	247	243-298	248-310	268-340
Width occ. condyle	132-161	111-151	111-140	135	118-139	127-165	133-175
Depth to for. magnum	94-134	89-120	81-115	110	92-114	91-119	97-134
M^1-M^3 length	105.2-106	90-102	81.8-97.9	82	-	-	-
M^3 maximum width	29.6-30	27.8-29.1	22.3-31.4	27	-	-	-
Core shape: 1 symmetric, 2 asymmetric	1	1	1	1	1	2	2
Core axis: 1 arched, 2 sinuous	1	1 or 2	1	1	1	1	1
Growth Pattern: 1 spiral, 2 straight	2	1 or 2	2	2	1 or 2	2	2
Core rotation: 1 none, 2 forward, 3 backward	1	3	3	3	3	3	3
Horn curvature: 1 continuous, 2 base straight, 3 recurved	2	1	1	1	1	1,3	1,3
Horn core tip: 1 no twist, 2 posterior twist	2	2	2	2	2	1	1
Index of horn curvature	128-147	121-147	115-182	130	126-149	107-153	126-152
Index of horn compression	83-108	86-104	81-107	102	84-98	73-103	70-78

Index of horn curvature = (length on lower curve / straight line length) x 100
Index of horn compression = (dorsal-ventral diameter / antero-posterior diameter) x 100

Abstracts of Senior Research Papers

presented at

The 88th Annual Meeting

of the

South Dakota Academy of Science

USE OF CONDENSED CORN SOLUBLES FOR PRODUCTION OF SUCCINIC ACID BY *ACTINOBACILLUS SUCCINOGENES*

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ABSTRACT

Succinic acid is utilized in food, pharmaceutical, surfactant, detergent, green solvents and biodegradable plastics industries. The total market size for succinic acid is more than $400 million/year. *Actinobacillus succinogenes* is a rumen organism that has been shown in previous research (Zeikus et al, 1999) to produce succinate concentrations up to 110 g/L. *A. succinogenes* is a facultative anaerobe that can utilize numerous substrates for succinate production. This research project is evaluating condensed corn solubles (CCS), an ethanol fermentation byproduct, as a basal medium for succinate production by *A. succinogenes.* Previous research with other microbes demonstrated that CCS was an excellent source of nutrients, however in some cases a filtered form of the medium performed better than the unfiltered CCS. Therefore, we used a filtered CCS medium, at a concentration of 240 g/L (wet basis). An extensive and lengthy acclimation process was required to obtain growth of *A. succinogenes* in the CCS-based medium. This involved repeated subculturing *A. succinogenes* in hybrid media containing progressively lower levels of tryptic soy broth (TSB) and higher levels of CCS. When *A. succinogenes* was able to grow in the CCS medium alone, the strain was lyophilized for storage. A growth curve was performed to compare the CCS medium with the lab medium TSB. The CCS medium resulted in a longer lag phase, but higher viable counts (2.4×10^9 CFU/ml) compared to TSB (2.0×10^9 CFU/ml). Currently trials are aimed at determining the optimal sugar concentration needed for succinic acid production. Future trials will also evaluate the effects of carbon dioxide on *A. succinogenes* metabolism.

EFFECTS OF MATERNAL SIZE ON EGG AND LARVAL CHARACTERISTICS IN SOUTH DAKOTA YELLOW PERCH POPULATIONS

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ABSTRACT

Maternal size can affect egg and larval characteristics for a variety of fish species. We assessed the effects of maternal size (total length [mm]; TL) in South Dakota yellow perch *Perca flavescens* populations using field and laboratory approaches. Total egg weight was positively related to female yellow perch TL with female perch over 300 mm TL carrying approximately 90 g of egg mass. Egg diameter (mm) was linearly related to female TL for yellow perch 180 – 240 mm collected from Reetz Lake, SD during late March 2002 approximately one month prior to spawning; however, no fish were collected between 250 and 300 mm TL. Egg diameters for two females > 300 mm TL were not substantially larger than egg sizes for 220-240 mm TL female yellow perch suggesting that the relationship between egg size and female size may be asymptotic. For laboratory experiments, 10 yellow perch 185-312 mm TL were collected from several South Dakota lakes immediately prior to spawning and were allowed to spawn in 38-L aquaria containing simulated aquatic vegetation (suspended conifer tree branches) with 3-5 male perch of varying TL. Egg diameter ranged from 1.0 to 1.5 mm; egg diameter varied 0.2-0.6 mm for an individual female. Female TL was significant in explaining 50% of the variability in mean egg diameter for yellow perch allowed to spawn under laboratory conditions. Significant differences in mean egg diameter among female yellow perch were often substantial, ranging from 0.10 to 0.32 mm with largest differences resulting from comparisons of females > 300 mm TL and females < 200 mm TL.

SOURCE WATER DEFINITION FOR A SPRING IN A FAULT-CONTROLLED ALLUVIAL VALLEY

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ABSTRACT

A perennial spring that forms a tributary to Battle Creek on the eastern flank of the Black Hills was studied for source water identification and definition. The spring has a sustained discharge of approximately 4 cfs even in low precipitation years. Landsat satellite imagery was used to track spring migration using vegetation within the riparian habitat based on Normalized Difference Vegetation Index (NDVI). These and anecdotal data suggest a perennial water course has remained fixed below the spring source which has, in past years, moved in an up-valley direction. Seismic refraction and reflection surveys indicated that depth to the water table deceased in a southerly direction from approximately five to zero meters at the spring. Structurally, at least one fault was shown to penetrate vertically through major bedrock aquifers extending to the Precambrian basement rocks. Six monitoring wells were installed and used to confirm the depth to water table. Analyses suggest that the spring has mixed source waters; upwelling from deep bedrock aquifers and augmentation by flow through shallow alluvial aquifers. The shallow alluvial aquifer(s) potentially source from alluvial fan deposits and/or gypsum sinkholes in hydrologic connection with stream gravels. The shallow aquifer(s)s store and act as conduits for meteoric water and in high precipitation years are responsible for the upstream migration of the spring.

THE INFLUENCE OF PRE-BURN CANOPY COVERAGE ON POST-FIRE USE BY BLACK-BACKED WOODPECKERS IN THE JASPER FIRE

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ABSTRACT

Black-backed Woodpeckers *(Picoides arcticus)* are strongly associated with young burns and are a species of special concern for a variety of state and federal agencies. We tested a model that predicted Black-backed Woodpecker presence in post-fire environments based on pre-fire canopy coverages. We used a GIS to choose 2 "suitable" sites (i.e. pre-burn canopy coverage >70%), 2 "marginal" sites (i.e. pre-burn canopy coverage 40-70%) and 2 random sites (canopy coverage variable) within the Jasper Fire. Model parameters were based on breeding activities elsewhere in the species' range. We surveyed the above sites (each 300-400ha) during the summers of 2001 and 2002. We predicted that Black-backed Woodpeckers would occur primarily on the "suitable" and "marginal" sites. Black-backed Woodpeckers did not nest in 2001 but 89% of all Black-backed Woodpecker nests (n=12) in 2002 were detected in the "suitable" and "marginal" sites. Nest trees and characteristics surrounding nest trees differed from random forest conditions, suggesting that Black-backed Woodpecker nest site selection occurs at a number of spatial scales. The data provide preliminary support for the model, but additional field seasons are needed to determine 1) how the model functions over multiple years and 2) the role of food availability in influencing temporal responses of Black-backed Woodpeckers to fires.

A COMPARATIVE STUDY OF SEED CHARACTERISTICS FROM SELECTED SPECIES OF THE AMARANTHACEAE AND CHENOPODIACEAE

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ABSTRACT

The families of the Amaranthaceae and Chenopodiaceae are herbs and shrubs known for their weedy nature. The Amaranthaceae with 60-65 genera include the pigweeds *(Amaranthus)* and the cock's comb *(Celosia)*. These are found in temperate to tropical regions of America and Africa with twelve genera represented in the U.S. The Chenopodiaceae contain 102 genera and include the goosefoot and lambsquarters *(Chenopodium)*, as well as salt bush *(Atriplex)*, kochia *(Kochia)*, and Russian thistle *(Salsola)*. The latter is characteristic of halophytic (salty) soil and found in cosmopolitan areas around the world, with 14 genera native to the U.S.

Systematic botany has shown a close relationship between the two families and recently compared various characteristics with differing results. No studies, however, have examined seed characteristics. Seeds of each species are unique in morphology and our purpose is to analyze seeds from each family and determine if there is a set of discriminating traits unique to that particular family. These distinctive characteristics could be used to determine whether the two groups should be combined or remain as separate families.

A cursory examination of seed coat morphology was conducted using a dissecting microscope. In addition, seeds were cut to reveal their interior morphology. Both, the inside, as well as the outer seed were examined in detail under the scanning electron microscope (SEM) to conduct a multivariate analysis.

Preliminary results show variances within the species of both Amaranthaceae and the Chenopodiaceae but no clear evidence to support maintaining the two as distinct groups.

MICROBIAL INHIBITION IN RESPONSE TO TREATMENTS OF HYDROGEN PEROXIDE AND FORMALIN ON LANDLOCKED FALL CHINOOK SALMON EYED EGGS AS DETERMINED BY SCANNING ELECTRON MICROSCOPY

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ABSTRACT

Scanning electron microscopy was used to compare microbial growth in landlocked fall chinook salmon eggs receiving daily 15 min treatments of 1,667 mg/L formalin, 700 mg/L hydrogen peroxide treatments, or no chemical treatments during incubation in vertical-flow incubators from egg eye-up to hatch. In eggs that were not chemically treated, bacterial numbers significantly increased from 2,413 bacteria/mm^2 on the external egg membrane surface at the start of the experiment to 69,598 bacteria/mm^2 12 days later. Eggs receiving no chemical treatment had bacterial numbers at the end of the experiment that were significantly greater than those on eggs receiving either of the chemical treatments. The number of bacteria attached to the external egg membranes did not significantly differ between eggs treated with either formalin or hydrogen peroxide throughout the study. Fungal growth was negligible and only observed in control eggs. The external membranes of control eggs were visibly degraded over the 12-day period. Egg survival was significantly lower in control eggs compared to eggs receiving either of the chemical treatments, and was significantly correlated to bacterial numbers. More recently, we have used low vacuum scanning electron microscopy to quickly estimate microbial populations attached to the external egg membrane of landlocked fall chinook salmon eggs. The eggs required no preservation or treatment. The quick and efficient procedure developed with low vacuum SEM allowed for real time microbial population estimates, which were given to hatchery personnel in order to determine the most appropriate chemical treatment regime, thereby potentially reducing chemical discharges in hatchery effluents.

TRACKING BUFFALO FROM SPACE: AN ANALYSIS OF ECOSYSTEM CHANGE USING REMOTE SENSED DATA

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ABSTRACT

The purpose of this paper is to report the landscape scale ecological changes that have occurred on a bison ranch in the Powder River Basin of East-central Wyoming. Prior to westward expansion, the Powder River Basin of Wyoming supported millions of bison *(Bison bison bison)* and were considered primary hunting grounds for many Plains Tribes. With the near extinction of bison and subsequent introduction of domestic cattle and agriculture, and more recently mining and coalbed methane production, this area has undergone extensive ecological change over the last century. Surplus bison from the Yellowstone Park were reintroduced onto a 60 thousand acre ranch (the Durham Ranch) in 1959 and populations have flourished under various management strategies. The Holistic Resource Management (HRM) strategy was introduced onto the ranch in 1985 and has continued to present. The objectives for this study were to quantify long-term short grass system response to bison grazing under a HRM regime using information derived from satellite based multispectral radiometry. Specifically, data on surface albedo and normalized difference vegetation index (NDVI) were gathered from 1985 to 2002 on a semi-arid shrub steppe grassland system grazed by bison under the HRM strategy. The results indicate that ecological conditions have changed under this management strategy, however, drought within these years may have influenced the findings. Further studies that combine ground-based data with satellite data will provide a clearer picture of ecological impacts across multiple spatial scales.

Keywords

Albedo, bison grazing, Holistic Resource Management, NDVI, remote sensing, semi-arid short-grass prairie

USE OF SATELLITE IMAGERY TO DOCUMENT TIMBER HARVEST ACTIVITY AND OTHER LAND COVER CHANGES IN NORTHWESTERN MONTANA

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ABSTRACT

We were interested in using satellite imagery to classify land cover types and logging activity in NW Montana. The study was conducted on the Swan Lake drainage in the Flathead National Forest. We based our analysis on Landsat multispectral scanner images from three different decades; 1972, 1986, and 1992. The images were analyzed using the Idrisi and Multispec software programs. Using a supervised classification procedure, the study area was classified largely into six different land cover types including older forest, recent clearcuts, young forests, lakes, snow, and rock. Ground truthing evidence indicated that much of the study area appeared to be properly classified. There were some problem areas, most notably avalanche chutes, alpine meadows, and other natural meadows that often were misclassified as recent clearcuts.

We refined the classification procedure by combining spectral data from images taken decades apart. Avalanche chutes, natural meadows, and other natural features tend to retain similar vegetation cover over time, thus the spectral signatures of these areas should remain relatively unchanged over time. By contrast, the spectral signature of clear-cut areas should change over time, due to regrowth of the forest. Thus, by subtracting the spectral values from images of the same area taken a decade apart, the natural meadows and other unchanging areas should yield a series of spectral values near zero. A similar subtraction procedure in clear-cut areas should result in a large difference in spectral values. The subtraction procedure appeared to improve land cover classification in a number of our problem areas.

SURVEY OF BIOLOGICAL CONTROL OF LEAFY SPURGE (*EUPHORBIA ESULA* L.) WITH *APHTHONA* FLEA BEETLES IN CENTRAL COLORADO

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ABSTRACT

Leafy spurge (*Euphorbia esula* L), a dicotyledonous herbaceous deep-rooted perennial, has become a noxious weed in the United States during the last one hundred years, and is reported in more than half of the states today. *Aphthona* flea beetles, native to Eurasia, were introduced in the United States in the early eighties as biological control for leafy spurge. At the Elbert County, Colorado study site, flea beetles were released in 1993, and the current study was performed during the 2000 and 2001 growing seasons. The purpose of this study was to examine the relationship between spurge, flea beetles, and other vegetation.

The six-acre site included various terrain types, the majority of which was a dry creek bottom. Fourteen one half meter by one half meter plots were flagged and included a range of vegetation density and terrain. A control site was located one mile north of the main site, in the same dry creek bed. This site had high spurge density, low density of competing vegetation, and no flea beetles had been released.

The current study showed that in the plots, spurge was suppressed from the 2000 to the 2001 growing season. In general, grass and spurge density were inversely proportional and the number of spurge and flea beetles were directly proportional. Terrain variability, temperature, and distance from the point of release of the beetles all played a role in spurge suppression. Although not completely eradicated, the spurge population was significantly lower in study sites in comparison with the control site.

PRIMARY CAVITY NESTERS IN PONDEROSA PINE *(PINUS PONDEROSA)* FORESTS IN SOUTHEASTERN SOUTH DAKOTA: HOW DO NESTING STRATEGIES VARY WITH FOREST BURN HISTORIES. PRELIMINARY RESULTS

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ABSTRACT

Ponderosa pine *(Pinus ponderosa)* stand characteristics are largely defined by fire history. Avian communities are also affected by fire because of the affects of fire on stand density. These data are the preliminary results of a five-year project studying prescribed fire and cavity nesting communities in the Black Hills, South Dakota. The objectives of the project include; determine how songbird populations change after prescribed fire and stand clearing wildfire, how do cavity nesting communities respond to prescribed fire, and if fuel loads decreased after prescribed fire?

Nest searching was completed on six study sites of approximately 300 hectares each. Two sites are in a 10 year old wildfire, two sites are in unburned, unlogged forest and will receive a prescribed fire treatment after three years of pre-burn data collection, and the last two sites are control sites in similar green forests. In each site, nest searching, point counts, and vegetation plots were completed during the summer of 2002. Twenty randomly selected points were used for point counts and vegetation plots in each unburned site. Vegetation methods used on random plots and on nests were designed to determine nest site preferences as well as fuel loads in each plot.

Thirty-nine nests were found, 29 in the two old burn sites, and 10 in the green forests. Although sample sizes from this preliminary year are too small to compare statistically, nest sites had higher density of snags than random sites. Nesting success was nearly equal in burned and unburned habitats (approximately 80%).

ADVANCED VISUALIZATION FOR SCIENCE PROBLEMS

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ABSTRACT

The Black Hills Advanced Visualization Lab (BHAVL) was established in 2002 within the Institute of Atmospheric Sciences (IAS) to develop a tool to help university and industry research and teaching. The setup consists of a 2-projector Mechdyne Power Wall with head-tracking, and an SGI Onyx supercomputer to drive the immersive visualization system. The present BHAVL configuration has proven its worth developing proof-of-concept applications for education and research across the SDSM&T campus. Data for these collaborations have been provided by investigators from other units on campus to BHAVL personnel. These datasets were then translated into formats compatible with software packages being used and evaluated by the visualization group.

Two key examples that demonstrate the scientific benefit of visualization are in materials processing (Advanced Materials Processing (AMP) and Mechanical Engineering) and paleontology (Museum of Geology and Department of Geology and Geological Engineering). Numerical simulations of the Friction Stir Welding process were provided by AMP investigators. The original finite element model output of velocity, temperature and pressure were converted into a 3-D regularly gridded field. As flow trajectories were interactively added to the simulation results, investigators were able to see circulations within the process which had only been hypothesized as well as highlighted fault regions forming in the weld zone. The Museum of Geology had a traumatized Oligocene sabertooth cat skull CT-scanned, which was used to generate a 3D data cube allowing scientists to *unobtrusively* investigate the specimen without compromising the integrity of this valuable and unique specimen.

C-LOCK: THE SOUTH DAKOTA CARBON SEQUESTRATION PROJECT

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ABSTRACT

Global warming concerns have prompted industries in many countries including the United States to procure offsets for emissions of greenhouse gases. This has led to an active trading market. One ton of carbon dioxide (CO2) not emitted into the atmosphere generates a Carbon Emission Reduction Credit (CERC). CERC value depends on the accuracy that an incremental CO2 reduction or uptake can be quantified, and ranges from five dollars to more than $170 per ton of CO_2 not emitted/removed.

The State of South Dakota has funded the Institute of Atmospheric Sciences at SDSM&T to develop an internet-based system that will allow individual farmers to quantify CERCs accrued on their property. The project, called C-Lock, started in 2001, is a system designed to maximize the value of CERCs for South Dakota producers.

C-Lock is an internet-based registration system linked to a Geographic Information System (GIS) coupled to numerical models to quantify carbon storage as a function of climate, soil, and management for specific pieces of registered land.

CERC generation ranges from a few dollars/acre for minimum-till to $20/acre/year for CRP. The value of credits accrued since 1990 in CRP may approach $150 million dollars. Future research may potentially generate CERCs from diverse alternatives. River and stream erosion control, landfill methane, and wind energy all have the potential to generate CERCs.

BAT BIODIVERSITY ON MONTSERRAT, ST. MARTIN, SABA, AND STATIA

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ABSTRACT

The Caribbean islands of Montserrat, St. Martin, Saba, and Statia have endured many natural disasters, each resulting in decreases in the local bat populations. Saba was severely damaged by Hurricane George in September of 1998 and is still recovering from the loss of most of its' forest, birds, and bats. Bats can only be found on the leeward side of Mt. Scenery where a small patch of forest and fruiting trees remain untouched by storms and human development. Saba's sister-island Statia was also hit by Hurricane George. Statia is dominated by a volcanic cone (The Quill) whose protective crater offers a small patch of tropical forest in which birds and bats receive shelter from tropical storms while the remoteness and difficult terrain of the crater prohibits human development. St. Martin's Loterie Farm includes the last remnant of tropical rain forest on this over-developed, tourism-dominated island. Loterie Farm acts as a refugee for what remains of St. Martin's bats, birds, and rare species of lizards. The newly-active volcano (1995) on Montserrat has resulted in catastrophic habitat loss which is correlated with the extirpation of three species of bat *(Sturnira, Noctilio, Chiroderma)* and dramatic decreases in the populations of two other species *(Natalus, Tadarida)*. Clearly, natural/manmade disasters dramatically affect biodiversity patterns on small islands. A revised species-area curve for the Lesser Antilles is presented that reflect the loss of bat biodiversity on these four islands.

DISTRIBUTION OF BIG BROWN BATS IN SIOUX FALLS, SOUTH DAKOTA

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ABSTRACT

The big brown bat, *Eptesicus Fuscus,* is a very common commensal species of bat found throughout the United States. During 2001-2002, Sioux Falls Animal Control and the South Dakota Department of Health removed 447 nuisance bats from 225 private residences in the Sioux Falls area. These animals were subsequently tested for rabies at the ADRDL facility at SDSU. Rabies-negative carcasses were turned over to our lab for identification and analysis. Collection localities were divided into three groups: 1) juveniles, pregnant females, and lactating females, 2) females, and 3) colonies. For convenience, a location was considered a 'colony' if more than one bat was removed from that address. These localities were plotted on a street map of Sioux Falls, South Dakota to try to identify general distribution patterns of bats with respect to their proximity to city parks and bodies of water. Special attention was paid to any correlation between these foraging habitats and reproductive status and/or the location of colonies. Based on the foraging habits of big brown bats, it was expected that a high concentration of pregnant females, juveniles, lactating female bats and colonies would be found in areas where there was an abundance of water and foraging habitat. Instead, the opposite pattern was noted. Roost sites were not associated with water/foraging habitats; rather they were tied to older neighborhoods in the center of Sioux Falls where older structures provide abundant roosting opportunities. Roost availability, not access to foraging habitat dictated bat distribution in this particular urban area.

MODERNIZING A TRADITIONAL QUALITATIVE ANALYSIS COURSE

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ABSTRACT

In order to introduce a modern instrumental method into a traditional inorganic qualitative analysis course, an ion chromatography method was developed to separate the thirteen anions encountered in that course. Although complete separation of all thirteen anions was not achieved, the combination of chromatographic data and wet chemistry (chemical reactions) allowed students to readily identify the ions in their unknowns and to observe the strengths and drawbacks of both methods. The final method employed inverse UV detection at 270 nm using a Hamilton PRP X-100 anion exchange column and a sodium benzoate eluent at pH 8-10 with a flow rate of 1.0 mL/min.

IDENTIFICATION OF EUROPEAN-LIKE PRRS VIRUS IN THE UNITED STATES

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ABSTRACT

Porcine reproductive and respiratory syndrome (PRRS) is a viral disease of swine that is distributed worldwide and is responsible for major economic losses among pork producers. The syndrome is caused by the PRRS virus (PRRSV), which is an enveloped, positive-strand RNA virus. There are two major strains of the virus, one in North America and one in Europe. PRRS can be diagnosed through virus isolation, fluorescent antibody examination, immuno-histochemistry, and the polymerase chain reaction (PCR), as well as serology. The European form of the virus has recently been identified in the US. This has made the diagnosis of PRRS more complicated, due to substantial antigenic and genetic differences between the two major strains of the virus. Therefore, the purpose of this ongoing work was to characterize these European-like PRRSV isolates identified in the US and to modify currently available diagnostic tests for the accurate detection and diagnosis of this disease. Several of these virus isolates were adapted to cell culture and analyzed using a panel of monoclonal antibodies directed against the structural proteins of the virus. This antigenic analysis revealed a recognition pattern more consistent with the prototype European strain, Lelystad, than with North American isolates. Nucleotide sequence analysis of selected genomic regions indicated a 95-96% identity with the Lelystad strain, but only a 70% identity with the North American reference strain. These new isolates were incorporated into diagnostic serology assays to monitor animals for exposure to European-like PRRSV. Antigenic and genetic information was used to modify other diagnostic assays to ensure the accurate identification of European-like PRRSV.

EFFECT OF AUXINS AND ANTIBIOTICS ON ROOTING IN SOYBEAN TRANSFORMATION

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ABSTRACT

Inducing roots is one important step in soybean transformation. Antibiotics are usually used in medium for either preventing contamination or selecting as a marker. Some protocols suggest not using them in the rooting medium because they may inhibit rooting. In this experiment, transformants were selected with herbicide, and surviving shoots were cut off and transferred into rooting medium to induce roots. The effect of different auxins and antibiotics on rooting was investigated. The results showed that roots were induced normally in the medium containing antibiotics when both indole-3-butyric acid (IBA) and napthaleneacetic acid (NAA) were used. There was a significant positive correlation between the height of shoots and the number and length of the roots induced.

Keywords

Auxins; Antibiotics; Rooting; Soybean Transformation

CONVERSION OF A CHEMICAL FOUND IN GARLIC TO AN ANTI-CARCINOGEN

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ABSTRACT

Garlic contains anti-carcinogenic chemicals called allyl sulfides. One of these compounds, called diallyl disulfide (DADS), is broken down in the body to allyl mercaptan (AM). This chemical may prevent oncogenes from mutating and causing cancer by preventing the methylation of guanine by nitrosamines. The mystery presented by DADS is that, although it probably remains in the body for only a few hours, its anti-carcinogenic effects may last up to two days (C.R. Morris 2000). One theory is that the sulfhydryl (SH) group of DADS-derived AM binds to an available sulfhydryl group on a protein already present in the body. This would slowly release AM and hence allow its effects to persist in the body even after AM itself and DADS could no longer be detected.

In this experiment, a method was developed to determine AM by measuring its concentration in headspace air over an AM solution in water by using gas chromatography (GC) with flame ionization detection. The method was used to determine AM produced from DADS. Dimethyl sulfoxide (DMSO, 70% in water) was chosen as the solvent although it produced another volatile compound, identified as dimethyl sulfide by GC-mass spectrometry, on reaction with DADS or AM. To liberate AM from DADS, the DADS was treated with dithiothreitol (a thiol or RSH compound) in alkali to expedite the reaction DADS + RSH → AM + RSSR. Alkali is needed to convert RSH to the reactive RS^- species, which permits dithiothreitol to react with DADS. Thus DADS solutions in 70% DMSO were treated with NaOH and dithiothreitol for 1 hour at 37°C. The AM was then converted from the nonvolatile RS^- form to the volatile RSH form by adding H_2SO_4. Finally, the samples were incubated for another 1 hour at 37°C in headspace vials to allow the AM to saturate the air space, and GC of the headspace gas was run to detect and determine AM.

Although a successful method was developed that allowed for the detection of AM from DADS *in vitro,* attempts to detect AM in the livers of DADS-treated rats were unsuccessful. (Supported by grant 00A080 from the American Institute for Cancer Research)

STABILITY OF N-ACETYLCYSTEINE AND MELATONIN IN RELATION TO CARCINOGENESIS

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ABSTRACT

When estrogen, in the form of estrone and estradiol, reacts with DNA; the formation of depurinating adducts occurs (Cavalieri, 2001). These adducts form apurinic sites that are converted into tumor initiating mutations through error prone DNA repair (Devanesan, 2001). Over time the mutated genes caused by the depurinating adducts affect cell growth and death and are believed to initiate the development of cancer. It is for this reason that estrogens have been called the "ultimate carcinogen" (Cavalieri 2002) and research using antioxidant compounds that are able to prevent the formation of harmful estrogen metabolites holds great promise. N-acetylcysteine (NAC) and melatonin have both been identified as compounds that block the formation of depurinating adducts. NAC is able to block depurinating adducts by binding to the estrogen catechol thus, preventing it from attacking DNA (Anaizi, 1997). In addition, NAC is a precursor to glutathione, an important free radical scavenger. Melatonin is also a free radical scavenger, and assists in preventing oxidative stress to the cell that may lead to DNA depurination. For this reason, it was important to examine the long-term stability of N-acetylcysteine (NAC) and melatonin in tap water under varying conditions to determine the appropriate preparation and storage methods for experimentation. Using High Performance Liquid Chromatography (HPLC), concentrations of melatonin and NAC were determined over a ten-day period. Hydrogen peroxide was added to one set of samples to simulate autooxidation, a second set of samples were exposed to light to stimulate photo-degradation and a third set was sonicated to remove oxygen from the solution that might cause degradation. The control set was kept at room temperature and blocked from light exposure. As expected, the samples exposed to hydrogen peroxide and light exhibited greater degradation than both the control and sonicated set. While sonication helped to prevent oxidation of thiol-containing groups in NAC, photo-degradation was the major instability factor in these samples over a ten-day period. These data provide evidence that the most appropriate method for preparing and storing water supplemented with NAC and melatonin should include 1) sonication of the solution to remove any oxygen and thus preventing oxidation of thiol groups and 2) protection from light exposure.

PROGRESS TOWARD IDENTIFYING GENES REGULATING TRANSCRIPTION OF THE HMW GLUTENINS IN WHEAT

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ABSTRACT

The objectives of this project are to identify, map, and study the genes that regulate the expression of the high molecular weight (HMW) glutenin genes in bread wheat, *Triticum aestivum* L. The HMW glutenins play a key role in wheat baking quality. They also represent a valuable model system for studying the regulation of orthologous and paralogous genes in polyploid species, and the evolution of the regulatory systems controlling these genes. This project represents the first comprehensive search of the wheat genomes for genes regulating the transcription of the HMW glutenin genes. Using ditelosomic lines in Chinese Spring background and the normal Chinese Spring genotype, wheat endosperms containing zero and three doses for each of the 42 chromosome arms in wheat are being created. For chromosome arms where no ditelosomic lines are available, tetrasomic versus normal comparisons will be used. Total RNA was isolated from the endosperm tissue and quantitative reverse transcription polymerase chain reaction (RT-PCR) will be performed on the RNA samples. Amplification of the four HMW glutenin gene transcripts present in Chinese Spring wheat will allow the transcription of these genes to be accurately measured. Comparisons of gene expression between the zero and three dose levels for each chromosome arm will indicate which chromosome arms contain regulatory loci that modulate the expression of each of the HMW glutenin genes. For each regulatory locus found, the chromosome arm location, direction of effect (positive or negative), and relative strength of the effect will be determined.

MOSQUITO POPULATIONS FROM EASTERN SOUTH DAKOTA DURING 2001 AND 2002

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ABSTRACT

In 2001, the South Dakota Department of Health initiated a program to monitor mosquitoes in South Dakota for the presence of the West Nile Virus. During the first year (2001), a pilot survey was conducted near Brookings, SD. To collect mosquitoes, CDC miniture light traps were used without carbon-dioxide baiting, beginning on July 3 and ending on August 2, 2001. Results from this small study (total of 2,042 mosquitoes during 10 collection days) showed that the most common mosquotes were *Aedes vexans* (88.2%), *Culex tarsalis,* (5.2%), and *Aedes dorsalis* (4.9%). An additional survey was conducted during the summer of 2002 focusing on 8 different sites (Brandon, Brookings, Huron, North Sioux City, Oak Lake Field Station, Watertown, Waubay and Yankton) in eastern South Dakota. Mosquitoes were collected with the same traps used for 2001, however, the traps were baited with carbon diaoxide (dry ice). Trapping began on June 1 and ended on September 1, 2002. A total of 18,971 mosquitoes were collected from the 8 sites during the 127 trapping days of this survey. From this population, 21 different mosquito species from 8 different genera were identified. The vast majority of mosquitoes were *Aedes vexans* (86.3%), but *Culex tarsalis* was also present in significant numbers (7.2%). *Aedes vexans* populations varied to a greater degree during the summer than did *Culex tarsalis*. The public's perceptions of the danger of West Nile Virus transmission is probably more determined by *Aedes* population than by *Culex* populations even though *Aedes* likely plays little or no role in the transmission of this disease.

AQUATIC INSECT COMMUNITIES, LITTORAL HABITATS AND SHORELINE CHARACTERISTICS IN EASTERN SOUTH DAKOTA

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ABSTRACT

Recently, biological monitoring has become an important part of state water quality protocols, but few studies have focused on invertebrate community attributes within littoral zone habitats. The objective of this study was to define relationships between insect community attributes, littoral habitat and shoreline characteristics. Random locations within the littoral zone were sampled from seven basins during June to August 2001-2002. Six significant associations were found between invertebrate metrics and habitat measures from the combined lake data set (n=160). Percent Odonata was positively associated with percent canopy and negatively associated with cobble/boulder substrate (rho=0.29 and –0.30, respectively) while percent Corixidae was positively correlated with cobble/boulder substrate (rho=0.31). Percent filters and Tanytarsini were positively correlated with macrophyte wet biomass (rho=0.39 and 0.35, respectively) while percent sprawlers was positively correlated with percent macrophyte cover (rho=0.30). Of these six correlations, none were consistently significant within all individual basins and only two were above the critical value necessary for significance (rho=0.34) within individual basins. Two hundred significant insect versus habitat associations were found within individual lake basins (n=20-25). Total richness, percent Hemiptera, percent Coleoptera, percent Ephemeroptera, percent climbers, percent predators and percent clingers were significantly associated with habitat within five or more of our individual study basins. These results reveal the individual character of prairie lake basins through associations between insect community and habitat attributes. Those metrics consistently and significantly associated with habitat among several basins within a region provide focus for development of an index of biotic integrity for northern prairie lakes.

IDENTIFICATION OF THE IMAGE DENSITY ENHANCEMENT REACTIONS FOUND WITH TONED ALBUMEN SILVER PHOTOGRAPHIC PRINTS OF THE 19TH AND EARLY 20TH CENTURY

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ABSTRACT

The chronicle of the historical period from the middle-1800's to the early 1900's was largely recorded, not by the written word, but by the photograph. Several image-making techniques were used during that period. In comparison to the salted paper technique, Ambrotype, tin-type and Daguerreotype methods, the Albumen printing method enjoyed greater wide-spread use and commercial success. An albumen image is a silver-based photographic image making process that uses egg white, Albumen, as the paper-sizing agent. An investigation of the toning chemistry and mechanism of image density enhancement reactions on albumen photographic material will be presented. Albumen photographic prints were prepared using 19th century formulations and techniques. During image development, a gold toning formulation will be introduced whereby the image silver is replaced, in part, by gold. This reaction is based on a reduction-oxidation mechanism known as a metal replacement reaction, and was used to impart rich tones and archival quality. Compared to the silver print, gold toning would result in a print with enhanced overall density and contrast. This enhancement is not supported by the chemical theory, and the reason for such an enhancement is unknown. Image density enhancement suggests that other compounds, not predicted by the formulation chemistry, are being formed. We will use x-ray diffraction and laser-induced breakdown spectroscopy to identify the chemical species present on the surface of these images.

QUANTIFYING ELECTRONIC EFFECTS ASSOCIATED WITH LIGAND SUBSTITUTED COBALT METAL-CENTER COMPLEXES

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ABSTRACT

Long-range energy transfer processes are required if molecular assemblies are going to function as key components in nanotechnology devices. Carbon and silicon-based polymeric structures have been shown to manifest these energy transfer properties; however, there have been some limitations. Dynamic events, along a polymeric backbone, often serve to decouple the molecular assembly essentially cutting the wire. Transition metal containing supramolecular assemblies have recently garnered interest as potential nanoscale electronic system. In the laboratory of Dr. Steve McDowell, novel polyheterometallic molecular structures are being synthesized to overcome the limitations found with the linear polymeric systems. The unique nature of these new supramolecular structures is the incorporation of selected transition metal centers that heretofore have not been utilized as structural components in supramolecular assemblies. These selected metal centers will permit the design and tuning of supramolecular structures such that specific electronic and dynamic properties, such as the absorption, storage, and conversion of photonic energy and the modulation of molecular motion will be realized within the structure. Electronic spectroscopic methods will be used to quantify the effect of ligand substitution on the electronic behavior of the monomer components of these supramolecular designs. Effects on transition strength will also be presented as a function of solvent-type and polarity. Ligand substitution and solvent effects will then be used to optimize the design of a polyheterometallic assembly capable of exhibiting long-range electronic coupling and super-radiative energy transfer.

INVESTIGATION OF FLUORANTHENE INTERACTIONS WITH HUMIC ACID ISOLATED FROM SOUTH DAKOTA TOP SOIL

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ABSTRACT

Soil contains water-soluble substances that can assist in promoting plant growth, and continues to be a key ingredient in many fertilizers. One major component, found in the top soil layer, is humic acid. Humic acid is a complex ensemble of organic-based components produced by the decay processes of plant and animal matter. The humic acid macromolecular structure comprises highly conjugated aromatic, hydrophobic, and hydrophilic domains. Side-group functionality includes carboxylic acid and nitrogen-based groups, as well as, carbohydrate and peptide fragments. This macromolecule, having regions of varying polarity, is capable of binding polyaromatic hydrocarbons (PAH) by both weak and strong-force interactions. Fluoranthene is a PAH that is produced as a by-product of oxygen-poor combustion. Fluoranthene exhibits carcinogenic activity; and therefore, the fate and transport property of this by-product is of concern. Prior research has suggested that fluoranthene and humic acid bind to form a non-reversible, static complex. If this is the case, then the complex is capable of greater, long-range, transport that may eventually end up in a ground-water source. We will present evidence as to the kinetics and mechanics of this interaction. Using steady-state and time-resolved fluorescence techniques, we will present data that follows the interaction between humic acid and fluroanthene under a variety of environmentally-relevant conditions. We will also begin to identify specific and non-specific chemical reactions that may serve to greater enhance the lifetime of the toxin.

GC/MS ANALYSIS OF HUMAN CERUMEN

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ABSTRACT

Human cerumen is a complex biological matrix. Such chemical complexity requires chromatographic separation for the identification of trace components. Chromatographic separation includes solid-phase microextraction, thin layer chromatography, and selective precipitation to minimize sample heterogeneity. Cerumen is a nonpolar, waxy substance that the body uses to eliminate waste substances of similar polarity. Since the cerumen is nonpolar in nature, certain drugs and substances will preconcentrate themselves and give results where water-based testing (saliva, urine, and blood) may not allow detection at the same level of concentration. Cerumen is sampled with the aid of a metallic hoop to minimize contamination from the sampling procedure. Once the cerumen is collected, it is dissolved in selected solvents prior to introduction into the GC/MS. The GC/MS utilized is a HP 5890 with a 5970 quadrupole MSD. The GC is optimized for flow rate and temperature programmed to give a chromatogram that offered good separation. Multiple fatty acids and cholesterol are separated and identified. Preliminary work with the cerumen of a test subject that has been diagnosed with multiple sclerosis shows the antispasmotic drug methenamine. The subject's methenamine medication was discontinued several months prior to his cerumen sampling, and his physician indicated that the drug should have been absent at the time of the sampling. Since the drug is detected long after the expected duration of interaction, this matrix may prove to be very useful for drug detection in human subjects.

SYNTHESIS AND PHYSICAL CHARACTERIZATION OF COBALT(III) COMPOUNDS AND COMPLEXES WITH POTENTIAL AS COMPONENTS IN SUPRAMOLECULAR STRUCTURES

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ABSTRACT

Inorganic supramolecular chemistry and architecture, also known as molecular architecture, crystal engineering, and inorganic/metal-organic hybrids, is currently an actively investigated area of inorganic chemistry. The general goal is the preparation of well-ordered solid state systems that incorporate transition metal centers. These systems are designed to provide specific chemical and/or physical properties such that they may find application as key components in nanotechnical devices such as molecular switches and probes. Current work is presented which details the investigations into the use of a well-characterized family of cobalt(III) compounds and complexes, the cobaloximes(III), as participating structural units in supramolecular chemistry. Studies involving both model compounds (corners and edges) and target supramolecular structures (molecular squares) are discussed. Details of the synthetic investigations and the physical characterization of the cobaloxime(III) compounds will be included in the presentation.

CONTINUED STUDIES IN THE APPLICATION OF HYDROGEN DIHALOCOBALOXIMES(III) IN THE SYNTHESIS OF ORDINARY AND NOVEL Co(III) COMPOUNDS AND COMPLEXES

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ABSTRACT

Hydrogen dichlorocobaloxime(III), $H[CoCl_2(dmgH)_2]$, and hydrogen dibromocobaloxime(III), $H[CoBr_2(dmgH)_2]$, are useful synthetic reagents that are easily prepared in very high (~ 95 – 100%) yield from commercially available reagents. The compounds are very stable, exhibiting no decomposition during extended storage periods under normal atmosphere (no special precautions are taken to exclude moisture or air). Current work is presented which details earlier as well as recent investigations into the use of these reagents for the synthesis of members of the well-known family of cobalt(III) compounds known as the cobaloximes(III). The broad utility of the hydrogen dihalocobaloxime(III) compounds as starting reagents in synthesis is demonstrated. A key aspect to these syntheses is the liberation of halo(solvent)cobaloxime(III) from the appropriate starting reagent, which is accomplished through the use of a proton scavenger. The details of the evaluation of numerous inorganic and organic proton scavengers for their utility and efficiency in synthesis are given.

APPLICATION OF "HYDRATED COBALT(II) SACCHARINATE" IN THE SYNTHESIS OF COBALT(III) COMPOUNDS AND COMPLEXES

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ABSTRACT

Trans-tetraaquabis(saccharinato)cobalt(II) dihydrate ("hydrated cobalt(II) saccharinate, $Co(sac)_2.6H_2O$") was prepared and characterized as a biologically relevant compound in the early 1980's, a time when saccharin and its ionic forms were considered to be potential carcinogenic substances. Since that time, relatively little application for the material has been found. Recent work has proven that this underutilized material has many favorable characteristics such as its solubility in a number of organic solvents and the simultaneous poor Lewis base (ligating) - excellent Bronsted base (proton accepting) behaviors of the saccharinate anion. These and other characteristics make it an ideal starting material for the synthesis of a number of Co(III) compounds and complexes. Details of a number of syntheses utilizing "hydrated cobalt(II) saccharinate" as a starting reagent are presented as well as the physical characterization of the products of these preparations. One key synthesis is one in which the poor Lewis base behavior of saccharinate is intentionally reversed leading to the preparation of an inner-sphere saccharinatocobalt(III) compound.

THE EFFECTS OF ADVANCED PHOTOPERIOD TREATMENTS ON PRODUCTIVITY IN BLACK-FOOTED FERRETS *(MUSTELA NIGRIPES)*

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ABSTRACT

Pre breeding sexual development, and post breeding productivity were monitored to determine the effects of advanced photoperiod treatments (14 day hours / 10 dark hours) on subsets of the breeding populations of black-footed ferrets at the National Black-Footed Ferret Conservation Center between 1997 and 1998. Treatments began on or around the winter solstice for each year and continued until treatments matched ambient light conditions. Pre-breading testicular development and percent keratinization of cervical superficial cells were monitored weekly to determine readiness in the males and estrus onset in the females, respectively. The animals were bred according to Species Survival Plan protocols and sire, breeding and whelping success were recorded. The results indicate no significant differences in male testicular development, readiness or sire success between control and treatment groups. However, light treatments greatly influenced estrus onset, breeding and whelping success in the treatment females. Specifically breeding and whelping success in the one-year cohort were significantly reduced while breeding success in the two-year cohort was significantly reduced. In terms of management for this endangered animal, careful consideration must be made prior to administering advanced photoperiod treatments to females under three years old.

Keywords

Advanced photoperiod, black-footed ferrets, breeding success, whelping success, sire success, productivity

INSECT-HABITAT RELATIONSHIPS IN INTERMITTENT STREAMS OF EASTERN SOUTH DAKOTA

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ABSTRACT

Relationships between habitat and invertebrate community structure are an important aspect of bioassessment. Little effort has been made to address these relationships in intermittent streams. The objective of this effort was to examine relationships between habitat and insect community metrics in intermittent streams in Eastern South Dakota. Habitat parameters were measured at 21 sites August 2001 and April, June and August 2002. Aquatic insect samples were collected from all sites, August through October 2001 and April through September 2002. Spearman rank correlation analysis was performed on mean site values (n=21) for habitat and insect community metrics. Only significant correlations ($p<0.05$) are reported here. Several invertebrate metrics were positively correlated with substrate, bank, and flow measurements. Percent Chironomidae and sprawlers were associated with percent unstable substrate (rho = 0.41 and 0.45, respectively) while percent Ephemeroptera plus Trichoptera were positively associated with fine gravel (rho = 0.47). Numbers of filterers were associated with greater bank erosion, undercut banks and stream flow (rho = 0.42, 0.60 and 0.90, respectively). In contrast, percent Diptera and Trichoptera and Ephemeroptera richness were negatively associated with emergent vegetation (rho = -0.46 to -0.50) and percent predators were negatively associated with stream flow and percent bank erosion (rho = -0.58, -0.73, respectively). These results demonstrate strong relationships between insect community composition, richness and guild metrics and habitat characteristics which may facilitate bioassessment of intermittent streams in Eastern South Dakota.

A CONSERVATION ASSESSMENT OF THE ANTIGUAN GROUND LIZARD, *AMEIVA GRISWOLDI*, FROM ANTIGUA, LESSER ANTILLES

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ABSTRACT

For over 5000 years, native island fauna of the West Indies have sustained the effects of anthropogenic activity. Since then, humans have introduced various predators (i.e. rats, mongoose, cats, and other commensals) to the West Indies, some of which have had negative effects on the indigenous species of these islands. These effects are largely due to the lack of adaptive defenses needed to survive effective predation by invasives. Two rare endemics of Antigua, the critically endangered Antiguan racer *(Alsophis antiguae)* and the Antiguan ground lizard *(Ameiva griswoldi),* have dramatically declined due to the presence of such predators. Conservation threats to *A. griswoldi* were assessed throughout Antigua, Barbuda, and on four offshore islands. Density and presence of *A. griswoldi* varied at each site due to the presence of *A. antiguae* (an effective natural predator on *A. griswoldi*), introduced predators, prey available to *A. griswoldi,* genetic factors, soils, vegetation, and probably various other factors. Future studies concerning the effect of rat eradication on *A. griswoldi* populations should provide reliable recommendations for the essential control of non-indigenous species. Furthermore, ongoing inventories are needed to ensure the survival of *A. griswoldi* and will likely benefit the conservation of *A. antiguae.*

AN UNUSUALLY HIGH NUMBER OF GASTROLITHS IN A PLESIOSAUR (REPTILIA) FROM THE LATE CRETACEOUS MARINE DEPOSITS OF VEGA ISLAND, ANTARCTIC PENINSULA

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ABSTRACT

A joint expedition of American and Argentinean scientists to Antarctica discovered the weathered remains of a large, unidentified elasmosaurid plesiosaur in the Cape Lamb Member of the Maastrictian Lopez de Bertadano Formation. Associated with the plesiosaur skeleton were an unusually large concentration of relatively small gastroliths. These extremely rounded normally polished clasts were found with large rib and girdle elements.

This occurrence is significant not only for the number of gastroliths but also for the potential to gain insight into the physiology of these marine reptiles. Gastroliths have been thought to play a role in digestion and/or as ballast for bouyancy and stability within the water. Although some of the plesiosaur skeleton was weathered away and gastroliths were lost, over 2,600 gastroliths were recovered. Of these, a representative sample of 500 have been found to range between 46.66g and .04g, but nearly 90 % are in the smaller end of the range (<2g). The total weight of the representative sample is .64kg; total weight of all recovered gastroliths is approximately 3kg.

The large number and small size of gastroliths has led to new hypotheses concerning their origin and function. Either a large number of small clasts were originally swallowed or larger clasts were swallowed and subsequently worn into smaller fragments. If the latter hypotheses is true, some type of blind organ may have existed which acted as a sediment trap and the clasts were not passed. A second hypothesis is simply that stones were small during intake and settled to the ventral portion of the stomach where they were mechanically weathered and may have been eventually passed.

The Antarctic research was funded through a grant from the Office of Polar Programs, National Science Foundation (OPP #0087972).

NEW PLEISTOCENE LOCAL FAUNA FROM THE SAND HILLS AT THE GRAVES/POTTER LOCALITIES, CHERRY COUNTY, NEBRASKA: A PRELIMINARY REPORT

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ABSTRACT

Over several years, fossils have been collected at the Graves/Potter Localities in the Nebraska Sand Hills by the land owners, Suzanne and LeRoy Graves, and through expeditions under the direction of the second author. The site was originally found by Albert Potter, who contacted the second author. The Graves/Potter local fauna was collected from two closely related sites designated as SDSM V8618 and V8619. The assemblage was collected from reworked eolian dune sand found near the Niobrara River. Based on the presence of *Bison,* the local fauna from the Graves/Potter Localities are restricted to the Rancholabrean Land Mammal Age.

Represented in this faunal assemblage are Osteichthyes (inc. *Ictalurus*), Amphibia (inc. *Ambystoma, Bufo, Rana, Pseudacris*), Reptilia (inc. Serpentes), Aves (inc. Phasianidae, Accipitridae, and Charadriiformes), and Mammalia, as well as, Gastropoda, Pelecypoda and *Celtis*. Approximately 90% of the assemblage is comprised of rodents including sciurids *Spermophilus* and *Cynomys,* castorid ?*Castor*; geomyids *Thomomys* and *Geomys,* and cricetids *Microtus, Neotoma, Reithrodontomys,* and ?*Peromyscus*. The lagomorphs are represented by both *Sylvilagus* and *Lepus,* and one insectivore *Scalopus* (Talpidae) occurs. About one percent of the assemblage is comprised of carnivores: *Canis, Mustela, Taxidea,* and *Felis*. Artiodactyls are represented by the cervids ?*Odocoileus* and *Wapati;* the bovid *Bison;* and the camelid *Camelops*. Perissodatctyls include *Equus,* and proboscideans occur.

Fossil preservation at Graves/Potter appears in two categories: poorly mineralized but with exquisite preservation and well mineralized but fragmentary and normally water worn. The latter elements include typical Miocene taxa such as giant tortoise and rhinoceros and were clearly reworked by riparian processes. The former group includes bison, proboscideans, and giant camels indicating a late Pleistocene age. The Pleistocene mammalian taxa are dominated by *Spermophilus* (ground squirrel) and *Cynomys* (prairie dog), indicating relatively dry, upland conditions occurred within the paleodrainage area.

BODY WEIGHT, SERUM LEPTIN, AND OVULATION RATES IN LETHAL YELLOW AND MAHOGANY MICE

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ABSTRACT

The lethal yellow mouse (Ay/a) exhibits adult onset obesity. Coupled with the increasing body fat is a decrease in fertility. Mahogany (mg/mg), a more recently discovered mutation, appears to modify the effects of the lethal yellow mutation, reducing the degree of obesity. Leptin, a hormone produced by fat cells, becomes elevated in obesity and can lead to the development of leptin resistance.

Four genotypes were used in this study: lethal yellow (+/+ Ay/a), black controls (+/+ a/a), mahogany yellow (mg/mg Ay/a) and mahogany black (mg/mg a/a). All mice were females and 150 days of age, the time at which obesity and the decline in fertility become apparent in the lethal yellow mice. Average body weights were 25g for black control mice, 42g for lethal yellow, 30g for mahogany yellow, and 27g for mahogany black. Leptin levels were 2.8ng/ml for black controls, 28.9ng/ml for lethal yellow, 10.6ng/ml for mahogany yellow, and 2.9ng/ml for mahogany black mice. Thus the mg/mg Ay/a mice had significantly reduced obesity and serum leptin levels compared to the +/+ Ay/a mice but still had greater obesity and serum leptin than mg/mg a/a and +/+ a/a controls.

Ovulation rates were identical in all four genotypes with an average number of oocytes at 9-10 per ovulation. Thus the infertility apparent in lethal yellow mice at 150 days of age is not due to decreased rates of ovulation. A more plausible cause may be reduced egg and embryo viability in the lethal yellow mouse, perhaps due to excess serum leptin and consequent leptin resistance in cells of the ovarian follicles. Undergraduate participation in this study was funded by the NIH BRIN grant to the University of South Dakota School of Medicine.

EFFECTS OF DIFFERENT FIRE INTENSITIES ON UNDERSTORY VEGETATION DIVERSITY IN THE JASPER BURN AREA OF THE BLACK HILLS

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ABSTRACT

Fire has become an increasingly important issue in western states because of the frequency and severity of many recent wildfires. Years of fire suppression policy have resulted in higher fuel loads that cause fires to burn more intensely. This paper presents a study on the effects of different fire intensities on the understory vegetation at the Jasper Burn Area in the Black Hills of South Dakota. It was hypothesized that high intensity fires would be more damaging to forest understory recovery, while low intensity fires might lead to increased diversity by stimulating the growth of more fire tolerant native species. It was also hypothesized that the low intensity burn sites would have fewer invasive species compared to the high intensity burn or unburned sites. The results however did not conform to our original hypotheses. Species richness and diversity were not significantly different between high and low intensity burn sites. In fact, the unburned sites had significantly higher species richness and diversity compared to either the low or high intensity burns. Analysis of individual species changes revealed that fire of any intensity resulted in the loss of fire intolerant species, but that fire did not appear to be stimulating growth of fire tolerant native species. The absence of an increase in fire tolerant natives may be due to a lack of seed source or individuals to resprout. Recovery of natives in this system may occur more slowly than originally thought and may require additional burn events before recovery is complete.

CONSERVATION OF THE CRITICALLY ENDANGERED SNAKE, THE ANTIGUAN RACER *(ALSOPHIS ANTIGUAE)*

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ABSTRACT

Since 1995 the Antiguan Racer Conservation Project has worked to conserve the critically endangered snake, the Antiguan racer, *Alsophis antiguae.* The snake was nearly driven to extinction due to introduced predators, including rats and mongoose. Rats have been eradicated from several small offshore islands and surveys of the lizard prey items of the snake have been made. One of these prey items, the Antiguan ground lizard *(Ameiva griswoldi),* is a rare Antiguan endemic. The snake is now known from slightly more than 100 individuals confined to Great Bird Island, a 7.7 ha island near Antigua, plus two newly reintroduced populations on two nearby islands. Recent surveys of the Antiguan ground lizard on Great Bird Island have shown that this species has been seriously affected by snake predation. Green Island, a 43.25 ha island near Great Bird Island, was the recent recipient of five male and five female snakes, the first of several planned reintroductions to the island. Although populations of the lizard prey appear to be reduced on Green Island due to introduced rats, which were eradicated prior to the recent snake reintroduction, we believe that Green Island could eventually hold as many as 400 – 500 snakes. Green Island may be the most promising island for the eventual recovery of the Antiguan racer.

ECOLOGICAL INTERACTIONS AMONGST THREE SPECIES OF LIZARDS IN ANTIGUA, LESSER ANTILLES

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ABSTRACT

We analyzed the impact of multispecies interactions in lizard communities consisting of different combinations of three ecologically and morphologically distinct Antiguan lizards; *Anolis leachi* (a large tree anole), *A. wattsi* (a small bush or ground-dwelling anole), and *Ameiva griswoldi* (a large ground lizard). We compared habitat use, activity, and relative abundance on five offshore islands differing in lizard community composition. On islands with *A. griswoldi* and *A. wattsi*, *A. wattsi* perched higher, were least abundant, were less active, and used higher perches when *A. griswoldi* were active. Islands with all three lizards showed similar daily activity patterns, but *A. wattsi* perched lower and were more abundant. On islands with *A. leachi* and *A. wattsi*, *A. wattsi* perched lower, were found more frequently in sunny microclimates, were more abundant, and did not shift perch height use during the day. On one island where *A. griswoldi* recently went extinct, daily activity and microclimate use of *A. wattsi* were similar to the island without *A. griswoldi*. However, perch heights were higher and abundance was intermediate, similar to islands with all three lizards. These results suggest that interactions affecting habitat use, activity, and relative abundance persist among these lizards for some time after one species goes extinct. Predation or competition by *A. griswoldi* and *A. leachi* on *A. wattsi* may explain some of the differences observed among islands.

SURFACE MODIFICATION OF FILLER HAVING A NEGATIVE COEFFICIENT OF THERMAL EXPANSION

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ABSTRACT

Zirconium tungstate (ZrW_2O_8) is a unique material with a negative coefficient of thermal expansion. In order to fully utilize this material as a filler, a surface treatment needs to be developed to better improve the wetting and dispersion capabilities of the filler. This work describes an initial study to characterize the filler as well as investigate fatty acid and silane surface treatments for eventual compounding with thermosetting matrices. It was found that ZrW_2O_8 has a point-of-zero charge between pH 2.7 – 3.0. This data was used to set the parameters for the surface treatments. Sodium oleate was adsorbed to the zirconium tungstate from solution at pH 10. This pH was chosen to maximize the electrostatic repulsion between the particles and the surfactant headgroup. Three concentrations were used, 1 and 5 x 10^{-4} M and 1x10^{-3} M. All concentration exhibited oleate at the surface of the particles as judged by infrared bands for aliphatic $-CH_2$ moieties. In addition to sodium oleate, γ-aminopropyltrimethoxysilane (APS) was used to modify the zirconium tungstate surface. This surface modification was performed at pH 4.5 to facilitate silane bonding to the surface. Similarly to the sodium oleate, APS adsorption was confirmed through infrared analysis. Further characterization of the chemistry of both the oleate and APS adsorption will be pursued through the use of x-ray photoelectron spectroscopy. Future work will also involve compounding and property testing of ZrW_2O_8-filled polymer matrix composites.

Keywords

Zirconium tungstate, sodium oleate, aminopropyltrimethoxysilane

EFFECT OF HYGROTHERMAL EXPOSURE ON POLYMER MATRIX COMPOSITE MATERIALS

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ABSTRACT

Polymer matrix composite (PMC) materials consist of reinforcing fibers encapsulated in a polymeric matrix. Unfortunately, PMCs often suffer from loss of strength due to extended environmental exposure, particularly in wet/humid environments, thus limiting their utility. To improve the environmental behavior of PMCs, a novel procedure for modifying the silica reinforcing fibers was developed. This procedure consists of chlorinating cleaned silica fibers by refluxing in thionyl chloride/toluene solutions for 96 hours. Next, the chlorinated silica has undecenylbromide grafted to the surface through a 24-hour reflux in ether with magnesium catalyst. Both cleaned and grafted silica surfaces were characterized by diffuse reflectance infrared (DRIFT) and the grafted surfaces were shown to contain bands due to aliphatic stretching from the undecenyl hydrocarbon chains. Placing the modified fibers in boiling water for 24 and 48 hours reduced the amount of undecenyl hydrocarbon chains by 30 and 35%, respectively from the amount present prior to boiling. In addition, the strength of the single fibers was measured by uniaxial tensile testing before and after boiling the fibers for 24 hours. The grafted fibers retained about 67.5% of their initial strength after boiling.

Keywords

Organofunctional coupling agent, silica, flexural properties, infrared spectroscopy

CHARACTERIZATION OF GRAFTED ORGANOFUNCTIONAL COUPLING AGENTS FOR POLYMER MATRIX COMPOSITES

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ABSTRACT

The objective of the research is the formation of a hydrolytically stable, grafted layer on glass surfaces for the inclusion into polymers to afford improved composite materials with enhanced properties. This was accomplished by chlorination of silica substrates followed by reaction of alkenylhalides with the chlorinated surface to directly graft the surface modifier to a silica surfaces. This grafted silane monolayer was evaluated by a variety of techniques including contact angle analysis and infrared spectroscopy. In particular, undecenylbromide was grafted to single crystal silica slides to provide excellent substrates for subsequent testing. The single crystal silica chosen was as it can be used as a substrate for attenuated total reflectance (ATR) spectroscopy using mid-infrared radiation. In addition, the contact angle of these grafted single crystals with water and heptane were measured. ATR experiments showed that strong asymmetric and symmetric $–CH_2$ stretching bands were present after grafting. These bands indicated that the surface coverage was approximately 80%. Contact angle measurements on the same crystal showed that the water contact angle was about 71 degrees, which also corresponds to ~80% coverage. Also, the grafted single crystal silica was placed in boiling water for 24 and 48 hours to test the ability of the grafted to material to withstand extreme environmental conditions. The contact angle was found to decrease to 62.5 degrees after 24 hours in boiling water and to about 42 degrees after 48 hours in boiling water. Thus, the surface coverage decrease to about 65% and then to 30% after 24 and 48 hours in boiling water, respectively.

Keywords

Single crystal silica, contact angle, ATR, organofunctional coupling agent

EXAMINATION OF POLYESTER FIBERGLASS RESIN CURING IN CONJUNCTION WITH THE MICROBOND TEST

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ABSTRACT

The microbond test is a method of classifying the bond strength between the fiber and resin in a polymer matrix composite. In our tests, a very small polymer bead is placed onto a glass fiber. This bead is then pulled through a set of fixed blades and the force at which the bead debonds from the fiber is recorded. The purpose of this investigation was to examine the induced strain caused by the curing of the bead, which may influence microbond test results.

The beads in this experiment were made of a mixture of polyester resin and liquid hardener, both available commercially (Dynatron/Bondo Corp.). The polyester beads were placed on the fibers and then immediately transported to an Olympus Microscope for the collection of pictures. A picture of the bead was taken every 30 seconds during the curing cycle and these pictures were later measured with the LECO 2001 Image Analysis System to determine the bead size parameters.

There was an average of a 3% radial strain introduced during the bead curing process with the polyester resin. The length of the beads didn't change. These results were used in a finite element analysis of the bead curing to determine the induced radial stress present at the start of the microbond test.

Keywords

Polyester resin, microbond test, curing, polymer matrix composites, finite element analysis

DEVELOPMENT OF A MORE EFFICIENT SOLVENT SYSTEM FOR THE RECRYSTALLIZATION OF BENZOIC ACID

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ABSTRACT

Recrystallization of benzoic acid is an excellent way to remove impurities. Traditionally insoluble impurities, such as dirt, were removed through the recrystallization of benzoic acid utilizing water as the recrystallization solvent. It was our goal to develop a solvent system that would use a lesser volume of solvent, as well as enable a greater percent recovery of benzoic acid compared to the original water system. This goal was achieved using an ethanol/water recrystallization solvent system.

DETERMINATION OF CARBON MONOXIDE AND CARBON DIOXIDE IN AUTOMOTIVE EXHAUST VIA FTIR

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ABSTRACT

A simple and efficient method for the determination of carbon monoxide and carbon dioxide in automotive exhaust has been developed utilizing FTIR. By preparing standard concentration curves for both carbon monoxide and carbon dioxide, and comparing the area under these curves to those FTIR curves generated from sampling automotive exhaust, both the carbon monoxide and carbon dioxide concentrations can be determined with reasonable precision.

ANALYSIS OF THE BONE CONCENTRATIONS PRESERVED IN THE MCKAY FORMATION, LATE MIOCENE, FROM THE MCKAY RESERVOIR, UMATILLA COUNTY, OREGON

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ABSTRACT

The unusual occurrences of fossil bone concentrations located in the McKay Formation (Hemphillian Stage) of northeastern Oregon led to the analysis of the preserved material held within. The McKay Reservoir locality covers approximately 100 yards, laterally, and contains other fossils, including those of scavengers and carnivores. The purpose of this study was to determine the source of deposition for these concentrations using evidence supported by the examination of the bone fragments. It is important to note that these concentrations are incompatible with the very fine-grained surrounding claystone sediments. The methodology for research involved the extraction of the bone fragments from the claystone matrix, their general measurements, species identifications, as well as the condition of the bones viewed through an SEM to show pathological or diagenetic evidence. The comparison of these factors with modern day phenomena led to the conclusion that in the Late Miocene this area was a floodplain for the Columbia River system. During times of flooding, the water would concentrate scat left by the carnivores where they were then buried by more sediment and preserved.

CHARACTERIZATION OF NATURALLY OCCURRING ACID ROCK DRAINAGE AND IMPACTS TO THE NORTH FORKS OF RAPID CREEK AND CASTLE CREEK NEAR ROCHFORD, SOUTH DAKOTA

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ABSTRACT

Surface and ground water quality data have shown that naturally occurring acid rock drainage has negatively affected reaches of the north forks of Rapid Creek and Castle Creek in the Black Hills near Rochford, South Dakota. Field and laboratory data were collected in 2002 and 2003. The acid rock drainage samples had a pH of approximately 2.5 to 3.5 and contained high concentrations of iron, aluminum, and sulfate. Uncontaminated surface water had a pH of approximately 7 to 8.5 and contained high concentrations of calcium, magnesium, and carbonate. When the acid rock drainage mixed with uncontaminated water of the north forks of Rapid Creek and Castle Creek, natural buffering reactions occurred, increasing the acid rock drainage pH to above 7 and causing iron hydroxides and aluminum hydroxides to precipitate. Much of the metal hydroxide precipitate coated the stream bottom and cemented the sediments together. Some of the precipitate was transported downstream, negatively affecting the stream habitat for several hundred meters. Much of the plant and animal life in these areas was stressed, leaving some stream reaches devoid of all life. Natural chemical reactions caused the impacts to attenuate, restoring the stream's habitat and water quality within approximately one to two km in the downstream direction.

AQUATIC INVERTEBRATE COMMUNITIES AND BIOMONITORING: THE IMPORTANCE OF TAXONOMIC RESOLUTION

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ABSTRACT

Invertebrates have long been monitored to evaluate water quality and habitat conditions within lakes and streams. However, limited expertise and funding has prompted managers and their consultants to simplify identifications which may undermine resource management efforts. This analysis was conducted to (1) summarize taxonomic composition and ecology of eastern South Dakota aquatic invertebrate communities and (2) evaluate differences in biomonitoring metrics resulting from different levels of identification. Invertebrate data were drawn from studies of 16 streams, six seasonal prairie potholes and eight semi-permanent prairie pothole basins sampled during five separate research efforts over a ten year period. While some differences in methodology were employed among studies, sweep nets were used in all but one study. Smaller streams and pothole basins in eastern South Dakota characteristically support high numbers of Diptera, Coleoptera and Hemiptera (Insecta), Euhirudinea and Oligochaeta (Annelida) and Hydracarina (Acari). Some of these taxa are more difficult to identify but may comprise over 50% of collected genera and more than 90% of total invertebrate numbers. In particular, the midge family Chironomidae is represented by genera varying significantly in their tolerance to organic pollution, functional feeding guilds and habit utilization guilds. Thus, intermediate taxonomy at the order or family level may eliminate more than 50% of taxonomic richness and reduce guild and pollution tolerance variability useful for delineating water quality and habitat patterns. These altered patterns may, in turn, lead to inappropriate management prescriptions for our lakes and streams.

THERMAL DEPENDENCE OF RESTING METABOLIC RATE, AND LIFE HISTORIES OF THE TOADS *BOMBINA*

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ABSTRACT

Temperature is an important environmental factor affecting performance of ectothermic vertebrates. A decline in temperature leads to decreased metabolic rate, which may result in reduced locomotor performance. Consequently, an organism's ability to escape from predators or capture prey may be compromised. Species that exploit highly variable thermal environments are especially vulnerable. Natural selection should act to reduce the influence of temperature on metabolic rate. Thus, it can be hypothesized that species living in highly variable and unpredictable environments, such as mountains, will exhibit a decreased dependency of metabolic rate on temperature compared to species inhabiting more stable environments. We tested the above hypothesis on a pair of European toads: the mountain yellow-bellied toad *Bombina variegata* and the lowland fire-bellied toad *Bombina bombina.* We used a Q_{10} coefficient to describe the dependency of metabolic rate on temperature. As expected, resting metabolic rate (RMR) increased with ambient temperature. At 27°C RMR was significantly lower in *B.variegata* (1.158 mlO_2/h) compared to *B. bombina* (1.387 mlO_2/h), illustrating the reduced temperature dependence in the mountain species. However, values for RMR did not differ significantly between the species at 17°C (0.454 mlO_2/h and 0.527 mlO_2/h, *B. variegata* and *B. bombina* respectively) or 6°C (0.106 mlO_2/h and 0.136 mlO_2/h, respectively). Q_{10} coefficients for *B. variegata* (3.41) and *B. bombina* (3.64) were in the direction predicted by our hypothesis but did not reach statistical significance. However, significant variance in Q_{10} existed between populations within species and likely reduced our power to detect species differences.

IMPROVED GROUND- AND SATELLITE-BASED METHODS FOR DERIVING LAI IN A BURNED PONDEROSA PINE ECOSYSTEM

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ABSTRACT

The purpose of our study is to conduct a series of field measurements and data analyses at field sites in the Black Hills of South Dakota to investigate the accuracy and various potential improvements of LAI derivations from satellite sensors. Permanent field sites were established within and around the 33,800 hectare Jasper fire (burned September 2000), in the southwestern Black Hills. The different levels of fire severity produced different canopy LAI values and therefore sites were selected to represent a continuum of LAI values. To account for the nonrandom nature of ponderosa pine stands and for the effects of clumping at various scales, correction factors were applied to the effective LAI values obtained from a LAI-2000 Plant Canopy Analyzer and hemispherical photos. Clumping indices from the needle and shoot scales, were taken from previous LAI studies conducted on ponderosa pine in Oregon. A Tracing Radiation and Architecture (TRAC) instrument was used to correct for clumping at scales larger than shoot. Corrected and uncorrected LAI values were then regressed against several spectral vegetation indices derived from IKONOS data with the intention of including Landsat ETM+, and MODIS data to the spatial scale analysis. Uncorrected LAI values produced a higher R-squared value (R^2 = 0.51) than the corrected LAI values (R^2 = 0.18) indicating that site specific clumping correction indices may need to be developed.

SYNTHESIS AND CHARACTERIZATION OF ISOMERIC TETRAARYLBISPHENOL A POLYCARBONATES

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ABSTRACT

Two novel monomers, the *meta* and *ortho* analogues of *p*-tetraarylbisphenol A, have been synthesized. Previous research in our laboratory has focused on the methodologies for synthesis of tetraarylbisphenol A analogues for eventual polymerization to novel polycarbonate materials. These syntheses utilized new diarylborinic acids in atom-efficient, ligandless, catalytic reactions that resulted in higher yields under milder conditions[1]. Isomeric analogues were designed in order to compare and contrast the properties of the polycarbonates prepared from them. Synthesis of the monomers was carried out via the Suzuki coupling reaction of 2,2-bis(4-iodophenyl)propane (I-BPA) with 3-methoxyphenylboronic acid and 2-methoxyphenylboronic acid, respectively[2]. The compounds formed were bis[4'-(3-methoxyphenyl)-phenyl]propane and bis[4'-(2-methoxyphenyl)-phenyl]propane, which were then deprotected with pyridinium chloride to afford bis[3'-(3-hydroxyphenyl)-phenyl]propane (*m*-TABPA) and bis[3'-(2-hydroxyphenyl)-phenyl]propane (*o*-TABPA). Both of these monomers were obtained in good yield, and their structures were confirmed by ^{1}H NMR, ^{13}C NMR, and IR. Novel polycarbonates were formed using established methods of interfacial polycondensation, with the exception that triphosgene was substituted for phosgene gas. The polycarbonates were soluble in common organic solvents, and were characterized by ^{1}H NMR, ^{13}C NMR, IR, and SEC-MALS. Their molecular weights ranged from 33,000 to 70,000 with polydispersities near 1.7.

[1] Hao, J. and Boyles, D. A. 224th ACS National Meeting, August 18-22, 2002, Boston, MA.

[2] Goodson, F.E.; Wallow, T.I.; Novak, B.M. Org. Syntheses 1997, 75, 61.

SYNTHESIS AND CHARACTERIZATION OF NOVEL POLYOXALATES FROM BISPHENOL A AND ITS ANALOGUES

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ABSTRACT

Polycarbonates are a well-known class of high performance polymers with outstanding properties including high ductility even at low temperatures. On the other hand, polyoxalates of bisphenol A and its related analogues are until this time unknown compounds which have been ignored more than likely owing to their reported decomposition by thermal and photochemical means. Oxalate esters, however, present intriguing possibilities and may in fact have the potential to undergo photochemical rearrangement to afford interesting materials. We are therefore interested in investigating the synthesis and properties of these materials. In particular, bisphenol A (BPA), bisphenol C (BPC), and their corresponding tetraaryl analogues, tetraaryl bisphenol A (TABPA) and tetraaryl bisphenol C (TABPC), the latter two of which have been synthesized in our laboratory. The synthesis of these polymers utilized both interfacial and solution polymerizations with oxalyl chloride and an amine scavenger. Their characterization by nuclear magnetic resonance and infrared spectroscopy, and LAZER light scattering methods will be presented.

SYNTHESIS AND CHARACTERIZATION OF POLYCARBONATES OF TETRAARYLCHLORAL

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ABSTRACT

Although its properties have made it unique in diverse market uses, commercially available polycarbonate (BPA-PC) is only a "good enough" material. The only way to enhance the properties of BPA-PC is to increase the molecular weight of the polymer. This, however, increases the viscosity of the material making processing exceptionally difficult. The synthesis of new materials exemplifies a crucial way to address the current processing limitations of higher performance polymers by changing the inherent properties of a polymer and decreasing the need for higher molecular weights. Taking into consideration the remarkable ductility of BPA-PC due to the aryl ring rotation and the fact that rigid rod materials exhibit liquid crystalline behaviors, we have designed new polycarbonate materials for study that help fulfill the need for enhanced polycarbonate properties. One of these polycarbonate materials is a derivative of the polycarbonate made from chloral (bisphenol C), the polymer of which has been known for nearly 40 years. We have successfully synthesized three new analogues of this material, each of which has four, rather than two, aryl rings. The monomers of these polycarbonates have been successfully synthesized from the iodine analogue of DDT through the use of the Suzuki reaction. These monomers were polymerized with triphosgene to afford the novel polycarbonate materials. Ortho, para, and meta isomers have been synthesized. Each step of the monomer synthesis and subsequent polymerization will be discussed. Characterization of these materials by nuclear magnetic resonance, infrared spectroscopy and laser light scattering will also be presented.

ANTIOXIDANT ACTIVITY OF FRUIT EXTRACTS FROM VIBURNUM LENTAGO

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ABSTRACT

The nannyberry plant *(Viburnum lentago)* is native to the eastern part of North America. It's a deciduous, multi-stemmed shrub that grows to about 9 m in height. Nannyberry fruits are about 10 – 15 mm in length and have an oval shape and a bluish-black color. These berries were widely consumed by the Native Americans. Consumption of fruits is thought to decrease risk of degenerative diseases (e.g. – diabetes, cancer, heart diseases, cataracts, arthritis) and aging, because the fruits are purported to contain large amounts of antioxidants. Antioxidants have been reported to have the ability to fight diseases caused as a result of oxidative stress. The objective of this research is to measure the antioxidant activity of nannyberry fruit extracts. Nannyberries were collected from five different locations in South Dakota state, Rapid City, Victoria Lake, Big Bend, Brookings and Spearfish. A DPPH assay was performed using ethanol extracts of nannyberries. The ethanol extracts were brought to dryness and dissolved in 70 % ethanol and DPPH. The absorbance was measured in each solution at 517 nm. (Three samples were prepared for each location and the average absorbance was calculated). The results showed very high levels of antioxidant activity for all samples. Nannyberries from Big Bend showed the highest antioxidant activity followed by those from Rapid City, Brookings, Victoria Lake and Spearfish. A large portion of the antioxidant capacity can be accounted for by polyphenol content of the fruit (measured using a Folin Reaction assay) and to a small amount of ascorbic acid, which was determined by metaphosphoric acid extraction and HPLC separation.

ANTIOXIDANT ACTIVITY IN NATIVE MINT TEAS TRADITIONALLY USED BY THE GREAT PLAINS TRIBES

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ABSTRACT

Teas contain antioxidants which neutralize damaging free radicals. Recent studies have shown that green tea can play an important role in the diet by providing a potent source of antioxidants that protect against degenerative diseases. In the Great Plains, the indigenous peoples have traditionally used mint teas in a manner similar to green tea in the Orient and recognize its general benefits to maintaining good health. We conducted a study to determine whether ceyeka (field mint) had antioxidant activity comparable to that of common green tea. Also tested were two other Native American teas Lavender Hyssop and Horsemint. Measurement of antioxidant activity was made using the oxygen radical absorbance capacity (ORAC) analyses, following the procedure of Wang and Stretch (2001). Results of the assay show that the mint teas compare favorably with green tea as a source of antioxidants.

QUALITY COMPARISON OF ISOBUTYLAMIDE CONTENT BETWEEN COMMERCIALLY AVAILABLE *ECHINACEA ANGUSTIFOLIA* AND SOUTH DAKOTA CULTIVATED PLANTS

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ABSTRACT

Echinacea angustifolia is a plant, native to the upper Midwest, which is commonly used to treat colds, flu and to promote activation of the immune system. *Echinacea* has been widely marketed throughout the United States as an herbal remedy. To compare the quality of products on the market to those of the roots produced in South Dakota, we compared dried root samples and 7 commercially available *Echinacea* preparations, purchased from local retailers All products, including the cultivated roots, were extracted by **10:1** ratio of methanol to plant material (v:w) The extractions were evaporated to dryness under vacuum and the resulting residue was redissolved in 1.0 ml of methanol. Isobutylamides were separated by reveres phase HPLC on a C 18 column with an acetonitrile solvent gradient as described by Bauer, et. al (Phytochemistry 28:505-508,1989).A comparison of isobutylamide content was made using the peak areas of the isobutylamides. In order to cover the variation in marketing approaches used for this plant, four liquid tinctures, one tea, and two capsule-based products were evaluated. Root material from cultivated *E. angustifolia* plants was obtained from the Plant Science Farm at South Dakota State University in Brookings, SD.

An index, based upon the area under the 5 most predominate peaks, was developed. Mean peak areas were determined for the whole roots and each of the commercial preparations. The mean values for isobutylamides from the whole roots on a gram dry weight basis was then compared to that of each of the preparations. A dollar value, based upon the per gram cost of actual *Echinacea* content of the preparations and the estimated wholesale value of *E. angustifolia* root set at $30 per pound ($0.06/g) was generated. Based upon the index values, the best values ranged from those of storebrands with a cost of $1.06/g to exclusive health store products with a cost of $16.81/g. with the average cost being $5.74/g. In terms of taking the recommended dosages, there appears to be relatively little *Echinacea* in these preparations when compared with utilizing whole roots of plants grown in their native soils and climate. Variability in quality control was also evident as index values for different lots of a given product and even different pills in the same bottle of a given product varied by as much as 25%.

The results of this study have implications for understanding the efficacy of *Echinacea* remedies. Testing of products grown in different regions and marketed in various preparations makes evaluating the potential of *Echinacea* difficult, if not impossible. Traditional use of the plants by Native Americans required a careful selection of plants from specific plant communities (ecotypes) and different preparations depending upon the symptoms being treated. Until a uniform quality control system is adopted by the industry, there appears to be little to recommend the use of commercial *Echinacea* preparations in the treatment the diseases for which it is marketed.

EXAMINATION OF ANTIOXIDANT ACTIVITY OF TRADITIONAL DAKOTA AND LAKOTA TEAS

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ABSTRACT

South Dakota's Native Americans drink several teas daily for pleasure and their purported healthful benefits. A tea made from the dried leaves of leadplant *(Amphora canescens),* is drunk throughout the day, for taste and relaxation. Teas such as Wacalyapi, a blend of choke cherry bark, *(Prunus virginiana)* and bur oak, *(Quercus marcrocarpa),* and mint tea, *(Mentha arvensis),* are used on a daily basis in many Lakota and Dakota homes. The teas consumed by the Lakota and Dakota peoples of the northern Great plains provide a source of antioxidants, such as polyphenols and flavonoides, in a manner analogous to green tea in the Orient. Plants were collected in early spring and into mid-summer, as is the tradition. The traditional Lakota and Dakota method of steeping herbs was used to make most of the teas, including the Asian green tea. Boiling of leadplant leaves, and the chokecherry and oak tree root bark was utilized as is traditional for those teas. Tea concentrations and extraction times followed the procedures provided by Native Elders. Teas were concentrated by lyophylization. The antioxidant activity of the concentrated teas were determined spectrophotometrically using a DPPH assay. All of the teas examined had significant antioxidant potential, with Sumac and Rose Hip Teas showing activities higher than that of the green tea controls. The antioxidant activity of rose hip tea is due in large part to the substantial levels of ascorbic acid (Vitamin C) known to be contained in these fruits.

SCREENING OF SOUTH DAKOTA NATIVE PLANTS FOR ANTIBIOTIC POTENTIAL

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ABSTRACT

Native plants of the South Dakota plains, which have been traditionally used to treat wounds and infectious diseases, are of interest because of their potential antibiotic properties. Specific plant species have been identified, collected and dried. Preliminary screening of P*hysallis virginiana, Monarda Fistulosa, Helianthus maximilani, Plantago rugelli, Sanguinaria Canadensis, Acorus calamus, Achillea millefolium, Arctostaphylos uva ursi, Artemisia ludoviciana,* and *Gentiana calycosa* have been conducted. Extracts of these plants were made with ethanol. The extracts were dried under vacuum and reconstituted to a concentration of 2g of dried plant material per mL of ethanol. The extracts were tested against several strains of bacteria to determine their antimicrobial potential. A wide range of gram-positive and gram-negative strains of bacteria including *Staphalococcus aureus, Staphalococus epidermis, Bacillus cereus, Eschericia coli, Corynebacterium xerosis, Micrococcus luteus, Micrococcus roseus, Citrobacter freundii, Mycobacterium smegmatis, Streptomyces viridosporous, Pseudomonas fluoresceus,* and *Pseudomonas aurngosa* were used in the assays. Antimicrobial potential was evaluated using a standard paper disk assay. For this assay, a paper disk is infused with 20 µL of plant extract and placed on an inoculated agar plate. After 24 hours, the zone of inhibition (or no bacterial growth) is measured. Once potentially useful plant extracts were identified, they were tested to determine their cytotoxicity. The cytotoxic assay was performed using brine shrimp. Test tubes of brine shrimp, sea water and plant extract were observed for 24 hours. After 24 hours the number of surviving brine shrimp were measured. Isolation of potentially useful chemical constituents, responsible for antibacterial activity, will be made using reverse phase and/or other types of chromatography, as is applicable. Identification of individual chemicals will then be made using GC-MS, LC-MS, and/or NMR.

SCIENCE EDUCATION OUTREACH INITIATIVES IN SOUTH DAKOTA: MOBILE SCIENCE LAB AND MNS PROGRAM

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ABSTRACT

In 2000, Governor William Janklow and the South Dakota Math, Science and Technology Council initiated the development of a mobile science lab for precollege science and math education in the state. Two mobile science classrooms were built in 53 foot converted semi-trailers to travel from school to school throughout South Dakota during the school year. The mobile science labs were developed to increase interest and exposure to science in South Dakota's School children, particularly in rural and underserved areas. In January, 2003, the first completed mobile lab was presented to the public as part of the inaugural program of "Science on the Move." Trial testing of the mobile van is presently underway as is the development of curriculum and lab activities. An overview of the mobile lab program and preliminary results from school visits will be presented.

A second science initiative that will be presented is the Masters of Natural Science degree at the University of South Dakota. The MNS program has been developed for middle and secondary school science and mathematics teachers to be delivered through the University of South Dakota in cooperation with South Dakota State University's Masters of Education degree. The program is designed to serve experienced science and math educators who are presently teaching science or math. Specifically, the program is designed to provide content-based coursework for teachers who have teaching assignments in areas different from their formal education discipline.

ELECTROANALYSIS OF AMINO ACIDS AT DIAMOND THIN-FILM ELECTRODES

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ABSTRACT

Diamond thin-film electrodes are well suited for electroanalysis due to their wide working potential window for aqueous solvents, low background currents and increased signal to background ratios as compared to conventional carbon-based electrodes. The applicability of electroanalysis of amino acids with diamond electrodes was investigated in alkaline media using cyclic voltammetry, and flow injection analysis with electrochemical detection (FIA-EC) in the amperometric detection mode. Well-resolved cyclic voltammetric oxidation waves, with respect to the background signal, were observed at the 1 mM level with $E_{1/2}$'s of ~+0.9 V vs. Ag/AgCl for 15 of the 17 "electroinactive" amino acids found in proteins. The voltammetric behavior was consistent with an oxidation mechanism involving a limited number of active microsites supporting electron-transfer. The proposed reaction mechanism for amino acid oxidation involves adsorption of the amine functionality at surface boron-sites, generation of hydroxy radicals at nearby non-diamond carbon sites, attack of the radical at the coordinated amino acid, and slow desorption of the product. The "electroactive" amino acids tyrosine, tryptophan and cysteine produced irreversible, diffusion-controlled oxidation waves at both diamond and glassy carbon with $E_{1/2}$'s < +0.9 V vs. Ag/AgCl.

ANALYSES OF LEAF AREA INDEX AND VEGETATION INDICES IN A FIRE CHRONOSEQUENCE IN SOUTHERN SIBERIA BY USING FIELD INVENTORY DATA AND MULTI-RESOLUTION REMOTELY SENSED DATA INCLUDING IKONOS, LANDSAT ETM+ AND MODIS IMAGERY

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ABSTRACT

Boreal forests represent a big terrestrial carbon pool and have significant influence in global climate change and the global carbon cycle. In this research, field inventory data and multi-resolution remotely sensed data (including 4m resolution IKONOS, 30m resolution Landsat ETM+ and 500/1000m resolution MODIS products) were used to analyze the leaf area index (one side total area of all leaves in a unit ground area) and vegetation indices in five different post fire sites in the boreal forest of Southern Siberia from 1999 to 2001. Cross-comparison between MODIS and ETM+ indicated that UTM bilinear projection of MODIS is the best choice for geo-registration in this case. The EVI (Enhanced Vegetation Index) is well correlated between MODIS and ETM+, while NDVI (Normalized Vegetation Index) is poorly correlated betweem these sensors due to the different spectral dimensionality of the indices. Sites chosen to represent one year, 13 years, and over 100 years post fire show that the correlations of Vegetation Indices (EVI and NDVI) and field LAI data changed from negative to positive. This may be attributed to the fact that regrowth of the overstory requires a much longer time period than in the understory. Validation of the MODIS LAI product using field data and high resolution IKONOS and ETM+ data were not significant due to large amounts of surface heterogeneity within the differentsample sites. These results provide baseline data that can be used when scaling plot-level measurements of forest density to regional-level estimates with satellite remote sensing.

THE RELATIONSHIPS BETWEEN ACTIVITY, STRESS AND CENTRAL MONOAMINES IN MALE NIH RATS

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ABSTRACT

Beneficial effects of physical activity for disorders such as anxiety and depression have been suggested by a number of clinical studies. Monoamine neurotransmitters, serotonin (5-HT), dopamine (DA) and norepinephrine (NE), appear to be involved in the exercise-induced effects on these disorders. Underlying mechanisms by which exercise influences monoaminergic activity is of importance, because research in this area could be instrumental in understanding the relation between human mental health and physical fitness. In this study, we describe the effects of voluntary wheel-running activity (8 wks access to running wheels vs sedentary) and stress using a restraint model (stressed vs non stressed) on central monoaminergic activity in male N-NIH rats. We examined monoaminergic activity in the striatum and hippocampus (CA1) regions of the brain, as these nuclei have been implicated in anxiety and depression responses to physical activity and stress. To obtain monoamine levels, brains were serially sectioned to 300 _m with an IEC cryostat (-7°C) and thaw mounted on glass slides. Brain regions were microdissected using a freezing plate and a dissecting microscope. Norepinephrine (NE), dopamine (DA), serotonin (5-HT) were measured using high performance liquid chromatography with electrochemical detection.

THIAMINE UTILIZATION IN WALLEYE EGGS

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ABSTRACT

Thiamine (Vitamin B_1) is important in basic cellular metabolism and a deficiency in this vitamin has been tied to several different diseases and neurological disorders in fish. Walleye in Lake Oahe may be at risk for thiamine deficiencies because one or more of the smaller fish that the walleye prey upon contain thiaminase, an enzyme that destroys thiamine.

The levels of thiamine, thiamine monophosphate, and thiamine pyrophosphate were determined in Walleye eggs at various stages of egg development. The total levels of thiamine dropped as the eggs developed, and some changes were seen relative levels of the various thiamine forms during development. Significant differences were also observed between eggs from fish taken from different locations in Lake Oahe; eggs of fish from Grand River at the upper end of Lake Oahe have higher levels of thiamine than eggs from fish taken from other locations.

PHOTON PROPULSION OF A GOSSAMER SPACECRAFT

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ABSTRACT

The propulsion of gossamer spacecraft is one critical issue that is being investigated by NASA for advanced propulsion methods to be used in future space missions. Visible light and microwaves are two types of photon energy that are being investigated. Due to the force of gravity, high intensity photon propulsion demonstrations and experiments on Earth destroy delicate sail material and skew results. The KC-135 "Vomet Comet" was used to propel a novel new type of sail material, node bonded carbon fiber microtruss (cfm), in two different experiments using 2.45 GHz microwaves and an incandescent halogen light. In each experiment, a microsail measuring twelve centimeters in diameter was guided by a monofilament while being propelled through the length of a vertical evacuated chamber. In the 1kW microwave experiment, design considerations included the electromagnetic characteristics of the material and the geometry of the entire system to maximize energy delivery to the cfm sail. In the incandescent experiment, a 0.65kW lightbulb against an aluminum base plate radiated light to a reflective mylar cfm composite sail. An accelerometer attached to the experiment frame measured vibrational and static accelerations while a video camera measured the sail motion. The microwave experiment failed due to a snag in the chamber despite inflight attempts to free the sail. The incandescent experiment showed mixed modes of acceleration. Analysis of the video and acceleration data using various imaging software resolved forces acting on the sail. Sail acceleration data will be used for further evaluation of cfm as a sail material.

METHOD FOR THE DETERMINATION OF VOLATILE N-CONTAINING SPECIES PRODUCED DURING THE CONTROLLED PYROLYSIS OF HUMIC AND FULVIC ACIDS

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ABSTRACT

A thorough understanding of the biogeochemical carbon cycle requires a knowledge of the complex forms and fates of soil organic matter (SOM). Previous investigations by other researchers have demonstrated correlations for the accumulation and decomposition processes of carbon and nitrogen species in soils (Knops et al., 1999; Tian et al., 1992). Hence, an enhanced ability to obtain further information about the changes in N-containing SOM components should also translate to greater insight about C-containing SOM components. Based on this hypothesis, our laboratory embarked on the development of an analytical method for the selective and sensitive determination of volatile N-containing species released from the pyrolysis of SOM in soils.

This presentation summarized a capillary gas chromatographic-atomic emission detection (Cap-GC-AED) system that is coupled to a controlled pyrolysis sampling and cryogenic collection technique for the selective and sensitive determination of volatile N compounds. Initial characterization of this analytical method has been performed with two major components of SOM, humic and fulvic acids. Controlled pyrolysis of humic and fulvic acid was performed by heating samples of each compound from 200° to 900°C, with simultaneous cryogenic pre-concentration of the released volatiles. The subsequent qualitative and quantitative determinations by Cap-GC-AED showed the major N-containing volatile species from humic acid are hydrogen cyanide (52%), acetronitrile (9%), pyridine (2%), pyrrole (0.4%), and acetamide (0.25%) while fulvic acid produced hydrogen cyanide (60%), acetronitrile (6%), pyridine (1%), pyrrole (0.9%), and acetamide (0.3%). These same five compounds are also prominent species measured during the pyrolysis of soils. The presentation concluded with an interpretation of these analytical results and their implication for obtaining information about general classes of SOM and the relative magnitudes of each pool.

CVD GROWTH MECHANISM FOR MICROCRYSTALLINE SILICON THIN FILMS

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ABSTRACT

A high rate growth method of hydrogenated microcrystalline silicon, μc-Si:H, has been developed with very low hydrogen dilution ratio on foreign substrates, using a remote electron cyclotron resonance - plasma enhanced chemical vapor deposition (ECR-PECVD) process. In this work, the key variable was the hydrogen dilution, a ratio of hydrogen to silane, $[H_2]/[SiH_4]$, which ranged from 3.3 to 10, adding helium systematically. Phase transition from amorphous to microcrystalline states was observed as the amount of added helium was varied. It has been found that hydrogenated microcrystalline silicon films with more than 70 % of crystalline volume fraction were formed at high growth rates of 3.2 Å/sec at low substrate temperature below 300 °C from the mixture of silane and hydrogen with a low hydrogen dilution ratio of as low as 3.3. The addition of helium did not increase the growth rate significantly, but it quickly served as disrupting microcrystalline formation. In addition, the substrate temperature-dependent phase transition was observed. The structural, electrical and optical properties, by Raman shift, x-ray diffraction, dark and photo conductivity, activation energy of dark conductivity, and photosensitivity measurements, were investigated to grow good quality μc-Si:H films at the low hydrogen dilution ratio with high growth rates.

CHANGES IN THE MORPHOMETRY OF RAPID CREEK AS A RESULT OF URBANIZATION AND ITS IMPACT TO THE BROWN TROUT FISHERY

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ABSTRACT

Since the late 1960's and the early 1970's, South Dakota Department of Game, Fish and Parks (SDGFP) has made several efforts to improve the brown trout fishery in Rapid Creek through Rapid City. In June of 1972, a flood with an estimated peak discharge of 50,000 cfs took the lives of 237 residents of Rapid City. Following this devastating flood, a greenway was established adjacent to the stream to minimize future damages. Since the establishment of the greenway along Rapid Creek, the City of Rapid City, SDGFP, the Bureau of Reclamation ad the South Dakota Department of Environment and Natural Resources have collaborated on bank stabilization and fish habitat improvement projects worth and estimated $750,000.

The SDGFP discontinued stocking brown trout in the reach of Rapid Creek below Canyon Lake in the early 1970's and this wild brown trout supported approximately 1,800 to 2,000 brown trout per mile through the 1990's. A decrease in the number of brown trout and an increase in the number of white suckers between 1985 and 1999 became a concern to SDGFP.

In 1877 John Brennan and Samuel Scott established Rapid City when they surveyed and platted 1-square mile of land along Rapid Creek. In 1877, the length of stream flowing through this land was approximately 2 miles long. After 125 years of growth, increased urbanization, stream straightening and channelization, the same reach of stream is approximately 1-mile long.

As a result of this straightening and channelization, there is less deep pool habitat in this reach of stream. Likewise there has been an increase in stream velocity, which may be impacting the brown trout population.

DAKOTA SKIPPER POPULATION GENETIC STRUCTURE IN A FRAGMENTED NATIVE PRAIRIE LANDSCAPE

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ABSTRACT

The Dakota skipper (Hesperiidae: *Hesperia dacotae*) is a lepidopteran native to central North American tallgrass and mixed-grass prairie. Agricultural conversion has resulted in the loss of approximately 98% of its native habitat in Iowa, Minnesota, North and South Dakota, and Manitoba, Canada. The species has been extirpated from Iowa and only remnant fragments of tall and mixed-grass prairie remain in government and private preserves. As a result, it has been considered for protection under the US Endangered Species Act and is listed as Threatened by the State of Minnesota and the Province of Manitoba. We used protein electrophoresis to assay genetic variability at nine sample locations throughout its current range. Twenty-one isozyme loci were assayed, 12 of which were polymorphic. Significant isolation by distance was detected among the seven Minnesota and South Dakota sites suggesting historic dispersal among these populations in continuous habitat. The two northwesternmost sites in Manitoba were similar in allele frequencies and showed significant genetic divergence from the other sample locations. These results suggest that preservation of the remaining genetic diversity of Dakota skipper populations will require preservation of habitat fragments from throughout its geographic range.

SELECTIVE SEPARATION OF BIOPOLYMERS FROM MICROBIAL FERMENTATION

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ABSTRACT

Our laboratory is interested in value-added products of ethanol production. Microbial fermentation on a value-added medium, comprised of condensed corn solubles (CCS), provides a route to several value-added products including polyhydroxyalkanoates (PHA). Currently major production costs in PHA production are fermentation media and the extraction process. Use of a CCS derived medium and alternative extraction processes are investigated in this project.

Polyhydroxyalkanoates are microbially produced biopolymers. The extraction of lypholized cells generally includes a lengthy (10 h) chloroform (large volume) Soxhlet extraction with subsequent precipitation, separation, and purification. One goal of this research is to find a method that both decreases the time of extraction and provides a purer extract, while being scaleable to industrial production. Preliminarily, supercritical fluid extraction (SFE) and accelerated solvent extraction (ASE) were examined with several solvents including ethyl acetate, chloroform, and ethanol. Ethanol was found to be an effective solvent in ASE, and modifier in carbon dioxide based SFE. Both compounds are readily available in ethanol plants. With ethanol, the precipitation step (necessary with the other solvents) was eliminated, a more pure extract was obtained, and amount of solvent and time of extraction were drastically reduced.

To reduce PHA production costs we have explored the use of CCS as a basal medium. Several strains of bacteria are able to produce PHA's from lipids, such as the corn oil that is not recovered in dry mill ethanol production. This makes SFE more attractive as an extraction method because an initial SFE carbon dioxide step without modifier can be used to remove any unused lipid material.

ELECTROCHEMICAL SYNTHESIS OF SUCCINIC ACID IN VARIOUS MEDIA

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ABSTRACT

Apart from organic electrosynthesis at conventional electrode materials, there has been a long search for the development of newer electrode materials with specialized properties. Several newer modified electrode materials are being developed continuously not only for organic electrosynthesis but also in other areas of electrochemistry like fuel cells and electrohydrometallurgy. The present paper discusses the reduction of maleic acid at the modified electrode material, Ti/ TiO_2 electrode.

Electrosynthesis Succinic acid has been synthesized by the reduction of maleic acid by galvanostatic electrolysis in various media in a batch reactor at an undivided or quasi-divided cell separated by membrane or separator, using a modified electrode, Ti/ TiO_2 electrode. The reaction conditions were optimized with respect to current density, electrolyte, electrolyte strength and membranes. The product succinic acid was obtained in high yields in the range of 85-95% depending on the experimental conditions. Current efficiencies were also high. The product was characterized by its melting point and FT-IR spectrum.

Cyclic voltammetric studies were also carried out for the reduction of maleic acid at the Ti/ TiO_2 electrode in these media. The mechanism of reduction of maleic acid which involves heterogeneous redox catalysis by surface fixed redox groups is discussed.

The advantages of the present method over chemical methods is discussed.

MONTE CARLO MODELING OF NANOTUBES IN SUSPENSION

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ABSTRACT

Nanotube suspensions have been modeled via Monte Carlo simulation. A computer model was used to realize networks of nanotubes with random location and orientation. The nanotubes were modeled as capped interpenetrating cylinders placed in a unit volume. These networks were expected to behave as a percolation problem. The critical fractional volume (CFV) of cylinders (associated with the onset of percolation) was determined numerous times and analyzed. The aim of this study was to consider nanotubes of high aspect ratio, a (a=length/diameter), and to determine the effects that high aspect ratio may have on the CFV. It was found that the CFV is inversely proportional with increasing aspect ratio in the limit of high aspect ratios. This results in the need for very low percent volume loadings (%volume ≤ 0.01%) of nanotubes to create a conductive network (percolation cluster). These findings are in good agreement with recent experimental data involving the thermal conductivity of carbon nanotube suspensions.