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Editor
Kenneth F. Higgins

Co-Editor
Steven R. Chipps

Terri Symens, Wildlife & Fisheries, SDSU
provided secretarial assistance

Tom Holmlund, Graphic Designer

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Abstracts of Senior Research Papers presented at The 86th Annual Meeting of the South Dakota Academy of Science

CONSOLIDATED MINUTES OF THE EIGHTY-SIXTH ANNUAL MEETING OF THE SOUTH DAKOTA ACADEMY OF SCIENCE APRIL 5-6, 2001 UNIVERSITY OF SOUTH DAKOTA, VERMILLION, SD

The Executive Council met at 7:00 p.m. Thursday 5 April 2001 for a final check of plans for the day to follow.

President Lenore Koczon opened the executive committee meeting, noted that a quorum was present, and thanked Ken Higgins for timely presentation of the 2000 Proceedings.

Neil Reese opened discussion about the Internet, noting that the SDAS site will have to be moved because the provider is changing. Cost for a commercial site is about $50.00 per month and cost for a domain name would be about $35.00 per year. It was decided to explore the possibility of having one of the campuses host the site. The possibility of putting the 2000 Proceedings on the internet was also addressed. Problems with this are changes in student personnel and time. Ken asked if there would be a loss of revenue if the proceedings were available free on the internet.

Registration will start at 7:15 tomorrow. Karen Olmsted has lined up two secretaries ready to assist Bill Soeffing with registration. Lenore has requested information for the executive committee including a membership list with affiliation, address, phone numbers, and e-mail. Neil requested a list of officers. Bill handed out a list of the 2000-2001 Executive Committee, a current membership list, and a list of members who have paid in advance for 2001. Bill mentioned that he has a form for use at registration that will include annual dues $20.00, meeting registration of $10.00, and banquet registration $12.00. Ken mentioned that it is customary to allow complementary tickets for fellows and spouses. Royce reported that the banquet was co-hosted by the Academy and IdeaFest. At the banquet the Chair will call on the Presidents of Ideafest and the Academy, awards for the outstanding Physics teacher will be presented to Steve Pociask, and to Joanne Dankey and Scott Sturlaugson for Biology teachers of the year. The Academy honored two Fellows, Emil F. Knapp and Carroll Hanten.

The Nominating committee will have the following positions to fill, Secretary/treasurer, Second Vice President, and two members-at-large. Dan Heglund and Robert Tatina will be going off as members-at-large. Lenore suggested that the Secretary-Treasurer position be split into two positions. The jobs are large enough to require separation and include for the secretarial position, the taking of minutes, keeping track of registration, and the database. Correspondence includes AAAS, the National Academy of Science, papers for incorporation with the State of South Dakota every two to three years, responding to requests for information and the duties associated with the annual meeting. The treasurer portion keeps track of the finances, writes checks and provides an annual report to the Academy. If this position is split, it will require an amendment to the by-laws and a vote by the membership. Requests for reprints will need to be forwarded to Ken. Lenore suggested that the Academy consider the e-billing with the US postal service. This service will allow tracking changes for up to 12 months. Payments can be made as an individual representing a corporation. For example, Neil would like to pay students working on the web page on a monthly basis and funds could be withdrawn from this account.

Bill Soeffing provided the Treasurers report and mentioned that the program that he had been using for keeping track of finances called Quicken is not compatible with Office 2000. Raising dues to $20.00 had a positive impact on the balance. Bill mentioned that a significant cost is the bulk mailings go out for the Call for Papers, and for the Program announcement. The Academy had a CD with Dakotah Bank that is due to mature soon. It was suggested that because the Academy has sufficient funds for operation, to allow the CD to rollover for another term.

The 2002 meeting of the Academy will be at Augustana, and the 2003 meeting will be at SDSMT. The executive committee will meet in the fall, most likely in September or early October.

Ken Higgins provided the Proceedings report and passed out copies of the 2000 proceedings. Page costs are $25.00/page. USD is the repository of the Proceedings, but some issues are missing. Ken has worked to bring, where possible, the State University Libraries up to date with missing issues. For some issues that are no longer available, the solution may be to provide photocopies of the missing volumes. Currently, the libraries at Huron and the Tribal Colleges do not participate. The Academy is responsible for mailing copies to members and the Academy pays for the cost of mailing copies of the proceedings to participating Libraries. The cost of an issue of the Proceedings is currently $10.00 including postage

Ken suggested that the Academy provide honoraria of $100.00 to Terri Symens and Di Drake for their able assistance above their normal duties. Neil requested $500.00 to pay for a student to assist with the academy web site.

Several items for consideration at the fall meeting of the Executive Committee were discussed. 1) The process by which Fellows are nominated and selected is complex and time consuming. Neil proposed that the nomination process be simplified to include a current vitae and a letter of nomination. Royce and Bill seconded the motion. The committee discussed the expectation that in three to five years the Academy will have a critical mass of Fellows who will be in charge of the process of selection of new Fellows. 2) In addition, Ken pointed out that the by-laws were last updated in 1989 and need to be updated again. 3) Bob Tatina moved and Royce Engstrom seconded to bring before the membership a motion to split the Secretary-Treasurer position into two positions. Bill has forms for changing the by-laws and promised to provide an electronic copy. 4) Neil Reese noted that the Academy apparently does not have letterhead or an official logo and suggested that this item also be placed on the agenda. 5) Several members suggested that the committee discuss the status of the Junior Academy, the relationship of the Academy to Science fairs, recognition of teachers. Miles and Andy will brainstorm and bring a report to the meeting.

President Lenore Koczon opened the meeting on Friday 6 April and Karen Olmstead welcomed all to campus. In his address at the opening session, President-Elect Charles Lamb discussed the Scientific Landscape of the 21st Century. Papers for the Academy began at 8:30 a.m. on Friday 6 April, and continued throughout the day. Eighty-two papers were presented. One hundred twenty-six individuals attended the annual meeting, 61 regular members and 65 associate members.

Respectfully submitted,
Donna Hazelwood, DSU
SDAS Secretary

SOUTH DAKOTA ACADEMY OF SCIENCE
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SECOND PAST-PRESIDENT	Royce Engstrom, USD Chemistry, 677-5370 or 6396 Rcengstr@usd.edu
MEMBERS-AT-LARGE	Dan Heglund, SDSM&T Chemistry, 394-2421 Dheglund@msmailgw.sdsmt.edu, FAX 394-1232
	Robert Tatina, DWU Biology, 995-2712 Rotatina@dwu.edu
	Donna Hazelwood, DSU Natural Sciences, 256-5187 Hazelwod@pluto.dsu.edu
	Michael Wanous, Augustana Biology, 274-4712 Wanous@inst.augie.edu, FAX 274-4718

STATEMENT OF RECEIPTS, DISBURSEMENTS AND CHANGES IN CASH BALANCES FOR FISCAL YEAR 2000

Cash Balance on 1 January 2000		
Certificate of Deposit	$	61733.74
Savings Account	$	9.15
Dakota State University Activity Account	$	586.00
Checking Account	$	8759.42
TOTAL BEGINNING CASH	$	15528.31
Receipts		
Membership Dues (Life-33 / Regular-56 / Associate-26)	$	1120.00
Annual Meeting Registration	$	930.00
Luncheon and Banquet Tickets	$	632.00
Interest on Investments	$	220.14
TOTAL RECEIPTS	$	2902.14
Disbursements		
Annual Meeting		
Program & Facilities (Tri-State, Moorhead, MN)	$	297.33
Supplies	$	94.73
Dining	$	718.02
Web Page Development	$	206.25
Publication of the Proceedings of the SDAS	$	1054.58
TOTAL DISBURSEMENT	$	2370.91
Cash Balance on 31 December 2000		
Certificate of Deposit	$	6393.88
Savings Account	$	9.15
Cash for Deposit	$	1280.00
Checking Account	$	8376.51
TOTAL ENDING CASH	$	16059.54

REPORT OF THE RESOLUTIONS COMMITTEE

The South Dakota Academy of Science wishes to thank the University of South Dakota for hosting the 2001 meeting. In particular, we are grateful to the local arrangements committee — Karen Olmstead, Royce Engstrom, Tina

Keller, Miles Koppang, and Jan Small, for their hard work in producing an excellent meeting.

Thank you to Lenore Koczon for her dedication as President of the Academy for the past year. Thank you also to Charles Lamb, President-Elect, for his address on the future of science in South Dakota.

The Academy wishes to thank Bill Soeffing for his service as Secretary-Treasurer over the past several years. A special thanks goes to Editor Ken Higgins for his oversight of timely publication of the Proceedings.

Congratulations to Emil Knapp and Carol Hanten who this year have been elected as Fellows of the South Dakota Academy of Science.

Congratulations also to Steve Pociask who is distinguished as the South Dakota Biology Teacher of the Year; also to Joanne Dankey and Scott Sturlaugson who are to share the honor of South Dakota Physical Science Teacher of the Year.

The Academy welcomes Wally Klawiter, Everett White, and Arlen Viste as Life Members of the Academy.

Respectfully submitted,
Gary Larson, Resolutions Committee

SDAS PROCEEDINGS REPORT

First, I want to thank those who helped me manage and produce the 1996, 1997 and 2000 Volumes of the Proceedings for the S.D. Academy of Science: Terri Symens — Invoices, Mailing Labels, Correspondence and Entering Names and Titles for the Program; Tom Holmlund — Proceedings Layout, Figure Scanning and Final Copy Formatting; Donna Hazelwood — Meeting Notes, etc.; Emil Knapp — Periodic Assistance; and several members who helped with obtaining member names and addresses at various Universities or Colleges

All back issues including the 2000 Volume of the Academy Proceedings have been published and many have been distributed. Finances for producing the Proceedings and article reprints appear to be adequate, given the $25 rate per printed article or abstract page. The use of the SDSU accounting system has been a positive action to date. The USD Library system has agreed again, as they had formerly, to act as the repository and distributor of past volumes of Academy Proceedings. Joe Edelen is the contact person. They will provide storage, shelving and mailing of requested volumes, but the academy will have to handle invoices and collection of payments. He says most libraries sell extra copies of proceedings for $5-10 per copy. I collected all extra copies from Emil Knapp and Bill Soeffing and have delivered all (a truckload) to USD to combine with the dozen or so boxes that they have on hand. Copies of the 1996-2000 Proceedings have been delivered to all University Libraries for the schools usually represented at the Academy meetings. Some libraries are missing one or more volumes from their collections. Two copies of each volume of the proceedings have been sent to the contact for the National Academies — Tom Weaks at SASA Managing Editor and Professor Emeritus of Biological Sciences, Marshall University, Huntington, WV 25701. Steven Chipps and I are currently working on finding proper abstracting services for academy papers of full length so that authors will receive reprint requests, etc. Eighty-six presentation titles were submitted for the 2001 program and Proceedings. Dr. Steve Chipps, my counter part with the Coop Unit at SDSU, will serve as Co-Editor for the 2001 proceedings. This will ensure continuity with proceedings production through time. I have also been contacting former life members and retired or out-of-state members and have found that several are deceased and that many others no longer wish to receive their complimentary copies the Proceedings. Several said to save the costs and use the funds elsewhere on behalf of the Academy.

Proceedings Disbursements/Receivables Through July 31, 2001

	1996	1997	1998	1999	2000	Total
Layout, Formatting	1,194.00	1,221.00	0.00	990.00	780.00	4,185.00
Publication	2,899.00	3,441.80	2,245.95	2,954.80	2,585.92	14,127.47
Reprints	677.88	1,034.67	1,526.17	299.75	0.00	3,538.47
Miscellaneous Printing	5.22	54.51	45.72	57.22	0.08	162.75
Supplies,Phone,Postage	37.70	104.88	160.56	50.25	35.01	388.40
TOTAL EXPENSES	4,813.80	5,856.86	3,978.40	4,352.02	3,401.01	22,402.09
TOTAL INVOICED	4,875.00	7,348.00	3,830.00	5,200.00	3,635.00	24,888.00
Profit / Loss to date	***61.20***	***1,491.14***	***-148.4***	***847.98***	***233.99***	***2,485.91***

Respecfully submitted,
Ken Higgins, Editor

PRESIDENTIAL ADDRESS

The Scientific Landscape of South Dakota in the 21st Century

Address to the South Dakota Academy of Science
April 6, 2001

Presented by Charles F. Lamb
Black Hills State University
Rapid City, SD 57701

Whenever we pass from one relatively large unit of time to another, whether it be from year to year or from millennium to millennium, we seem compelled to assess our progress and to prognosticate into the future. I would like to take the opportunity of our first South Dakota Academy of Science meeting in the new millennium (at least, by my reckoning) to take a brief look at what roles our academy might play in maintaining its place as a valuable (and valued) scientific entity in the future of South Dakota.

As residents of the northern Great Plains, landscape typically means hundreds of miles, or tens of thousands of acres, and the scientific landscape before us today is equally as expansive. We live in a society becoming increasingly dependent on scientific information and scientific literacy. This is not a new trend, by any means, but the relationship between society and science is growing exponentially, and appears to continue to do so. When we look back on the last decade, or the last century, the nature of science has not changed much but the ways in which it is done, and the rate at which it is done, have changed considerably. How many of us in this room could have known, in our undergraduate days, the magnitude of effects on our scientific activities, let alone on our everyday lives, that would engulf us with the coming of the "digital age"? I used to laugh at my mentors as they pitied the new generation of scientists and our infatuation with computers when, in fact, it is increasingly evident that the future lays at the feet of those who are most adept at utilizing digital breakthroughs and innovative technologies, and the pioneers of yesterday can easily become the dinosaurs of tomorrow. I use computers as an example of the changes ahead of us because they have become so pervasive in the lives of every citizen of South Dakota, but the truth is that this pattern of technological advancement is evident in every one of the disciplines represented here today, and we as scientists become increasingly important to the future success of our state. Our fellow South Dakotans will be asked to make informed decisions on socially prominent issues such as cloning of tissues or offspring; genetic manipulation of crops, livestock, or humans; new and virulent infectious diseases; the impacts of population growth and land-use practices, including effects on air, water, and soil quality, global warming, biological diversity; space research programs; neutrinos and particle physics; and the societal value of applied and basic scientific research. Our academy can play a vital role in South Dakota being ready for the adventures and opportunities that the new millennium has in store for us.

How can the Academy best serve the scientists and the citizens of South Dakota? The South Dakota Academy of Science was founded in 1915 for "the promotion of scientific research, the diffusion of scientific knowledge and scientific spirit, and the unification of the scientific interests of the state." The founding president, Dr. Hilton Ira Jones of Dakota Wesleyan University, saw the functions of the Academy to include an "association with appreciative souls" and a means to "break down isolation and stimulate research".[1] Our mission has changed little in the eighty-six years since, although we have expanded the innaugural objectives somewhat. 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.

The stated role of the Academy in fulfilling this mission is threefold: to promote scientific research and publication, strengthen science teaching, and provide a forum for the improvement of public understanding of science. The Academy is currently working toward all three of these objectives, but it is our responsibility to continually search for the most effective ways to fulfill our mission.

The focus of scientific research is being redefined to respond to the current needs of society. The challenges facing us now are not the same as those that were burdening South Dakota's scientific community in 1915 (although Dr. Jones's statements do have a certain resonance even today). Dr. Thomas Cech, a chemistry professor at the University of Colorado and President of the Howard Hughes Medical Institute, has identified several major trends developing in scientific research. These include the impact of constantly evolving technologies, an increasing importance of teamwork and interdisciplinary approaches to scientific problems, and innovative approaches to integrating science education with research.[2] The goals of the Academy and the market forces currently at work in science appear to be in harmony. This is evidenced by the success that South Dakota's scientific community has been enjoying recently, in numerous collaborative ventures involving multiple academic institutions, often in conjunction with scientists working for various state and federal agencies or corporate entities. The capacity for science is here, and the institutional support is certainly increasing, but what can the Academy do to help us conduct research and improve science education and scientific understanding in South Dakota?

There are several mechanisms already in place through which we could accomplish our objectives. The annual meeting of the Academy is already an effective tool for sharing our research interests and looking for potential collaborative opportunities. It is a uniquely interdisciplinary meeting where scientists from across the state can work together toward developing innovative solutions to some of the state's scientific issues. In addition, it is a venue well-suited for the training of our undergraduate and graduate students in the communication of their research results and in scientific discourse. It would be even more effective if we could find ways to increase the participation to include more of our colleagues and broaden the scope of our interactions. The Academy also has a long history of working toward improving science education in South Dakota. Current examples of these efforts include cosponsorship of a science education workshop conducted in association with the annual meeting, a junior academy for high school students, and an active involvement in the SDBOR Science Discipline Council.

One area in which we clearly need to increase our effectiveness is in our communication – both within the scientific community and throughout South Dakota. So much of our dissemination is of competitive sound-bites – touting the accomplishments of one individual or one institution, and not explaining the relevancy of what we do to the citizens of South Dakota. If we want to have an impact on the scientific competency of South Dakota, we need to develop a collective voice that will say something to South Dakotans. As Bruce Alberts, President of the National Academy of Science, said recently: "In the 21st century, science and scientists will be judged on how well they help solve local and world problems, not on how well they generate new knowledge. The impact of our research is everywhere, and we must step out and make sure that our work is understood and appropriately used by the world."[3] I ask that the members of the Academy consider this calling as we busy ourselves with the science of South Dakota at this meeting. Only with your input and engagement will we be able to perform the functions that our state needs of us.

Thank you.

LITERATURE CITED

[1]Jones, H.I. (1915) Presidential Address, Proceedings of the South Dakota Academy of Science. 1:20-25.

[2]Cech, T.R. (2001) Four trends to keep an eye on. HHMI Bulletin, January, 2001.

[3]Alberts, B. (2000) Science and human needs. Address to the 137th Annual Meeting of the National Academy of Sciences.

Complete Senior Research Papers

presented at

The 86th Annual Meeting

of the

South Dakota Academy of Science

RANGE EXPANSION AND FIRST DOCUMENTED NESTING OF GREAT-TAILED GRACKLES *(QUISCALUS MEXICANUS)* IN SOUTH DAKOTA

David L. Swanson and Eric T. Liknes
Department of Biology
University of South Dakota
Vermillion, SD 57069

ABSTRACT

Great-tailed grackles *(Quiscalus mexicanus)* formerly were present in North America only in southern Texas, but they have been expanding their range, primarily to the north and west, throughout the past century. Reports of this species have recently proliferated in the north central United States. Here we review the current status of the great-tailed grackle in South Dakota and report the first documented nesting of this species in the state. The first documented record of great-tailed grackle in South Dakota was a male that occurred on 14-15 May 1988 in Yankton County. No additional records of this species were documented for South Dakota until 1995, when birds from Charles Mix (6 April) and Clay (24 May-1 June) Counties were reported. Since that time, records of great-tailed grackles in South Dakota have occurred as far north as Brown and Deuel Counties and as far west as Lyman County, but no nests were documented until 1999. In 1999, we found three nests in a marsh lined with cattails *(Typha latifolia)* in Clay County. The first nest was discovered on 24 April and two additional nests were found on 1 May. All three nests were composed of woven plant matter (mostly cattails) and were suspended in the cattails approximately 40-60 cm above the surface of the water, which was about 50-70 cm deep under the nest. These nest locations are consistent with those in colonizing birds, although once established in an area, great-tailed grackles often expand their nesting sites to include non-marsh habitats. The two latter nests fledged five and three young, but the initial nest, with a clutch of five eggs, was abandoned and the eggs never hatched. These, along with another record from Minnehaha County in 1999, represent the first documented nest records for great-tailed grackles in South Dakota.

Keywords

Birds, great-tailed grackle, range expansion, nesting records, Clay County, South Dakota

INTRODUCTION

The great-tailed grackle *(Quiscalus mexicanus)* has greatly expanded its range in North America over the past century. Dinsmore and Dinsmore (1993) note two characteristics of great-tailed grackles that likely contribute to their range expansion. One, this species tends to wander widely so that some birds regularly encounter uncolonized areas. Second, additional grackles tend to follow pioneering birds, within a relatively short time period, into uncolonized areas. The general pattern during the range expansion has been for pioneering birds, often one to several individuals, to appear in an uncolonized area, to be followed by additional birds within a few years that establish a nesting population (Dinsmore and Dinsmore 1993).

Dinsmore and Dinsmore (1993) reviewed the range expansion of this species in North America through 1991. Briefly, in 1900 their range in North America encompassed only southern Texas. By 1950, grackles had spread to southern New Mexico and Arizona and northwestward in Texas. Since 1960, their range has expanded rapidly in three general directions, to the north in the Great Plains, to the northwest into the Rocky Mountain States, and to the west into southern and central California. Thus, by 1991 nesting had been documented from central California through southern Nebraska into western and central Iowa and south to Louisiana (Dinsmore and Dinsmore 1993). Through 1991, there was only one documented record of Great-tailed Grackle for South Dakota, a single male in Yankton County on 14-15 May 1988 (SDOU 1991). Moreover, there were no nesting records for the state by 1991, although nesting records were present by that time in central Nebraska and central and northwestern Iowa (Dinsmore and Dinsmore 1993).

The purpose of this paper is to update the status of the great-tailed grackle in South Dakota and to report the first documented nesting of this species within the state. In addition, we comment on future expected trends for this species within the state and region.

METHODS

To determine the past and current status and distribution of the great-tailed grackle in South Dakota, we systematically reviewed the Seasonal Reports in *South Dakota Bird Notes* from 1991-2000. Prior to 1999, the great-tailed grackle was on the review list of the Rare Bird Records Committee (RBRC) of the South Dakota Ornithologists' Union (Swanson 1999). Thus, before 1999 records of great-tailed grackles submitted to the Seasonal Reports required acceptance by the RBRC for their inclusion into the official state records and not all records appearing in the Seasonal Reports prior to 1999 were acted on by the RBRC. Nevertheless, for the purposes of this review, we have included these records in assessing the current distribution of great-tailed grackle in South Dakota. However, we do note records that were not acted on by the RBRC, but extend the range of the grackle within the state. In addition to Seasonal Reports records, we include some of our own personal observations that were not reported in the Seasonal Reports.

For the three nests that we located, we monitored nesting behavior of the adults and fate of the nest contents. Nests were checked three times during the nesting season, at intervals of 7-15 days, to determine if nests were still active.

Upon completion of the nesting effort for each nest, we recorded the general habitat and vegetative characteristics surrounding the nest area and made measurements of the nest itself. We also periodically visited the marsh where the nests were found over the remainder of the summer seeking any additional nesting behavior suggesting that grackles might have initiated another brood, as they sometimes do in other portions of their range (Baicich and Harrison 1997).

RESULTS AND DISCUSSION

Nest Documentation

Nesting of great-tailed grackles in South Dakota was first documented in 1999 at a marsh in Clay County located at 42°47'30"N, 96°52"'21"W (legal description: T.92N, R.51W, Section 16). We first observed great-tailed grackles in 1999 in this area on 20 March in a plowed field directly southeast and adjacent to the nest marsh (Table 1). The first nest in this marsh was located on 24 April when a female flew to the nest carrying nesting material. Two additional nests were located in the same marsh on 1 May. The phenology of these nests is summarized in Table 1. The 24 April nest represented the first great-tailed grackle nest documented for South Dakota, although another nest of this species was found the following day, 25 April 1999, in Minnehaha County (Nathan Pieplow, personal communication). We observed fledglings from one of the nests found on 1 May and the other nest found on 1 May probably also produced young. However, the nest found on 24 April was abandoned with 5 eggs (Table 1).

Table 1. Nesting phenology for great-tailed grackle nests in the Clay County marsh during 1999.

Date	Significant Observations
20 March	3 males present in plowed field adjacent to nesting marsh; later at least 4 males were present in the nesting marsh area, but only one remained throughout the entire nesting season.
24 April	First nest (Nest 1) was located as a female flew to the nest carrying nesting material. One male and a second female were also observed on this date.
1 May	Nest 1 had a clutch of 5 eggs and the female was incubating as we approached the nest. Two additional nests were located on this date, one with 5 eggs (Nest 2) and one with 3 eggs (Nest 3).
14 May	Nest 1 still had 5 eggs and the female was not present in the nest area; probably the nest had been abandoned by this date, as this is outside of the normal hatching period of 13 days (Tutor 1962). Nest 2 had 5 hatchlings present and Nest 3 had 2 hatchlings and 1 egg. Two males and three females were observed at the marsh on this date.
29 May	Nest 1 still had 5 eggs, definitely abandoned at this point. Nest 2 was empty, but intact, with a few pinfeathers present at the bottom of the nest suggesting that fledging had occurred. Nest three had three fledglings present in the immediate nest vicinity; one actually flushed from the nest on our approach.

We continued to observe the marsh periodically after nesting efforts were complete, through the end of July 1999, to determine if adults engaged in behaviors suggesting a second nesting attempt. These observation periods occurred at least once per week, generally lasted for 5-15 minutes, and occurred at all times of day. No behaviors or other evidence suggesting that great-tailed grackles were double-brooded at this location was detected. At some other breeding locations great-tailed grackles are at least occasionally double brooded (Baicich and Harrison 1997). Noteworthy sightings after the completion of nesting efforts at this location included seven apparent juvenile (based on brownish plumage coloration) great-tailed grackles in a flock departing from a woodlot about 0.5 km west of the nesting marsh on 13 July. Two apparent juveniles were also observed in a cornfield just east of the nesting marsh on 14 July. Single juveniles (based on brown plumage and dark eyes) were observed flying into the woodlot to the west of the nesting marsh on 30 July and at another marsh about 3 km from the nesting marsh on 31 July. The high number of apparent juveniles observed in the immediate vicinity of the nesting marsh suggests that both nests found on 1 May successfully fledged young.

The three nests were all suspended in cattails *(Typha latifolia)* and were bowl-shaped and composed of woven plant matter (largely cattails) (Fig. 1). All nests were located within 4 m of open water. Nests were located approximately 40-60 cm above the surface of the water and water depth below the nests ranged from about 50-70 cm. Marsh nesting is typical for great-tailed grackles, particularly for the first birds to nest within a particular area (Dinsmore and Dinsmore 1993, Baicich and Harrison 1997, Jaramillo and Burke 1999). Later individuals may inhabit and nest in a wider variety of habitats, including groves, thickets, towns, and city parks, but they remain associated with rather open areas and prefer nesting near water (Kaufman 1996, Jaramillo and Burke 1999). Nest dimensions ranged from about 15-20 cm external diameter, 10-13 cm internal diameter, 22-27 cm external depth and 10-15 cm internal depth (Fig. 1). Nests were larger than those of yellow-headed blackbirds, *Xanthocephalus xanthocephalus,* which also nested within the marsh. The eggs were subelliptical in shape and pale blue-green in color, with dark brown spotting and drizzling. Clutch size in these nests ranged from three to five. Baicich and Harrison (1997) state that great-tailed grackles usually lay clutches of 3-4 eggs, although sometimes clutches are as large as five eggs, and Jaramillo and Burke (1999) list the average clutch size as about 3.5. Thus, two of three nests in South Dakota had clutch sizes at the very upper end of the typical range for this species. Clutch size increases with latitude in a number of bird species (Ricklefs 1980) so the high clutch sizes in these nests from the northern portion of the breeding range suggest that great-tailed grackles may also follow this pattern, as posited by Jaramillo and Burke (1999).

Status and Distribution

The great-tailed grackle range expansion in North America has been classified as an explosive expansion, where the species colonizes isolated locations at the forefront of the expanding range and later fills in the gaps between the

Figure 1. Great-tailed grackle nest discovered on 24 April 1999 in Clay County, South Dakota. The ruler on the nest is 16 cm long. Note the construction of the nest largely from woven cattails *(Typha latifolia)* and the suspension of the nest in the cattails about 40-50 cm above the surface of the water. This nest had a clutch of 5 eggs, but was abandoned before the eggs hatched.

isolated colonies and the main range (Dinsmore and Dinsmore 1993). In colonizing a new location, the general pattern is for pioneering non-breeding individuals to appear in an uncolonized area, followed in a few years by additional birds that establish a breeding population. Dinsmore and Dinsmore (1993) report the average interval between the first observation of great-tailed grackles within a state and the first nesting record as 4.8 years for 13 states in which breeding populations had been established by 1991. For southern prairie states (Oklahoma, Kansas, Nebraska, Iowa, Missouri, and Colorado) this interval ranges from 0 years in Iowa to 7 years in Missouri, and averages 3.7 years (Dinsmore and Dinsmore 1993).

The first documented record of great-tailed grackle for South Dakota was in 1988 in Yankton County (SDOU 1991). No additional records of this species occurred in South Dakota until 1995, when there were two records: a male at Lake Andes National Wildlife Refuge, Charles Mix County, on 6 April, and five birds (four males and one female) near Vermillion, Clay County, from 24 May-1 June. The latter record was the first for a female in South Dakota. In 1996, there were also two records, a pair at Salt Lake, Deuel County in late April and May, and a male near Vermillion on 16 May. The pair at Salt Lake was present at the same location throughout the nesting season, suggesting possible nesting, but no nesting evidence was found. There were eight records in 1997 that ranged from 19 April in Miner County to 25 October (four birds) in Kingsbury

County. These included a record of a pair near Wagner, Charles Mix County, the female of which was observed carrying nesting material, but no nest was found (Cantu 1998). Nine records in 1998 spanned the period from 28 March (Charles Mix County) to 11 October (Lincoln County). These nine records included a report from Brown County, the northernmost record for the state (a record not acted on by the RBRC) and records of at least three birds from 17 April through 20 July near the marsh where we found nesting grackles in 1999. By the end of 1998, great-tailed grackle records for South Dakota had proliferated to a level where the RBRC removed them from the review list of rare birds in the state (Swanson 1999). Another eight records occurred in 1999, from 20 March through 26 November, including the nesting records reported here and two records of nesting evidence from Minnehaha County. The Minnehaha County records were of a female on a nest on 25 April and a female carrying nesting material at a separate marsh later in April (Nathan Pieplow, personal communication). Also in 1999 was a record of five birds from Lyman County, the westernmost record of this species in the state. In 2000, there were five records, including the first two winter records for the state, 13 birds from 4-6 February in Sanborn County and a single bird 26 February in Charles Mix County. The winter of 1999-2000 was very mild, which could have permitted these birds to winter, but it also may have facilitated early migration, so whether these birds were wintering birds or early migrants is not known.

In summary, current records of great-tailed grackle in South Dakota extend from the southeastern part of the state north and west to Lyman County and north and east to Brown and Deuel Counties (Fig. 2). Documented nesting records exist only from Clay and Minnehaha Counties, but records of nesting behavior (carrying nesting material) or of multiple birds present at one location for extended periods during the breeding season that are suggestive of nesting also exist from Charles Mix, Lyman, and Deuel Counties. It is likely that additional nesting records will occur over much of eastern South Dakota in the future if the pattern of explosive expansion continues.

The interval between the first sighting of a great-tailed grackle in South Dakota and the first documented nesting is 11 years, which is considerably longer than the 3.7-year average for this interval from other prairie states with breeding records cited by Dinsmore and Dinsmore (1993). However, the first possible nesting date in South Dakota was the Deuel County record in 1996. Using this record as the first nesting date within the state decreases the interval to eight years, but this is still higher than the range for southern prairie states. The relatively long interval between first observation and breeding in South Dakota likely reflects the relatively low number of observers within the state, but it may also suggest that the rate of colonization is slowing as expansion proceeds northward in the Great Plains.

To investigate this latter possibility, we examined records for great-tailed grackles from northern Great Plains states. North Dakota and Minnesota also show relatively long intervals between the first observation for the state and the first nesting. The first record of great-tailed grackle for North Dakota was 3 June 1995 in Cass County (Berkey 1995). Breeding was suspected, but not confirmed for North Dakota in the summer of 2000 in Ransom County (Martin

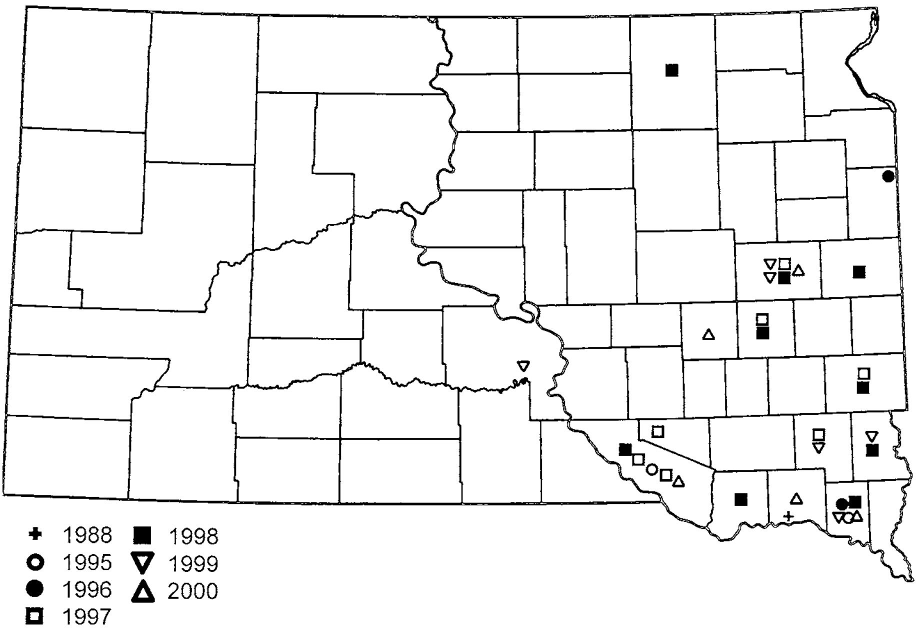

Figure 2. Distribution of great-tailed grackle records in South Dakota through the year 2000. We attempted to place records for particular counties at the site of observation with the county, but in many cases, only the county where the observation occurred was listed in the Seasonal Reports in *South Dakota Bird Notes.* In these cases, we placed the record in the center of the county.

2000), so the minimum interval for North Dakota is five years. For Minnesota, the first record was probably in 1982, although boat-tailed grackle *(Quiscalus major)* was not eliminated in this record (Egeland 1983). The first confirmed record for Minnesota was in 1993, from 3-10 April in Rice County (Granlund 1993). Nesting was suspected from the Minnesota-Iowa border at Grover's Lake Wildlife Management Area in 1998, where females were observed carrying nesting material on the Iowa side of the lake, but no nests were found (Hertzel and Hertzel 2001). Nesting was confirmed for Minnesota in 2000 from Jackson County (Hertzel and Hertzel 2001). Thus, the minimum interval from first observation to first nesting for Minnesota is five years, seven years to the first confirmed nesting, and the maximum is at least 16 years.

In the western northern Great Plains, this interval is nine years for Wyoming (Truan and Percival 1998), but the first observation and the first nesting were coincident in Montana (Berkey 1996). Thus, for these five northern Great Plains states, the interval between first observation and first nesting (using minimum values strongly suggesting nesting for North and South Dakota and minimum values for confirmed nesting for Minnesota) averages 5.8 (± 3.6, SD) years. This is longer, but not significantly so (Student's *t*-test; $t_9 = 1.11$, $P = 0.29$), than the 3.7 (± 2.8, SD) year average interval from the southern Great Plains, which suggests that the explosive range expansion of the great-tailed grackle is still underway.

ACKNOWLEDGMENTS

Thanks are due to Ron Martin for providing information on grackles in North Dakota and to Anthony Hertzel for providing a copy of the paper on great-tailed grackle nesting in Minnesota. Thanks also go to all of the South Dakota observers who submitted great-tailed grackle records to the Seasonal Reports in *South Dakota Bird Notes*. Finally, we wish to acknowledge the spring 1999 Ornithology Class at the University of South Dakota, as it was on a class field trip that we discovered the first great-tailed grackle nest.

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APPLYING SIMPLE SEQUENCE REPEAT (SSR) MARKER IN SCREENING *FUSARIUM* HEAD BLIGHT RESISTANT PARENTS

Lieceng Zhu and J.C. Rudd
Plant Science Department
and
Yang Yen
Biology and Microbiology Department
South Dakota State University
Brookings SD 57007

ABSTRACT

The QTL on wheat chromosome arm 3BS from *Fusarium* head blight (FHB) resistant cultivar Sumai 3 is a major contributor to FHB resistance. Two SSR markers (Xgwm533 and Xgwm493) have been found closely linked to the resistant QTL. This project aimed at screening FHB resistant parents used in the South Dakota spring wheat improvement program for these SSR molecular markers. This is the first step toward implementation of marker assisted selection (MAS). Fifty lines in the Fall Crossing Block (FCB00), 24 lines from the Preliminary Yield Experiment (PPY) in the year of 2000, and three FHB resistant lines with unknown pedigrees in spring wheat project, were analyzed with the SSR markers Xgwm533 and Xgwm493. Eight lines were found to possess Xgwm533, and 36 lines possess Xgwm493. This information will be applied in MAS for FHB resistance.

Keywords

Fusarium head blight, SSR, Molecular marker assisted selection, Spring wheat

INTRODUCTION

The resistance to *Fusarium* Head Blight (FHB, also called scab) is inherited in a quantitative manner (Waldron et al., 1999). The development of wheat cultivars resistant to FHB is hindered by the lack of sources of high levels of resistance and by low heritability of the available resistance resources (Anderson et al., 2000). Selection for molecular markers linked to FHB resistant QTLs has the advantage to enhance the efficiency of genetic improvement compared to selection for resistance in field or greenhouse because of the stability across years and environments. Efforts have been made to identify DNA markers linked to FHB resistance in wheat (Bai et al., 1999; Anderson et al., 2000). Simple sequence repeats (SSRs) are abundant, codominant, highly polymorphic and widely dispersed in diverse genomes as well as easy to assay by PCR. All of these, plus the easy dissemination among laboratories make SSRs an applicable marker in FHB resistant breeding.

Up to date, spring wheat cultivar Sumai 3 has been found to have the highest resistance to FHB and is widely used in breeding for FHB resistance. The most significant QTL for FHB resistance was located on the short arm of 3B chromosome. (Anderson et al., 1998). Researchers have found several SSR markers linked to the QTL in Sumai 3 or Sumai 3 derived populations. These markers are Xgwm533, Xgwm 493, and Xgwm389 (Anderson et al., Chen et al., Zhou et al., 2000) among which Xgwm 533 is the most closely linked marker and explains 17-24.6% variation of FHB resistance in the tested populations (Anderson et al., 2000). Xgwm389 and Xgwm493 are flanking the major QTL in 3BS. The linkage distance between the two markers is 10.1 cM. The probability of missing the major QTL by selecting both markers is 0.25% if the QTL is located in middle of the two markers (Zhou et al., 2000). These three markers are suitable to be applied in marker assisted breeding (MAS).

This project aimed at screening FHB resistant parents used in the South Dakota spring wheat improvement program for these SSR molecular markers. This is the first step toward implementation of marker assisted selection (MAS).

MATERIAL AND METHOD

Plant materials

Fifty lines in the Fall Crossing Block (FCB00), 24 lines from the Preliminary Yield Experiment (PPY) in the year of 2000, and three FHB resistant lines with unknown pedigrees in Spring Wheat Project were used in this research.

DNA isolation

DNA was extracted from 0.1g young leaf for each line using plant DNA zol solution and followed the manufacture’s procedure (Life technologies Inc.).

SSR analysis

SSR primers were synthesized by Life technologies Inc. according to sequence information published by Röder et al. (1998). PCR amplification followed the method of Röder et al. (1995). Silver staining was used to detect the PCR products after separation on a sequence gel following a protocol described by Xing et al (2000).

RESULT AND DISCUSSION

The summaries of the assay results are shown in Table 1. The results showed that out of all 78 assigned lines, eight lines had the SSR marker Xgwm533, and 36 lines had Xgwm493 (10%, 46% receptively).

Table 1. Summaries of SSR assay

Lines		Xgwm533 only		Xgwm493 only		Xgm533 and Xgwm493	
Pedigree	*Number*	+	-	+	-	+	-
With Sumai 3	23	3	16	7	12	4	8
Without Sumai 3	51	0	51	23	28	0	26
Unknown	4	0	3	1	2	1	2
Total	*78*	*3*	*70*	*31*	*42*	*5*	*36*

+: With markers
-: Without markers

Our results also showed that all lines with SSR marker Xgwm533 had Sumai 3 as resistance resources except N99-0107, which was developed by AgriPro Seed company, its pedigree information is unknown to our project. All the lines with this marker had at least moderate resistance to FHB.

Although Xgwm 533 was considered as the nearest marker linked to FHB resistance QTL in chromosome 3BS (Anderson et al, 2000), it existed only in a few lines and expressed differently among lines with same pedigree. About 70% of FHB-resistant lines did not have this marker even though they were derived from Sumai 3 indirectly. It seemed that the linkage between this marker and the 3BS FHB resistance QTL was easily broken through crosses.

A large proportion of the lines was assayed to have Xgwm493, including some susceptible lines without Sumai 3 in their pedigree. Therefore, this marker did not show much polymorphism between resistant and susceptible lines and thus must be used with caution.

One of the most commonly used FHB resistant lines in our breeding project SD 3411 were found to have marker Xgwm493. The information would be applied in MAS soon.

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HERBAGE NITROGEN CONTENTS AFTER A PRAIRIE PRESCRIBED BURN IN THE BLACK HILLS

F.R. Gartner and E.M. White
Animal & Range Sciences and Plant Science
South Dakota State University
Brookings, SD 57007

ABSTRACT

Effects fall burning of prairie have on the next year's herbage nitrogen content were studied. Warm-season little bluestem *(Schizachyrium scoparium [Michx] Nash.)* and prairie dropseed *(Sporobolus heterolepsis)* and cool-season *Carex spp.* and *Poa spp.* were the most abundant grass-type plants. The mineral soil did not heat to 38°C during the burn. The nitrogen content of the 0-2-cm layer did not decrease but plant-available phosphorus and organic matter increased due to the addition of charred plant fragments. Post-burn yields of warm-season herbage decreased significantly ($p>0.05$) in burned areas, and cool-season herbage yields increased in three of the four areas. Mulch weight was significantly reduced ($p>0.05$). Unburned plot herbage N (8.8 g kg^{-1}) was significantly larger ($p>0.05$) than the herbage of burned plots (7.6 g kg^{-1}). The N content of cool-season herbage (9.2 g kg^{-1}) was significantly larger ($p>0.05$) than the N content of the warm-season herbage (7.2 g kg^{-1}). Burned and unburned plots, respectively, had 5890 and 8304 g N ha-1 if the amounts in the two types of herbage were added. Nitrogen in the standing herbage and mulch of the unburned areas likely leached to the soil and supplied N to the next season's herbage.

Keywords

Grass-fires, prairie preservation, pine encroachment

INTRODUCTION

The new growth of grass, following a prescribed burn is frequently darker green and more vigorous than in unburned areas. This study was initiated to determine if the herbage N content is increased following a fire. Prairie fires can immediately increase the amount of NH_4-N, plant-available P, and organic matter in the 0-2-cm soil layer (White and Gartner, 1975). Soil NH_4-N and plant-available-P amounts increased as temperatures of a 10-minute heat treatment increased from ambient to 400°C. A similar study with soils from Ponderosa pine *(Pinus ponderosa)* forest found total N decreased in samples heated above 200°C (White et al., 1973). Soil organic matter, total N, NH_4-N, and extractable PO_4-P contents were similar after fall or spring burns of meadow and coniferous understories and for unburned areas in the Black Hills (White and Gartner, 1994a). However, soil lost organic matter, total N, and total PO_4-P beneath burned slash piles and the C/N of the 0-2-cm layer decreased. The NH_4-N increased in the 0-5-cm soil layer and NO_3–N decreased in the 2-5-cm layer (White and Gartner,1994b). Changes 15 or 16 months after the slash was burned were compatible with the initial changes. Fyles et al. (1991) reported slash burning two years earlier had not reduced N levels below those needed for early plantation growth except where slash was completely burned on coarse-textured soils. Ryan and Covington (1986) found the 0-15-cm soil layer NH_4-N and NH_4-N plus NO_3-N increased in prescribed burns of saw timber but not in stands of pole or sapling classes. Kovacic et al. (1986) also found NH_4-N and NH_4- plus NO_3-N increased but total N did not change in a 30-day post-burn period. Covington et al. (1991) reported NH_4-N increased immediately but that NO_3-N increased the following year. Monleon et al. (1997) found soil total C and inorganic N amounts had increased four months after prescribed underburning in Ponderosa pine in Oregon. Inorganic N amounts decreased to the amounts in the control plots within a year. Five years after prescribed burning, total C and N concentrations and N-mineralization rates were smaller.

MATERIALS AND METHODS

Prescribed-burn treatment

Thirty six and a half hectares of a prairie in the forested Black Hills were burned by the Forest Service in October, 1973 (Gartner and White, 1974) to control encroaching Ponderosa pine (380 trees ha^{-1}, 97% were 2.5 to 5 cm dia.). Oven-dry pre-burn herbaceous fuels in Area 1 through 4 located, respectively, on N-NW-, N-NE-, W-, and S-facing slopes were 2900, 5300, 3400, and 4100 kg ha$_{-1}$. Moisture contents were 16 percent for soils and 15 percent for fuels. As measured by materials with specific melting points, temperatures in the mulch layer, about 2.5 cm above the mineral soil, approached 540°C but did not reach 38°C in the mineral soil. In small saplings, temperatures above the soil ranged from 150 to 480°C at 30 cm, 65 to 150°C at 60 cm, and less than 65°C at 90 cm. Wind speeds were about 40-km hr^{-1} so the fire moved rapidly across the area and did not consume the mulch layer where it was moist.

Sampling

Prior to the prescribed burn, four pairs of 50x50 cm plots were located on 1. a N-NW-sloping colluvial area, 2. a N-NE-facing upland area, 3. a west-sloping narrow ridge with shallow soils, and 4. a steep south-facing slope. A 15x15-m area on each landscape was not burned. The 50x50-cm plots were located at two corners of the unburned areas in each of the four landscapes. Each 50x50-cm area was divided into four 25x25-cm subplots — two were untreated and two had the vegetation burned in the summer. The following

April, the 0-2-cm soil surface layer was sampled for laboratory analysis by methods described by Jackson (1958) for Walkley-Black organic matter, total macro-kjeldahl N, and 0.1N-NaCl-extracted P subsequently determined by the ascorbic acid procedure (Watanabe and Olsen, 1965). Soil particle sizes were determined (Soil Conservation Service, 1972) on a samples from each of the eight 50x50-cm plot.

The *plant species-sampling unit* consisted of locating four shoots lying on a transect and measuring the distances between them to calculate the shoot density. The transects were perpendicular to the even-numbered foot intervals in a hundred-foot measuring tape and the transects were one hundred foot long.

The samples for *herbage and mulch weights* were collected from five 20x50-cm areas located randomly on either side of nine transects located at the 5,10, 15,…45 foot-locations. Thus the weights are averages of 45 (9x5) sampling units. The herbage was dried, divided into warm-season and cool-season grass-type plants, ground, and analyzed for kjeldahl N content.

Cool- and warm-season vegetation that grew was sampled September 20 the season after the fall prescribed burn. Vegetation was collected from each 15x15-m unburned area and the adjacent burned area. Soil samples were collected from each of the four pairs of 50x50-cm areas located on the different landscapes. Vegetation was sampled along line transects. Herbage was divided into cool- and warm-season grass-like species dried, ground, and total macrokjeldahl N was determined.

Pre-burn vegetation

The most abundant pre-burn species are listed in Table 1 for the plots in the four landscapes studied. Warm-season little bluestem and prairie sand dropseed had the most shoots and the cool-season *Carex* and *Poa* plants had the third and fourth most abundant shoots. The abundance of the individual species were variable in the burned and unburned areas. The sums of the warm- or cool-season species are less variable except for landscape Area 2 where warm-season shoots in the areas to be burned are about half those in the plots not to be burned.

RESULTS AND DISCUSSION

Soils

Differences between the burned and the unburned plot soil content of organic matter and available PO_4-P were significant but not for the content of total N (Table 2). The total N content was correlated with the organic matter content for both the burned (r^2=0.80) and unburned (r^2=0.90) plot soils. The regression coefficients for the two were not significantly different (p=0.05). If the organic matter content is converted to carbon by the 58% conversion factor (Jackson, 1958), the soil C/N ratios are 16.9 and 16.2 for the burned- and un-

Table 1. Average number of shoots per square meter at four study areas for grasses, sedges, forbs, and woody plants in areas to be burned (B) or unburned (U).

		AREAS							
		1		2		3		4	
Plant	**Season#**	**B**	**U**	**B**	**U**	**B**	**U**	**B**	**U**
Scsc*	W	238	498	400	920	840	640	493	435
Sphe	W	310	82	251	250	155	128	493	97
Carex	C	233	379	122	143	273	241	311	210
Poa	C	200	74	8	72	19	23	83	127
Kocr	C	92	59	55	84	19	-	30	7
Stco	C	21	-	2	12	-	-	18	45
Agsu	C	7	15	2	12	-	-	3	-
Bogr	W	15	-	9	-	14	-	56	-
Ange	W	12	-	-	-	47	7	104	134
Spcr	W	2	-	-	-	-	-	-	-
Stvi	C	2	-	-	-	-	-	-	-
Sihy	W	-	-	2	-	9	-	18	23
Bocu	W	-	-	-	-	75	98	96	97
Bohr	W	-	-	-	-	47	45	8	75
Sum of W's	577	580	662	1170	1188	918	843	861	
Sum of C's	550	527	259	323	311	264	445	389	
Sum of forbs	217	336	94	132	169	151	179	67	
Sum of shrubs	42	97	74	310	119	15	38	-	
Sum of pines	17	15	118	213	33	7	13	-	

#W-warm season species. C-cool season species
*Abbreviations derived from first two letters of the genus and the species in order listed: *Schizachyrium scoparium, Sporobolus heterolepis, Carex species, Poa species, Koeleria cristata, Stipa comata, Agropyron subsecundem, Bouteloua gracilis, Andropogon gerardi, Sporobolus cry-tandrus, Stipa veridula, Sitanion hystrix, Bouteloa curtipendula, Bouteloua hirsuta*

Table 2. Mean total N, organic matter, and available PO_4-P contents of the surface 2 cm of soil in plots where vegetation was burned (B) or unburned (U).

Slope aspect	**Sub-plots**	**Total N**		**Organic matter**		**Avail. PO_4-P**	
		B	**U**	**B**	**U**	**B**	**U**
		g kg^{-1}		*g kg^{-1}*		*g kg^{-1}*	
N-NW	W	6.3	5.9	199	179	2.2	2.4
	E	7.1	6.7	188	177	1.6	1.6
South	E	3.9	3.6	102	90	1.5	1.7
	W	4.2	3.4	113	91	2.4	1.6
N-NE	S	7.2	7.2	241	213	3.9	3.1
	N	4.9	4.7	170	125	2.6	1.1
West	S	4.2	4.5	99	116	2.1	1.9
	N	4.1	4.2	113	127	2.0	1.4
	Mean	5.2	5.0	153	140	2.3	1.8
ANOV Significance							
Subplots		$p>0.01$		$p>0.01$		$p>0.10$	
Burn treatment		NS		$p>0.01$		$p>0.05$	
Interactions		NS		NS		NS	

burned-plot soils,respectively. The total soil-N contents were not significantly different for the burned and unburned plots but the means for the burned plots was slightly greater. Nitrogen-organic matter regression coefficients for burned and unburned plot soils were not significantly different. Burning the vegetation did not change the composition of the vegetation but did increase the amount of N and C in the soil. Available P contents were significantly greater for the burned-plot soils than for the unburned ones. Regressions of available P with organic matter for soils from burned and unburned plots explained 32% and 45% of the variation, respectively, in the data and the two regression were not significantly different (p=0.05). Thus, total N and organic matter contents of the 0-2-cm soil layer in the burned treatment plots probably are increased by the addition of small, unburned plant fragments. The available P contents may be increased either by the addition of the fragments or because the fire warmed the soil sufficiently to make P more available.

The percent clay in the soil samples collected at the diagonally located corners of the unburned areas were for the four landscape positions in numerical order 20.5 vs 21.2; 21.8 vs 19.9; 22.3 vs 18.4; and 20.0 vs 22.0. Thus the soil textures were quite uniform across the area and should not be a factor in explaining the differences in soil organic matter, total N, or available P.

Post-burn vegetation

Prescribed burning decreased the growth of warm-season grasses and increased the growth of cool-season species in Areas 1 through 3 but not in Area 4 (Table 3) where fire consumed the dry mulch. Area 4 was on a steep slope with weakly developed soil where little bluestem growth is favored over the growth of cool-season grasses (White, 1971, 1991). Mean yields of warm-season species were significantly greater (p>0.05) for unburned than burned plots (Table 3). Soils in Areas 1, 2, and 3 are more suited for cool- species than in Area 4 and prescribed burning increased their yield but not significantly. Mulch was significantly reduced (p>0.05) by the prescribed burn but the fire did not significantly increase the populations of forbs and shrubs.

Nitrogen content of the herbage.

Herbage for the N analysis was collected from 15x15-m unburned areas and from the adjacent burned areas. The soil samples from the 25x25-cm burned and unburned plots were collected at the two diagonally located corners of the unburned areas. Thus the soil samples were representative of both the burned and unburned plots. Differences in the N content can be attributed to the burn treatment and not to soil differences.

Cool-season herbage had a larger N content than the warm-season herbage (Table 4). The preceding fall-burn treatment decreased the N content of both the warm- and cool-season herbage. However, the soil N contents were not significantly different (Table 2) so the plant and soil N contents are not directly related. The herbage N contents are related directly to the treatments. Burned- and unburned-plot grass herbage (warm plus cool season)

Table 3. Weight of oven-dry live vegetation, and percent composition in burned (B) and unburned (U) areas at the end of the growing season following the fall prescribed burn.

	AREA							
	1		2		3		4	
	B	U	B	U	B	U	B	U
Warm-season grasses and sedge								
Weight kg ha^{-1}	643	887	715	821	556	690	540	734
Composition %	55	70	51	67	47	64	50	49
Cool-season grasses								
Weight kg ha^{-1}	111	57	213	193	174	98	323	532
Composition %	10	5	15	16	15	9	30	36
Forbs								
Weight kg ha^{-1}	209	175	176	93	157	159	191	220
Composition %	18	14	13	8	13	15	18	15
Shrubs								
Weight kg ha^{-1}	200	154	297	126	290	133	32	8
Composition %	17	12	21	10	27	12	3	1
Mulch								
Weight kg ha^{-1}	59	1400	540	1822	4	692	0	1569
Total live vegetation								
Weight kg ha-^{1}	1162	1273	1402	1233	1177	1080	1086	1494

Table 4. Mean total N contents of warm- and cool-season grassy plants where vegetation was burned (B) and unburned (U).

	VEGETATION TYPE				
	Warm season		Cool season		
Area	B	U	B	U	Mean
			g N kg^{-1}		
1	7.6	8.6	7.9	9.9	8.3
2	6.6	7.1	9.7	9.4	8.2
3	6.2	7.6	8.5	10.0	8.1
4	6.0	8.1	8.8	9.8	8.2
Mean	6.6	7.9	8.7	9.8	

Warm and cool season means, 7.2 and 9.2, and B and U means, 7.6 and 8.8, were both significantly different ($p>0.05$). Areas were not significantly different, $p=0.05$.

contained, respectively, 5,890 and 8,304 g N ha^{-1}, and they are significantly different. The unburned plot herbage may contain the N leached during the winter from the standing dead vegetation and mulch (White, 1973a and b).

CONCLUSIONS

The vigorous appearance of vegetation after a prairie fire is likely caused by the reduction in the total weight of herbage, which increases the amount of N, P, and other elements available to this remaining vegetation. Burning did not increase the soil N content but did increase the soil organic matter and available PO_4-P, likely because charred plant fragments were added to the soil. The grass herbage N content, the season after the prescribe burn, was larger in the unburned plots than in the burned ones. Burning volatilized the nitrogen in the herbage so that it was not cycled to the next seasons growth.

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SIMULATED EFFECTS OF ANGLER HARVEST ON AN UNEXPLOITED SOUTH DAKOTA YELLOW PERCH POPULATION

George D. Scholten, Daniel A. Isermann, and David W. Willis
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

ABSTRACT

We evaluated the population characteristics of an unexploited population of yellow perch *(Perca flavescens)* in recently formed Parks Pond, South Dakota. Yellow perch (N = 203) were collected with trap nets immediately prior to spawning in early April 2000. The majority of our sample consisted of male yellow perch (73%). Size structure of female yellow perch [proportional stock density (PSD) = 100] was higher than that of male perch (PSD = 43). Age structure of male fish was skewed toward younger individuals; 79% of males were younger than age 4. Conversely, nearly half of all female yellow perch collected were at least 4 years of age (47%). Maximum age of yellow perch in our sample was 5. Total annual mortality for the entire population based on the catch-curve method was 54%, which represented an estimate of natural mortality in the absence of fishing. Male yellow perch had a higher natural mortality rate (64%) than female perch (27%). Yellow perch in Parks Pond reached 254 mm at 3.5 years of age; female perch reached 254 mm faster (2.8 years) than male perch (4.6 years). Based on predictive modeling, introduction of angler exploitation at rates greater than 35% would likely result in marked reductions (>33%) in the number of 254-mm perch in the population if natural mortality remained constant.

Keywords

Yellow perch, *Perca flavescens,* growth, age structure, exploitation, simulation model

INTRODUCTION

Parks Pond is a privately owned water body in northeastern South Dakota that developed because of unusually high precipitation during the mid- to late 1990s. Because the lake is located entirely on private property, the yellow perch *(Perca flavescens)* population had not been exploited at the time of this study. Thus, this unique situation allowed us to evaluate the characteristics of an unexploited yellow perch population. The objectives of this study were to 1) determine the population characteristics of a newly developed but unexploited yellow perch population, and 2) predict the effects of various levels of angler exploitation on the perch population using a simulation model.

METHODS

Parks Pond, located approximately 5 km south of Holmquist in Day County, has a surface area of approximately 120 ha and a maximum depth of 9.1 m. Yellow perch were collected from the lake by South Dakota Department of Game, Fish and Parks (SDGFP) personnel using trap (i.e., modified fyke) nets during April of 2000, just prior to perch spawning. Thus, we expected the sample to be skewed toward mature adults.

Yellow perch size structure was visually assessed using length-frequency histograms, and quantified using proportional stock density (PSD; Anderson and Neumann 1996). All lengths were recorded as total length (TL). Sagittal otoliths were removed for age determination. Two readers aged whole otoliths under a dissecting microscope; if discrepancies occurred between the two readers, the otolith was viewed again and a final age assigned. Total annual mortality rates were determined from age structure using catch-curve analysis (Ricker 1975). Growth was summarized using mean lengths at age (i.e., time of capture) and the von Bertalanffy (1938) model. Size structure, age structure, mortality, and growth were determined for all fish combined, and individually by sex. To determine the potential effects of angler exploitation on this yellow perch population, we utilized the yield-per-recruit model provided in the Fishery Analyses and Simulation Tools (FAST) software (Slipke and Maceina 2000). We input the total annual mortality rate and the von Bertalanffy growth parameters for Parks Pond yellow perch that were calculated during this study.

RESULTS AND DISCUSSION

Population Structure and Dynamics

Two hundred and three yellow perch were collected in the trap-net sample; 73% of the sample consisted of male perch (Fig. 1). The PSD for females was 100, while PSD for males was 43; these two values were significantly different (X^2 = 53.26, $P<0.001$). However, trap nets were used to collect yellow perch during spawning, males typically mature at a smaller length than females, and males typically have a higher total annual mortality rate than females. Thus, the sampling gear and time likely explain the difference in size structure between sexes (Craig 1987; Carlander 1997). While maximum lengths were similar between the sexes, modal length was 300 mm for females but only 150 mm for males.

Age structure of male fish was skewed toward younger individuals; 79% of males were younger than age 4 (Fig. 2). Conversely, nearly half of all female yellow perch collected were at least 4 years of age (47%). Maximum age of yellow perch in our sample was 5, which likely is due to the young nature of

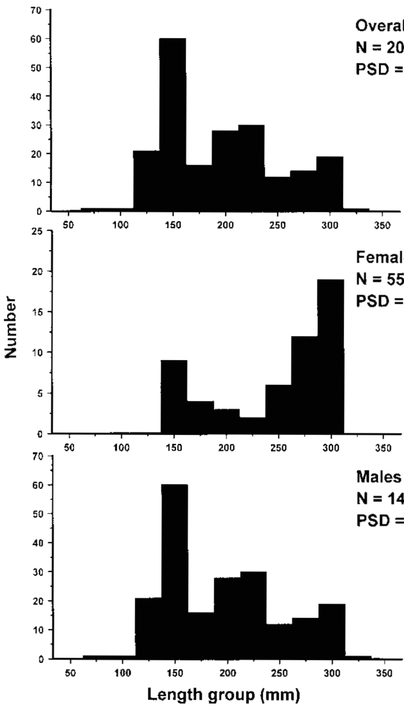

Figure 1. Length frequency of all (top), female (middle) and male (bottom) yellow perch collected with trap nets from Parks Pond, South Dakota, just prior to spawning in April of 2000. PSD = proportional stock density.

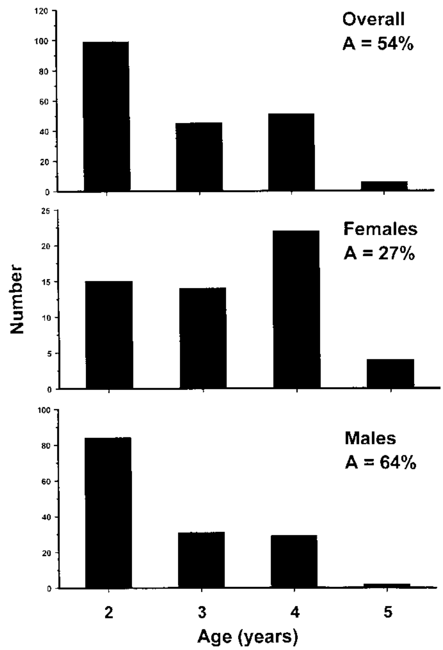

Figure 2. Age structure of all (top), female (middle) and male (bottom) yellow perch collected with trap nets from Parks Pond, South Dakota, just prior to spawning in April of 2000. A = total annual mortality based on a catch curve.

the population in this newly flooded lake. Yellow perch commonly reach age 10 in Michigan, Minnesota, and Wisconsin lakes (Carlander 1997).

Total annual mortality for the overall population sample was 54%; however, mortality for males (64%) was much higher than for females (27%). Because the yellow perch population in Parks Pond was unexploited, total annual mortality was considered an estimate of natural mortality. Yellow perch mortality rate commonly are highly variable, varying among geographic locations and among age groups within a population (Carlander 1997).

Overall growth of yellow perch in Parks Pond was relatively fast (Figure 3). Based on the von Bertalanffy model, yellow perch in Parks Pond reached 254 mm at 3.5 years of age. In a summary of 20 South Dakota yellow perch populations, Willis et al. (1992) found that perch averaged 251 mm at age 5. Female yellow perch reached 254 mm faster (2.8 years) than male perch (4.6 years) in Parks Pond. Mean length at age was significantly higher for female than male yellow perch ($P<0.002$ for all cohorts). Female yellow perch commonly exhibit faster growth and lower mortality rates than males (Craig 1987).

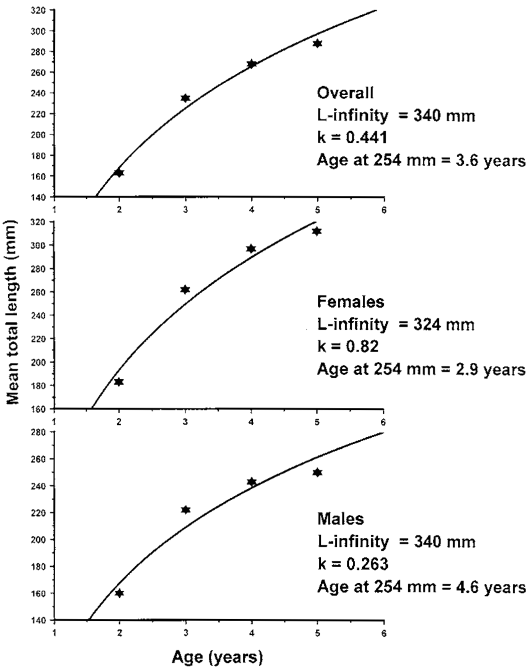

Figure 3. Growth of all (top), female (middle) and male (bottom) yellow perch collected with trap nets from Parks Pond, South Dakota, just prior to spawning in April of 2000. Stars represent observed mean length at age while the lines indicate predicted growth from the von Bertalanffy model. L-infinity = theoretical maximum length; k = growth coefficient.

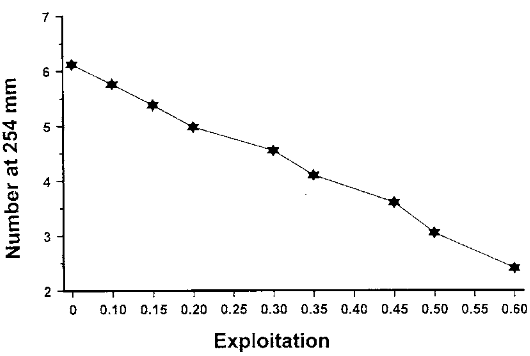

Figure 4. Predicted relative abundance of 254-mm yellow perch at various levels of angler exploitation in Parks Pond, South Dakota, based on simulation modeling. The FAST model predictions are based on a single cohort that begins with 100 age-0 fish. The model then calculates the number of yellow perch still present in the lake when they reach 254 mm in total length, given various levels of exploitation.

Simulated Effects of Exploitation

Based on predictive equilibrium-yield modeling, introduction of angler exploitation at rates of 35% or greater would result in reductions of 33% or more in the relative abundance of 254-mm perch in the population (Figure 4). Because of the fast growth rates exhibited by this population, a moderate number of yellow perch could be harvested while still retaining 254-mm perch in the population. Yellow perch exploitation rates ranged from 2 to 25% in Nebish Lake, Wisconsin, and from 5 to 34% in Escanaba Lake, Wisconsin (Kempinger et al. 1982).

The weaknesses of this prediction are that we are uncertain whether compensatory changes may occur in fish growth or mortality over time. Compensatory changes have been documented (e.g., Allen et al. 1998; Bister 2000), but such occurrences commonly vary by water and often cannot be predicted. Regardless, the model does allow insights into potential population structure changes at various levels of exploitation.

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REACTIONS OF HCCl WITH NO_x

Nichole M. Miller
Chemistry Department
Augustana College
Sioux Falls, SD 57197

John F. Hershberger and Mark Erickson
Chemistry Department
North Dakota State University
Fargo, ND 58105

INTRODUCTION

The combustion chemistry of chlorine containing compounds is of interest in both fossil-fuel combustion and hazardous waste incineration technology. Modeling these processes requires fundamental kinetic data on elementary radical-molecule reactions. We report here product channel measurements on reactions of HCCI with NO and NO_2 using eximer laser photolysis and infrared laser absorption spectroscopy.

METHODS

A vacuum system with a series of mirrors to bend the laser light, as in figure 1, was used to perform the reaction. A detector for the both the reaction and reference cells were attached to a oscilloscope which was connected to the computer in turn. The pressure of the reactant gasses was varied in order to find the optimal pressure ratio (Fig. 2). The various hypothesized reactions were as follows:

$$HCClBr_2 + h\nu(193\text{ nm}) \rightarrow HCCl + 2\,Br$$

$$HCCl + NO_2 \rightarrow HCN + ClO_2$$

$$\rightarrow CO + HCl + NO$$

$$\rightarrow NCO + HClO$$

$$\rightarrow HCNO + ClO$$

Secondary Reactions

$$NCO + NO_2 \rightarrow N_2O + CO_2$$

$$\rightarrow 2NO + CO$$

$$HCClBr_2 + h\nu(193\ nm)\ HCCl + 2\ Br$$

$$HCCl + NO \rightarrow HCNO + Cl$$

$$\rightarrow HCl + NCO$$

$$\rightarrow HCN + ClO$$

$$\rightarrow HNCl + CO$$

Secondary Reactions

$$NCO + NO \rightarrow CO_2 + N_2$$

$$\rightarrow CO + N_2O$$

The products were detected by means of rotational infrared spectra. The reactants were excited by an eximer laser at 193 nm and the products were detected using a transient signal (Fig. 3) collected with the oscilloscope. The products detected were as follows:

For reaction with NO_2:

$$N_2O\ (00^00, J=22) + h\nu(2241.117\ cm^{-1}) \rightarrow N_2O\ (00^01, J=23)$$

For reaction with NO:

$$N_2O\ (00^00, J=4) + h\nu(2227.843\ cm^{-1}) \rightarrow N_2O\ (00^10, J=5)$$

$$CO_2\ (00^00, J=6) + h\nu(2354.434\ cm^{-1}) \rightarrow CO_2\ (00^01, J=7)$$

$$HCNO\ (0000^00^0, J=14) + h\nu(2184.608\ cm^{-1}) \rightarrow HCNO\ (0100^00^0, J=13)$$

RESULTS

In comparing the differences in the intensity of the resonance and off resonance transient signals the branching fraction (ϕ) of each reaction. The HCCl + NO_2 reaction produced the NCO with ϕ=0.0336. The HCCl + NO reaction produced NCO with ϕ=0.239 and HCNO with ϕ=0.70.

CONCLUSION

The reactions behaved very similarly, as predicted, with NO working better than NO_2. The NO reaction produced the predicted products in greater amounts. This was determined to be due to the fact that NO_2 absorbs light more readily. Therefore there were not as many radicals formed to react with the NO_2. HCNO was thought to be the primary product channel of the reactions and proved to be in the reaction with NO. It was assumed that this would be found true for the reaction with NO_2 as well.

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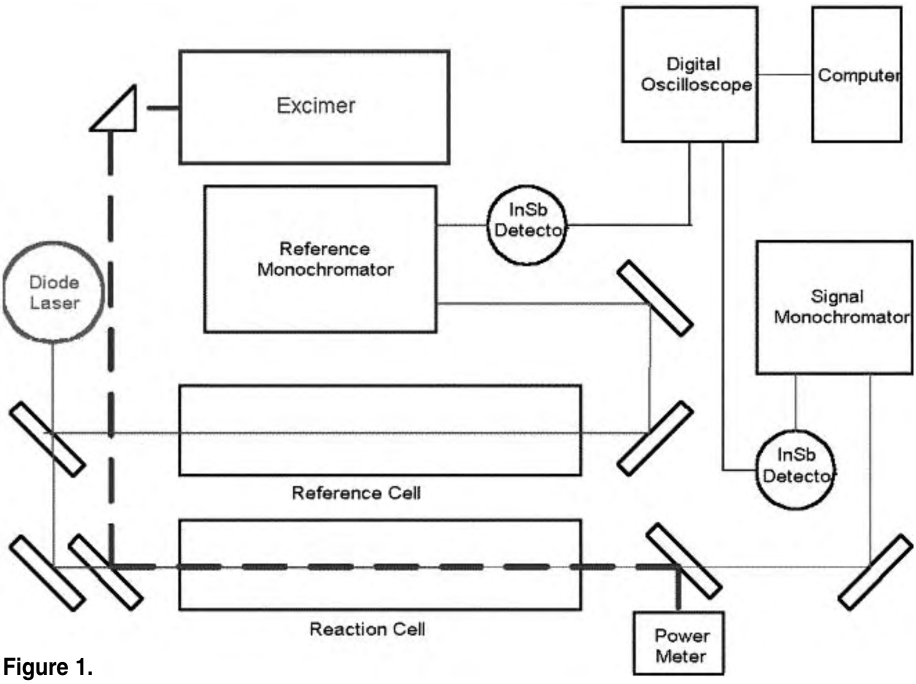

Figure 1.

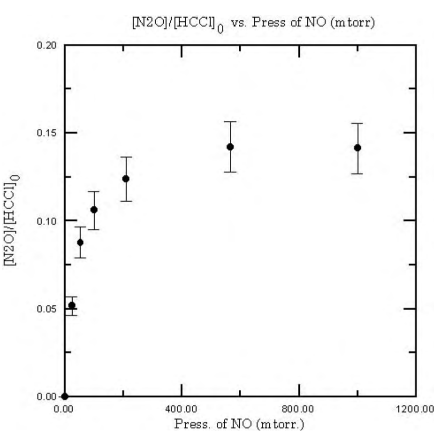

Figure 2.

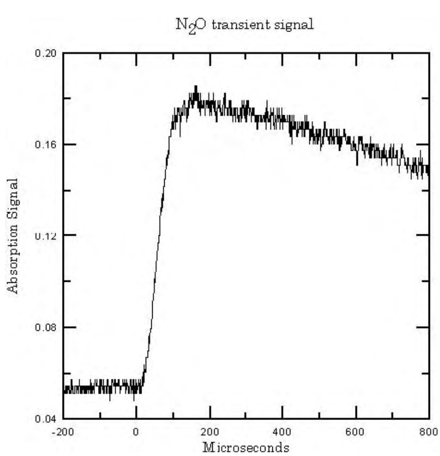

Figure 3.

PERFORMANCE OF SUNSHINE BASS *MORONE CHRYSOPS* (RAFINESQUE) x *M. SAXATILIS* (WALBAUM) INTENSIVELY REARED AT THREE DENSITIES

Michael L. Brown
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

John R. Ackerson
Missouri Department of Conservation
Aurora, MO 65605

Robert J. Mauk
Texas Parks and Wildlife Department
Wichita Falls, TX 76301

ABSTRACT

A controlled experiment was conducted to evaluate the effect of stocking density on various performance characteristics (*i.e.,* relative growth, feed conversion, survival, and relative weight [*Wr*]) of sunshine bass *Morone chrysops* (Rafinesque) x striped bass *M. saxatilis* (Walbaum) fingerlings. Sunshine bass (4.2 ± 0.3 g SE) were stocked at low (45 fish/m^3), medium (136 fish/m^3), and high (273 fish/m^3) replicated densities in a recirculating aquaculture system (RAS) and fed a commercial hybrid striped bass diet for 14 weeks. Cumulative relative growth was significantly ($P < 0.05$) higher for the medium density treatment at the conclusion of the experiment. The medium density treatment had the highest overall mortality (22%) due to loss of one replicate to a water flow problem, thus mortality was not attributed to density. Mortality in the high and low density treatments were 9% and 0%, respectively. Feed conversion varied considerably among densities throughout the experiment, but differed significantly for all densities during the final three weeks of the feeding trial and was lowest for the high density treatment. Final mean *Wr* values did not differ among treatments. Ammonia levels differed among treatments and increased proportionally with density during the experiment. Density index calculations for 170-mm sunshine bass in our RAS ranged from 0.8 to 0.14 (8.8 kg/m^3 to 14.9 kg/m^3). These results indicate that intensively reared sunshine bass can be successfully grown well into the phase II stage at a density index near 0.1.

INTRODUCTION

The hybrids of striped bass *Morone saxatilis* and white bass *M. chrysops* have been of considerable interest to both fishery biologists and fish culturists since the first crosses were produced in the mid-1960s (Bayless 1968; Bishop 1968). Currently, fish culturists prefer to produce reciprocal hybrids (sunshine bass, white bass female x striped bass male) because white bass females are more readily available than are striped bass females and easier to spawn (Kerby and Harrell 1990). Hybrid striped bass have gained wide acceptance as a sportfish, particularly in the southeast United States where, in large reservoirs, much of the prey base is commonly composed of gizzard *Dorosoma cepedianum* and/or threadfin shad *D. petenense.* Regulated reduction in commercial striped bass harvests, due to declining natural stocks on both the Atlantic and Pacific coasts of the continental United States, has promoted the development of commercial hybrid striped bass production for the food fish market. This economic aspect, coupled with the heterotic attributes of the hybrid striped bass, give them great potential as aquaculture food fish and as inland sport fish (Ware 1975; Williams et al. 1981; Kerby et al. 1983).

Recent advances in hybrid striped bass culture have been made primarily in the areas of controlled propagation, nutrition, and pond culture; however, the culture characteristics of hybrid striped bass reared under intensive conditions are relatively unknown. Specific densities and related culture parameters must be known to maximize growth and minimize size variation of hybrid striped bass to facilitate economic optimization of production. Piper et al. (1982) stressed that density is important economically to maintain carrying capacity. Many fish culturists use lower stocking densities to increase quality of fish and as fish size increases, proportionally decrease fish density (Piper et al. 1982). Fish density can influence a variety of culture factors including growth, survival, and behaviors such as cannibalism and the establishment of feeding hierarchies. Also, as density increases, water quality decreases which in turn affects survival, growth, and the physical condition of fishes (Nicholson et al. 1990). The objective of this study, therefore, was to investigate performance characteristics (e.g., relative growth, feed conversion, and survival) of juvenile sunshine bass held at various densities from phase I to phase II under intensive culture conditions.

METHODS AND MATERIALS

The intensive culture system consisted of 24 110-L aquaria connected to a closed freshwater recirculating system with a delivery rate of approximately 1-L min^{-1} and a turnover rate of 13 times/d. Water quality complied with standards suggested for striped bass and hybrid culture (Bonn et al. 1976; Lewis and Heidinger 1981; Rogers et al. 1982; Nicholson et al. 1990). Water temperature was maintained at 21 oC (± 0.1 SE) and dissolved oxygen was maintained near saturation by supplemental aeration; both were monitored several times weekly with a YSI 54 temperature and oxygen meter (YSI, Yellowsprings, OH).

A light:dark cycle of 12:12 h was maintained using incandescent lighting controlled by an automatic electric timer.

Fingerling sunshine bass (4.2 g ± 0.3 SE) obtained from Southern Illinois University (Carbondale) were randomly stocked at low (45 fish/m^3; 0.25 kg/m^3) medium (136 fish/m^3; 0.47 kg/m^3), and high (273 fish/m^3; 1.02 kg/m^3) densities with four replicates for each treatment. All fish were conditioned to the recirculating system and fed for one week prior to beginning the experiment. Aquaria were cleaned and mortalities removed and documented daily through the duration of the study. Weekly backflushing of the sand filter and cleaning of the biological filter (solids removal) were done to maintain favorable water quality. Dechlorinated water was added to compensate for the loss of water due to cleaning.

Initially, weights (± 0.1 g) were obtained for individuals in each tank. At the end of each week, total tank weight and average individual fish weight were recorded. Additionally, individual fish weights were measured weekly for all fish in the low density treatment and 10 randomly selected fish from each replicate of the medium and high density treatments. Fish were not fed for a 12-h period prior to the weigh period.

Feeding frequency was done by hand three times per day until the seventh week when belt feeders were incorporated in the experiment, then feeding occurred continuously over the 12-h day period. Feed used was a commercial hybrid striped bass diet (38% protein, 5% lipid; Southern States, Farmville, NC). Sunshine bass were fed at levels nearing satiation by feeding 10% of total body weight for weeks 1 to 3, 7.5% for weeks 4 to 8, and reduced to 5% for weeks 9 to 14; rations were adjusted weekly. Feed size was fingerling crumble #4 for weeks 1-8 and 3 mm extruded pellets for weeks 9-14.

Several water quality parameters were monitored each week either for each treatment or the biological filter. Carbon dioxide, total alkalinity, and total hardness levels were determined by titrametric methods (Hach Company, Loveland, CO) with samples from the biological filter. Total ammonia (NH_3-N), nitrite (NO_2-N), and nitrate (NO_3-N) concentrations in treatment tanks were measured at least weekly using a Hach 2000 spectrophotometer, and pH with an Orion pocket tester.

Each week of the experiment, cumulative (final weight - initial weight/initial weight x 100) and incremental (week ending weight - previous week weight/previous week weight x 100) relative growth, and feed conversion (weight of feed offered/weight gain) were determined. Overall mortality (%) for each treatment and individual relative weight *(Wr)* values were determined at the conclusion of experiment. Relative weight was calculated as $Wr = W/Ws \times 100$ where W is the actual weight (g) of an individual fish and Ws is a length-specific standard weight defined by the equation $\log_{10} Ws = -5.201 + 3.139 \log_{10}$ total length (mm) (Brown and Murphy 1991). Comparisons of feed conversion, cumulative relative growth, and incremental relative growth among treatments were done with analysis of variance and Tukey's multiple comparison tests using SYSTAT (1996). Statistical significance was $P \leq 0.05$ for all analyses.

RESULTS AND DISCUSSION

Growth pattern differences among treatments began to emerge during the second week of the study (Fig. 1). From week two through week seven cumulative relative growth for the low density treatment was significantly lower. By week eight, all treatments were significantly different with highest cumulative relative growth occurring in the medium density treatment followed by high and low treatments. Throughout the final five weeks of the study fish held at the medium density exhibited significantly higher cumulative relative growth than did fish held at low and high densities. Trends in incremental relative growth were similar among treatments (Fig. 1). The most dissimilar values were observed during the first month of the study; beyond week five there were no significant differences in incremental relative growth among treatments. Overall, sunshine bass held at the medium density produced the largest proportional weight gain by the end of the study. Similarly, Stickney et al. (1972) reared channel catfish *Ictalurus punctatus* fingerlings to three densities (8, 16, 24 kg/m^3) under intensive conditions and found the best growth occurred at the lowest density. A comparable rearing density was indicated in this study with an ending density of 8.8 kg/m^3, which corresponds to the medium density.

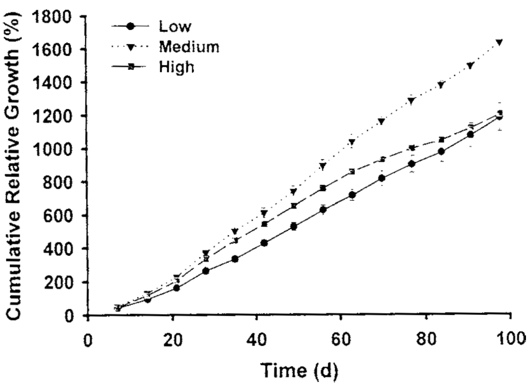

Figure 1. Cumulative relative (%) for low (45 fish/m^3), medium (136 fish/m^3), and high (273 fish/m^3) densities of sunshine bass. Vertical bars represent one standard error of the mean.

Piper (1975) proposed the density index as a guideline to determining maximum rearing densities for safe fish production in flow-through raceway systems. These indices relate fish density to fish length and are the proportion of the fish length used in determining kilograms of fish to be held per cubic meter of rearing space. Piper et al. (1982) reported that striped bass larger than 50-mm could be safely reared with a density index of 0.5, which follows the general procedures of trout culture. However, under intense recirculating conditions densities are likely to be substantially reduced depending upon the efficiency of biological and mechanical filtration. Our index calculations indicate that 170-mm sunshine bass can be reared from 8.8 kg/m^3 (medium density index = 0.08) up to 14.85 kg/m^3 (high density index = 0.14). Generally, it appears that sunshine bass can be intensively reared well into the phase II stage at a density index near 0.1 and maintain good growth.

Feed conversion (Fig. 2) differed little among treatments until week 11 of the study. During weeks 11 through 14 the high density treatment showed significantly poorer feed conversion than low and medium treatments. Similarly, Stickney et al. (1972) found that a high channel catfish density (24 kg/m³) produced the poorest feed conversion rate. Feed conversion was observed to decrease across all treatment when we switched to continuous belt feeding, as compared to three feeding periods separated by 4-h intervals during the early portion of the study.

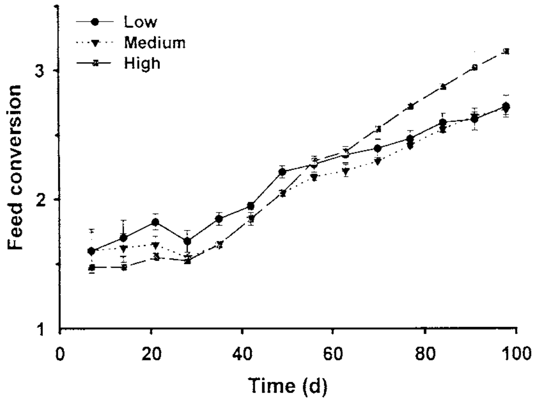

Figure 2. Feed conversion for low (45 fish/m³), medium (136 fish/m³), and high (273 fish/m³) densities of sunshine bass. Vertical bars represent one standard error of the mean.

To determine whether feeding hierarchies might have been established within tanks we examined the variability in individual weights over time (Fig. 3). Plots of weight standard errors for the three treatments indicated that by the conclusion of the study there were distinct differences that inversely corresponded with densities. For commercial producers maintaining size uniformity is an important processing and marketing aspect. Thus, selection of a culture density to achieve good growth should be balanced with a density likely to provide a fairly uniform fish size.

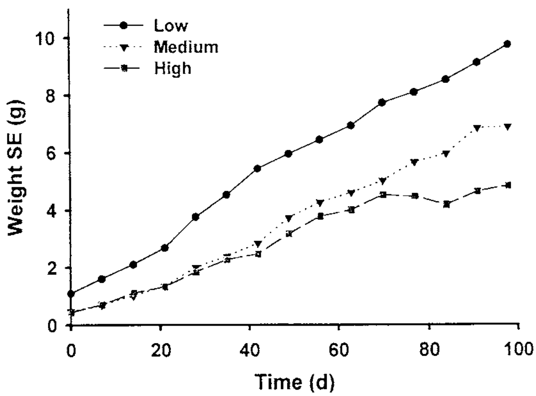

Figure 3. Mean weight standard errors (SE) for low (45 fish/m³), medium (136 fish/m³), and high (273 fish/m³) densities of sunshine bass.

With the exception of ammonia, all monitored water chemistry was acceptable for the culture of hybrid striped bass (Nicholson et. al 1990). Mean total hardness, total alkalinity, and carbon dioxide were 377.5 ppm (SE=10.7), 154.1 ppm (SE=4.6), and 26.2 ppm (SE=2.1), respectively, measured in the biological filter. Temperature and nitrate levels did not vary significantly among treatments. Striped bass have been shown to tolerate nitrate levels up to 800 ppm (Bonn et al. 1976). Nitrite concentrations increased linearly with density, but never approached a toxic level. Dissolved oxygen levels were equivalent between low (7.3 ppm, SE = 0.4) and medium (7.3 ppm, SE = 0.4) density treatments, but slightly lower (6.8, SE = 0.4) in the high density treatment. The pH remained relatively constant, between 7.7 and 7.8, across treatments for the duration of the study.

Relative total ammonia (treatment concentration — biological filter concentration) levels for each treatment are shown in Figure 4. These measurements were done in the afternoon for the duration of the experiment and prior to the last feeding through week six. Ammonia concentrations for the low density treatment deviated little from baseline levels and occasionally were lower than those determined in the biological filter. Generally, concentrations determined for the medium density treatment remained above the baseline level. Ammonia concentrations in the high density treatment were sporadically well above baseline levels; those measurements were associated with feeding and observed to decrease shortly thereafter. Unionized ammonia concentrations in the high density treatment were not determined to be potentially toxic, rarely exceeding 0.011 ppm as NH_3.

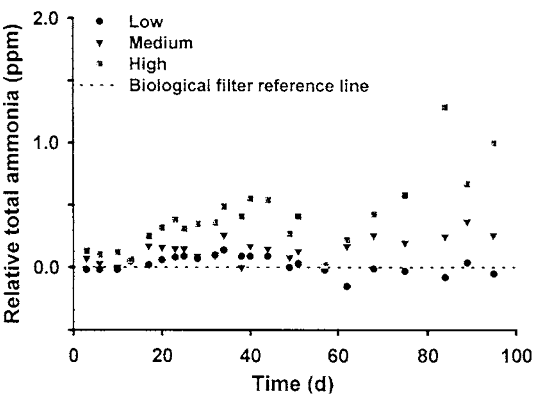

Figure 4. Total ammonia concentrations (mg/L), relative to the biological filter, for low (45 fish/m³), medium (136 fish/m³), and high (273 fish/m³) densities of sunshine bass.

Although the acute ammonia toxicity level is not known for juvenile hybrid striped bass, the 96-h LC_{50} values for NH_4OH in juvenile striped bass range from 1.5 to 2.8 ppm (Lewis et al. 1981). Bonn et al. (1976) recommended maintaining total ammonia concentrations below 0.6 ppm because chronic exposure to unionized ammonia commonly predisposes fish to disease (e.g., Piper et al. 1982; Soderberg 1994). There were no overt symptoms detected in this study; yet, gill epithelial surfaces were not examined. Reduced growth and lower feed conversions of fish contained in the high density treatment may be symptoms of excessive ammonia. For example, reduced growth has been observed in juvenile channel catfish and rainbow trout *Oncorhynchus mykiss* at unionized ammonia concentrations exceeding 0.12 (Robinette 1976) and 0.017 (Larmoyeaux and Piper 1973) ppm, respectively.

Overall, the highest mortality (22%) occurred in the medium density treatment followed by the high (9%) and low (0%) density treatments. However, the mortality in the medium density treatment resulted from of a water-flow restriction on one tank. Otherwise, mortality was 0% for the medium treatment because we did not directly attribute that loss to density.

Final mean *Wr* values for ranged from 92 to 94 and did not differ among treatments. The experimental fish were considered to be in good condition considering that a *Wr* value of 100 would be the 75th percentile of standard weights for hybrid striped bass.

In conclusion, these results show that a moderate stocking density of 136 fish/m^3 at 0.47 kg/m^3 provided satisfactory performance up to 8.8 kg/m^3 under these intensive culture conditions. Further research with densities in closed recirculating systems is necessary to precisely bracket the maximum density of sunshine bass fingerlings for optimal performance and also sizes at which densities should be altered.

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EFFECTS OF UN-IONIZED AMMONIA ON *HYDROPSYCHE MOROSA* HAGEN LARVA NET AND RETREAT CONSTRUCTION

Alethea Caraway and Nels H. Troelstrup, Jr.
Department of Biology and Microbiology
South Dakota State University
Brookings, SD 57007

ABSTRACT

The objectives of this study were to (1) describe natural variability in retreat and net mesh dimensions and retreat and net tending behavior for the hydropsychid caddisfly *Hydropsyche morosa* Hagen and (2) perform laboratory experiments to determine the influence of un-ionized ammonia on *H. morosa* retreat and net construction. *H. morosa* were collected from fifteen streams in eastern South Dakota and head capsules, nets, and retreats were photographed and measured. Caddis were exposed to 0.00, 0.025, 0.05 and 0.1 mg/L un-ionized ammonia for 48 and 96 hours within experimental stream chambers. Data indicate that exposing caddis to un-ionized ammonia caused them to change their net/retreat construction and tending behavior. Net mesh variability increased 123% in 0.025mg/L and 227% in 0.05 mg/L treatments relative to controls. Net and retreat dimensions in experimental streams also demonstrated significantly greater variability when compared to nets collected from reference streams, indicating a container effect. Behavior in treated chambers was slower and more lethargic when compared to control chambers. Results suggest that un-ionized ammonia influences *H. morosa's* construction abilities and behavior, most notably in net mesh and retreat dimension variability.

INTRODUCTION

Water quality issues are a global concern and vary regionally depending on rainfall, climate, geography, and local human activities (Hynes 1970). Traditional water quality assessment methods have focused on chemical and physical characteristics of water. However, many degraded lakes and streams have eluded detection due to a lack of spatial and temporal integration of abiotic monitoring data. Biological monitoring offers an additional, integrative suite of tools for detecting degraded aquatic systems (Rosenberg and Resh 1993). Most current biological monitoring methods focus on community structure rather than individual organisms. New methods are needed to address whole organism effects from habitat alteration and water pollution (Barbour et al. 1999). Petersen and Petersen (1983) suggest "changes at the level of individual species can be more useful than community changes since (1) a species response occurs before a community response and thus provides a form of environmental early warning and (2) the toxicant can be determined by bioassays on the responding species." These new methodologies would allow detection of disturbance effects prior to major shifts in community structure.

Net building members of the caddisfly family Hydropsychidae are very widespread and abundant (Wiggins 1977). Net spinning caddis larvae are classified as filter feeders and employ many different strategies to capture seston particles within their nets. Net mesh size is often influenced by water velocity and diatom concentration (Alstad 1987). Disturbances also influence net mesh size and construction. Petersen and Petersen (1983) found that heavy metals caused higher numbers of anomalies, specifically crosslinks, in nets built by Hydropsychids.

Un-ionized ammonia (NH_3) is listed as a pollutant of concern in 10 of 14 major South Dakota watersheds, including the Big Sioux watershed, which contains streams sampled for this study (South Dakota Department of Environment and Natural Resources 2000). South Dakota has approximately 9,937 river miles, of which 546 (of the monitored miles) have experienced minor to moderate degradation from un-ionized ammonia. Lakes have also been impacted. In South Dakota 800 lakes (<5000 acres in size) have experienced minor to moderate impact from un-ionized ammonia (South Dakota Department of Environment and Natural Resources 1994).

The objectives of this study were to (1) describe the natural variability in retreat dimensions, net mesh dimensions, and retreat and net tending behavior for the hydropsychid caddisfly *Hydropsyche morosa* Hagen and (2) determine the influence of un-ionized ammonia on *H. morosa* retreat and net mesh dimensions and behaviors. We hypothesized that treatments with elevated un-ionized ammonia would result in altered retreat/net dimensions and impaired retreat/net-tending behavior relative to controls.

MATERIALS AND METHODS

Over 150 stream sites were screened for caddisflies between the dates of April 24, 2000 and July 4, 2000. All stream sites were located in the Northern Glaciated Plains ecoregion. Caddis larvae were hand collected, identified and recorded. Those 15 sites containing the most *H. morosa* were used as collection points for laboratory experiments and those ten sites containing the most *H. morosa* were also sampled as reference streams to provide baseline measurements of head capsule, retreat length and width and net mesh sizes (Table 1).

Ten *H. morosa*, along with their nets and retreats were collected from each of the ten reference streams. Visual identification by head capsule pattern (Fig. 1) was used to select *H. morosa* (Schefter and Wiggins 1986). The selected caddis, nets and retreats were collected from various parts of the stream riffle and placed into plastic containers for observations. Visual observations of net/retreat interactions and duration of interactions were made for fifteen minutes. Collected caddis larvae, nets and retreats were then transported live

Table 1. Original fifteen sample sites, corresponding counties, and geographic locations.

Sample Site	County	Lat & Long		Site Use
Bachelor Creek reach 1	Moody	N43 55.57	W96 43.70	Reference & Experiments
Bachelor Creek reach 4	Moody	N43 57.88	W96 50.91	Experiments
Brookfield Creek	Moody	N43 53.76	W96 38.87	Reference & Experiments
Big Sioux trib A	Brookings	N44 23.90	W96 47.17	Experiments
Deer Creek	Brookings	N44 20.13	W96 41.27	Reference & Experiments
Deer Creek trib A	Brookings	N44 21.83	W96 36.45	Reference & Experiments
Deer Creek trib B	Brookings	N44 23.02	W96 30.79	Reference & Experiments
Hidewood Creek A	Hamlin	N44 36.71	W96 54.34	Reference & Experiments
Hidewood Creek B	Deuel	N44 42.20	W96 45.25	Reference & Experiments
Medary Creek trib A	Brookings	N44 19.84	W96 36.41	Not used - dry
Medary Creek trib B	Brookings	N44 17.32	W96 35.26	Reference & Experiments
Medary Creek trib C	Brookings	N44 17.57	W96 34.04	Reference & Experiments
Six Mile Creek	Brookings	N44 25.66	W96 41.23	Reference & Experiments
Spring Creek	Moody	N44 5.99	W96 36.46	Experiments

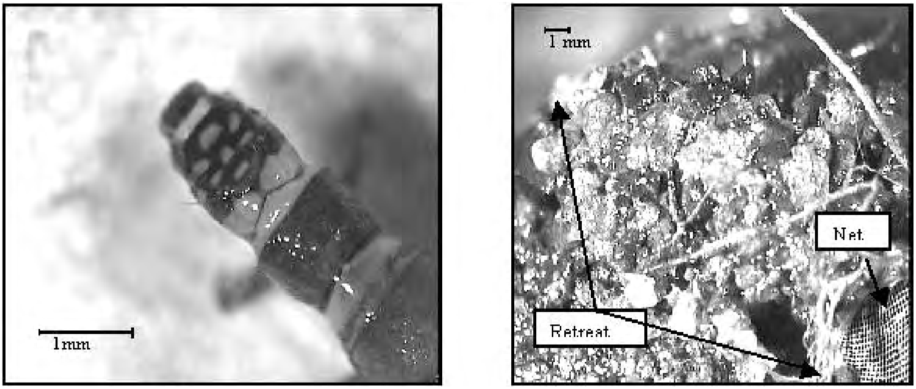

Figure 1. ***H. morosa*** **head capsule (dorsal view) (a) and retreat with net (b) collected from Hidewood Creek, Hamlin County, South Dakota.**

to the South Dakota State Environmental Biology laboratory for microscopic measurement.

Each head capsule, net and retreat were individually photographed and saved to disk with a code number linking every caddis with its net and retreat. Head capsules and nets were photographed at a power of 25x and retreats at a power of 7x. A stage micrometer was also photographed at 25x and 7x to facilitate measurement calibration. Head capsules were measured from eye to eye and retreats were measured at the widest and longest points. Net photograph threshold was adjusted to 200 to give a black and white appearance. Ten random cells were selected using a random numbers table; all other cells and background materials were erased. Measurements (height, width, and area) from the randomly selected cells were saved in text files by clicking the "filter": "measure": "features" option within Adobe Photoshop 5.5. All photos were measured in pixels and data were entered into an Excel spreadsheet and converted into millimeters using the calibration from stage micrometers.

Nine treatment chambers (38 L capacity) made of 6.35mm gray plastic and measuring 1.0 m long, 30 cm wide and 30 cm deep were used in experimental trials. Treatments were assigned at random within three blocks. This arrangement allowed for differentiation of treatment effects from potential laboratory gradients. Maxi-Jet PH Aquarium Pumps (model MP900, 0.242 L/sec.) were attached to each chamber. Ceramic floor tiles (3.5"x3.5") nestled in a minimal amount (approximately two handfuls) of gravel were used as substrate. Chambers were filled with 10 L of tap water and pumps were allowed to circulate at least 24 hours before introduction of the caddisflies.

Ten to twenty *H. morosa*, their nets, and retreats were collected from each reference stream site. Observations on net and retreat interactions (duration and frequency) were performed for fifteen minutes and recorded to the nearest second. Collected caddis were transported back to the lab in a glass aquarium. Larvae were randomly placed into each chamber and a slow drip of Kaytee Forti-Diet rabbit food (slurry concentration 5g/L) was introduced. Caddis were then left overnight and allowed to acclimate to the artificial stream channels.

Un-ionized ammonia treatment doses were set to bracket the South Dakota water quality standard streams supporting warmwater marginal fish life propagation (0.05 mg/L) (State of South Dakota 1999). Target treatment levels for experiment one were 0.050 mg/L (low) and 0.10 mg/L (high). Because of high mortality in experiment one, target concentrations for experiment two were reduced to 0.025 mg/L (low) and 0.050 mg/L (high). Chambers were dosed with NH_4CO_3 to reach target un-ionized ammonia concentrations. Dosage amounts were based upon water temperature and pH of the water source. Water temperature and pH were taken immediately after placing the caddis into chambers and the following day before treatments began.

All nets and retreats were destroyed prior to dosing. Pulse treatments were imposed by introducing the calculated amount of ammonium carbonate into the water stream of each channel. Water temperatures, pH and ammonia/un-ionized values were then taken immediately after dosing, one, two, and four hours after dosing. Morning and afternoon readings were taken for 72 hours following treatment. All ammonia measurements were made using a Hach field spectrophotometer following the Hach salicylate method #10031 (Hach 1997).

Chambers were observed once per day for fifteen minutes each. Net and retreat interactions and duration of interactions were recorded. Only those caddis, nets, and retreats that could be seen without disturbing the substrate or tiles were observed. No tiles were moved in order to keep all nets and retreats intact.

Half of the caddis, nets, and retreats within view in each chamber were removed forty-eight hours after treatment, representing an acute exposure. All were photographed, measured and recorded (as described above). If no retreats or nets were present half of the caddisflies were still removed and recorded as having no retreats/nets built. Following exposure for 96 hours (chronic exposure), the remaining caddis were removed with all nets and retreats. Pumps were shut off and the numbers of live, dead and pupating caddis were recorded. Chambers and tiles were triple washed with tap water. Used gravel was discarded and new gravel was collected and triple rinsed. Pumps were disassembled, cleaned and allowed to cycle new water for 24 hours. Chambers were then replaced in the rack following the random assignments. Each chamber was designated the same treatment level (control, low and high) for both experiments.

All data were entered onto Excel spreadsheets and imported into Statistix (Analytical Software 1994). Box and whisker plots were generated for all reference stream data. One-way analysis of variance (ANOVA) was used to evaluate experimental treatment differences after examination of treatment data indicated no significant block effects. Bartlett's Test was used to evaluate equality of variance among treatments. Those data displaying unequal variance by treatment were analyzed using the non-parametric Kruskal Wallace test (KW ANOVA).

RESULTS

Stream Observations

Head capsule data collected from reference streams demonstrated that all caddis collected were roughly the same size. Head capsule measurements fell between the intervals of 1.03mm and 1.31mm with one measurement falling outside this range, 0.81mm. Closer visual inspection of this specimen confirmed that it was an early instar *H. morosa*. Those caddis larvae used in experimental chambers had smaller head capsules than those observed from reference streams (KW ANOVA $p<0.01$). Average head capsule width taken from stream caddis larvae was 1.15 mm while that from experiment larvae averaged 1.06 mm.

While the average mesh area varied between reference streams, differences were not considerable. The majority of cells measured had an area within the range 0.05 to 0.20 mm^2 with the mean area of all sites being 0.11 mm^2. Only four of the 100 cells were determined to be outliers. The width of all retreats collected from reference streams fell between 5.50 mm and 11.50 mm. There were only two probable outliers measured from Deer Trib B and Hidewood B. These fell just over the 11mm mark. Average retreat width was very similar between all streams, ranging from about 7.54 mm to 9.25 mm. The overall average retreat width was 8.40 mm. In contrast, retreat length varied from 10.50 mm to 18.38 mm, with a mean of 14.62 mm. Average stream retreat lengths ranged from 13.15 mm to 15.40 mm.

Experiment Behavior Observations

Due to high mortality in the treatment chambers very few net/retreat interactions were observed (Table 2). Movements were observed to be very slow

Table 2. Observations from experimental chambers showing the number of nets/retreats and net/retreat interactions observed in each chamber and the number of *H. morosa* found dead and pupating after each experiment was completed.

Treatment	Total Number	#Alive	# Dead/ Pupating	#Net/ Retreat	#Net/Retreat Interactions
Control 1	30	8	17/5	1/7	0/0
Control 2	30	14	10/6	1/7	1/1
Control 3	30	7	17/6	5/7	2/2
(0.025mg/L)	20	5	4/11	1/5	0/0
(0.025mg/L)	20	6	6/8	3/6	0/1
(0.025mg/L)	20	4	7/9	1/5	0/0
(0.05 mg/L)	30	7	15/8	5/6	0/0
(0.05 mg/L)	30	9	12/9	1/6	1/1
(0.05 mg/L)	30	6	13/11	0/3	0/0
(0.1 mg/L)	10	1	5/4	0/1	0/0
(0.1 mg/L)	10	2	7/1	0/0	0/0
(0.1 mg/L)	10	1	8/1	0/0	0/0

and sluggish in the channels dosed with ammonium carbonate, but those in control channels seemed normal (compared to reference stream observations). A large number of caddis were observed trying to drift or move in treated stream channels, presumably to avoid the un-ionized ammonia. Thus, many larvae were found in the pumps, accounting for some of the mortality in the treatment chambers.

Morphometric Observations in Channels

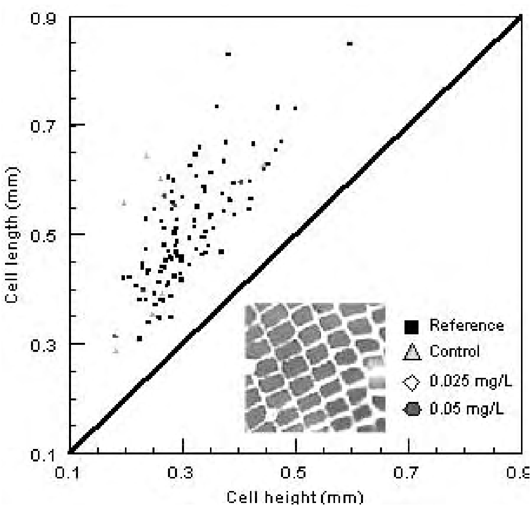

Figure 2. The relationship between cell length and height suggests that cells are not square in shape but more rectangular. No obvious treatment effects can be seen as the treatment measurements fall throughout the reference measurements.

Net mesh was found to be rectangular in shape (Fig. 2) and average mesh area did not appear to differ significantly among ammonia treatment groups (ANOVA, p=0.45). Mean mesh area for stream larvae and high treatment larvae were almost identical (0.11mm^2 and 0.12mm^2, respectively) while mean mesh area for control and low treatment nets was slightly lower (0.08mm^2 and 0.09mm^2 , respectively). The highest mesh area value was measured from reference stream larvae

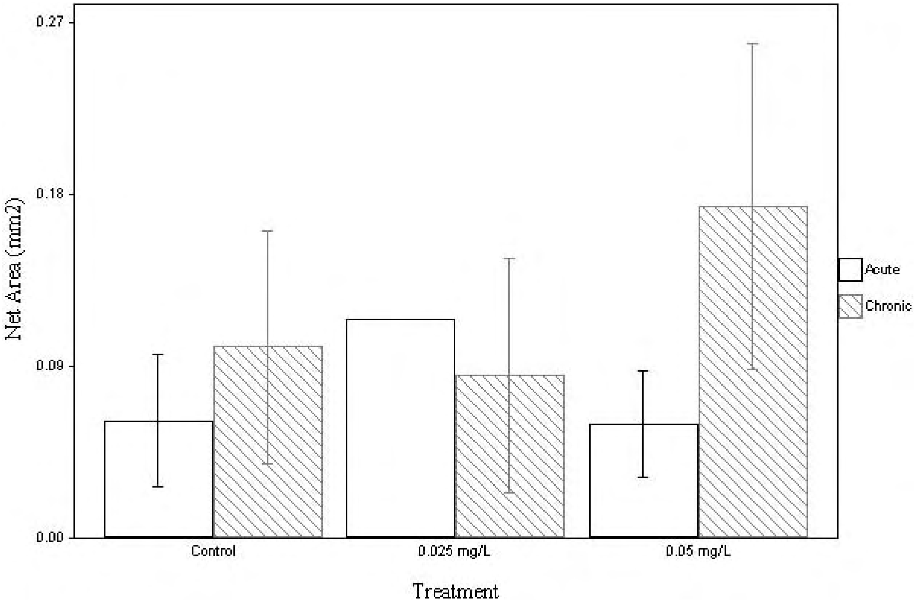

Figure 3. The average net mesh area from experimental streams broken out by exposure time to un-ionized ammonia. Acute exposure being 48 hours and chronic exposure equal to 96 hours in the treatment chamber. High mortality eliminated replicate larvae within the 0.025 mg/L treatment.

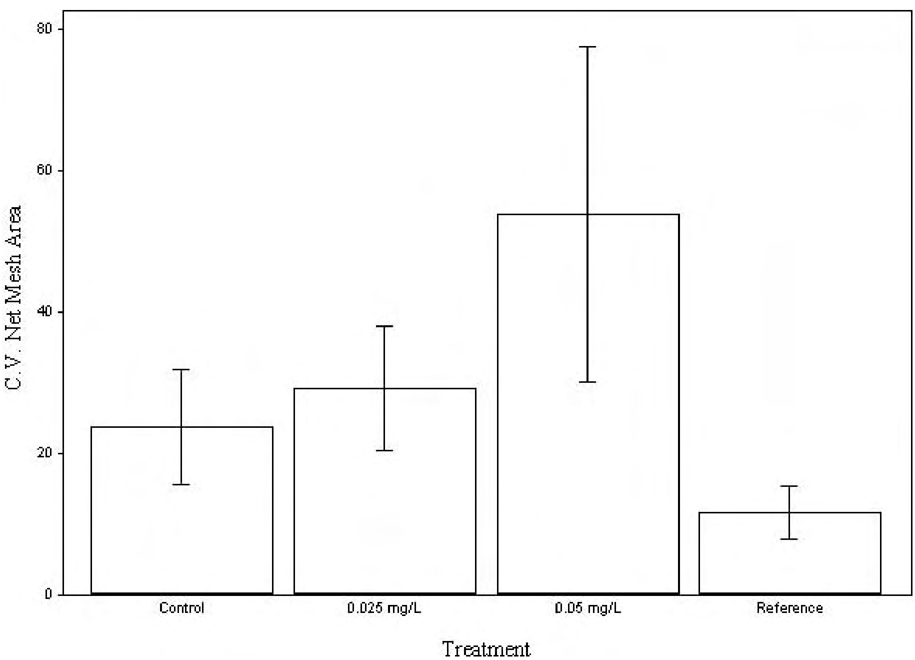

Figure 4. Coefficient of variability in net mesh area between reference sites and treatment streams.

while the lowest was taken from the low treatment ($0.35mm^2$ and $0.02mm^2$, respectively).

The effect of treatments on mesh area did vary by exposure time (significant treatment by time interaction; 2-way ANOVA p=0.039). The largest difference was seen in the 0.05 mg/L treatment (Fig. 3). Larvae exposed for 96 hours constructed nets with larger and more variable net mesh area than those exposed to acute exposure (48 hours). Control treatments demonstrated a similar pattern.

Mesh area variability was found to be lowest in control channels and highest in high treatment channels (Fig. 4; KW ANOVA, p<0.01). Control mesh area coefficients of variation averaged 23.7% with a minimum of 15.3% and maximum of 36.5% while those of low treatment channels ranged from 17.1% to 39.5% (mean = 29.2%) and those of high treatments ranged from 19.4% to 78.1% (mean = 58.9%). Much of the added variability in mesh area of treated nets appeared to be due to high numbers of anomalies and cross-links not observed in control channel nets (Fig. 5). Net mesh area coefficients of variation were low among reference stream samples by comparison to experimental channels, ranging from 3.5% to 22.1% (mean = 11.6%).

Experimental retreat widths fell well within the "normal" (reference stream) range (KW ANOVA, p= 0.43). All average retreat length measurements were approximately the same, but there was a wider range of measurements measured from experimental channels (KW ANOVA p= 0.03). Comparison of means revealed the difference was between the reference streams and 0.05 mg/L treatment (p = 0.15). Variability in retreat length and width was higher among measurements from experimental channels, with highest variability observed in 0.025 mg/L treatments.

CONCLUSIONS

H. morosa collected from reference streams in eastern South Dakota typically had similar net mesh size and retreat dimensions among all sampled sites. Larval hydropsychids construct nets with rectangular mesh of regular dimension (Loudon and Alstad 1990). Mesh size has been shown to vary by species and larval instar. Retreat lengths were slightly more variable than widths. This may be due to the size of substrates used to construct the retreats. Larger or smaller substrates may be located in different parts of the riffle, which would lead to the caddis in that particular part of the riffle building larger or smaller retreats.

Un-ionized ammonia seemed to inhibit *H. morosa* activities and impair retreat and net building behavior in low and high treatment channels. *H. morosa* observed in the control chambers moved freely and behaved in a manner similar to those in reference streams. In contrast, caddis in treated channels displayed slow, lethargic movements and some were observed attempting to drift. Many times there was no movement at all. The slow movements seen in the treatment chambers could be interpreted as the outward signs of physiological stress due to high un-ionized ammonia concentrations.

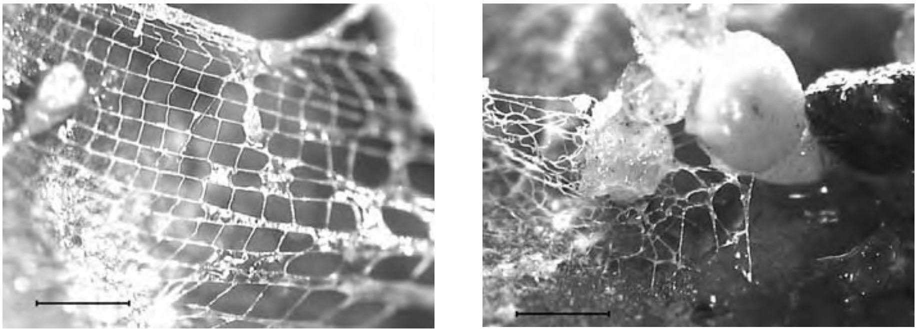

Figure 5. Nets collected from experiment 2, control treatment, chronic exposure (left) experiment 2 high treatment chamber (0.05 mg/L), chronic exposure (right).

The effects of un-ionized ammonia appeared to impair caddis net building leading to net mesh of irregular shape and with greater mesh area variability. Because of the varying net mesh sizes in the different treatments it can be inferred that the un-ionized ammonia had an effect on net construction abilities. Petersen and Petersen (1983) made similar observations, noting that exposure to heavy metals caused Hydropsychids to construct nets with more crosslinks between individual cells.

Low net and retreat building success in Experiment 1 was probably due to high mortality in treated channels, particularly in high treatment channels. This is cause for concern because the low treatment target concentration was established at the South Dakota water quality standard (0.05 mg/L un-ionized ammonia).

Results consistently differed between reference streams and control chambers. The purpose of the control chambers was to isolate treatment effects. It is clear that there was an effect on the caddis when transported and placed into an artificial stream. While no chemicals were introduced to the control there was higher net mesh variability observed compared to reference streams, presumably from the stress associated with transport to an artificial environment. This is supported by McElhorne (1987) who found changes in Trichoptera behavior and community structure when exposed to disturbances such as transport.

Results of this effort demonstrate the influence of elevated un-ionized ammonia concentrations on *Hydropsyche morosa* net construction and tending behavior. Combined results of field observations and laboratory experiments provide measures of natural variability and define specific whole organism responses to a common water quality problem. In contrast, most contemporary biological monitoring efforts focus on changes to algae, macrophyte, invertebrate, and/or fish community structure (Jones 1977, Statzner 1985, McElhone 1987, Basaguren 1990, Barbour 1999). While community endpoints are capable of measuring significant changes in environmental condition, biological responses to disturbance at the whole organism level must occur prior to changes in community structure (Anderson 1982, Evans 1991, Moller 1993, Manning and

Chamberlain 1994, Miller 1998). Early detection of watershed disturbance using whole organism indicators would allow management of disturbed areas prior to significant changes in community structure.

ACKNOWLEDGEMENTS

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NUTRIENT LOADINGS AND PHYTOPLANKTON DYNAMICS WITHIN A POWER PLANT COOLING POND

Amy L. Gronke and Nels H. Troelstrup, Jr.
Department of Biology and Microbiology
South Dakota State University
Brookings, SD 57007

ABSTRACT

Cultural eutrophication within the Ottertail Power Plant cooling pond has led to frequent blooms of noxious algae, fish kills, and odor problems. The objectives of this project were to (1) estimate phosphorus and nitrogen loadings to the cooling pond and (2) evaluate seasonal phytoplankton dynamics and pond trophic state. Water chemistries and phytoplankton samples were collected monthly over the period January 1 to December 31, 1998 and 1999. Total nitrogen, total phosphorus, and phytoplankton counts were analyzed according to standard limnological methods. Sources of nutrient loading include Big Stone Lake water, fly ash pond return flows, domestic wastewater and overwintering waterfowl. Big Stone Lake water was found to contribute the greatest nitrogen load (4.8 g m^{-2} yr^{-1}) while waterfowl were estimated to contribute the greatest total phosphorus load (0.54 g m^{-2} yr^{-1}). An average volume of 3,532,766 m^3/yr is pumped from Big Stone Lake into the Ottertail Cooling pond and contributes on average 76% of total nitrogen and 39% of total phosphorus loads. Overwintering waterfowl (average number = 13,464) contribute 27% of total nitrogen and 91% of total phosphorus load, respectively. Nitrogen:phosphorus ratios (by mass) average 3.2:1 in the cooling pond versus 15.7:1 in Big Stone Lake. Total phytoplankton cell counts averaged 39,099 cells/ml and ranged from 11,776 to 66,423 cells/ml. Diatoms, green algae and euglenophytes were found in great abundance during winter months (range = 0 to 30,248 cells/ml) while cyanobacteria predominated during the warmer summer months (range = 0 to 28,709 cells/ml) at all sites. High nutrient concentrations and low nitrogen to phosphorus ratios suggest that nitrogen may be limiting to algal productivity relative to phosphorus, favoring Cyanobacteria capable of fixing nitrogen during summer months.

INTRODUCTION

The Ottertail Power Plant by Milbank, South Dakota began construction in May 1971 and entered commercial operations on May 1, 1975. The plant is a coal-fired steam electric generating facility located in Grant County, South Dakota. A cooling pond provides water to the boilers inside the plant. This pond was designed as a zero discharge facility. Thus, water moving through the plant can only evaporate from the pond, concentrating nutrients and minerals within the pond basin. In addition, heated water exiting the plant provides overwintering habitat for large numbers of waterfowl.

Plant personnel have witnessed excessive summer algal blooms, severe odor problems, summer fish kills and calcium carbonate precipitation on structures within the pond and inside the plant. This project was initiated to evaluate current conditions within the pond and target problem areas for management focus. The objectives of this project were to (1) estimate phosphorus and nitrogen loadings to the cooling pond and (2) evaluate seasonal phytoplankton dynamics and pond trophic state.

STUDY AREA

The Ottertail Power Plant is located 3.2 kilometers west of Big Stone City, SD (Grant County; 45° 18'N, 96° 30'W). Water is pumped from Big Stone Lake to an adjacent cooling pond. The pond basin is 161 kilometers long, averages 4.3 meters deep and 145 hectares in area.

METHODS

Five sampling stations were established at roughly equidistant locations around the pond (Fig. 1). Measurements and samples were collected from 0.5 m off the bottom, mid-depth and 0.5 m from the surface at each location. Sampling occurred monthly over the period 1 January, 1998 to 31 December, 1999.

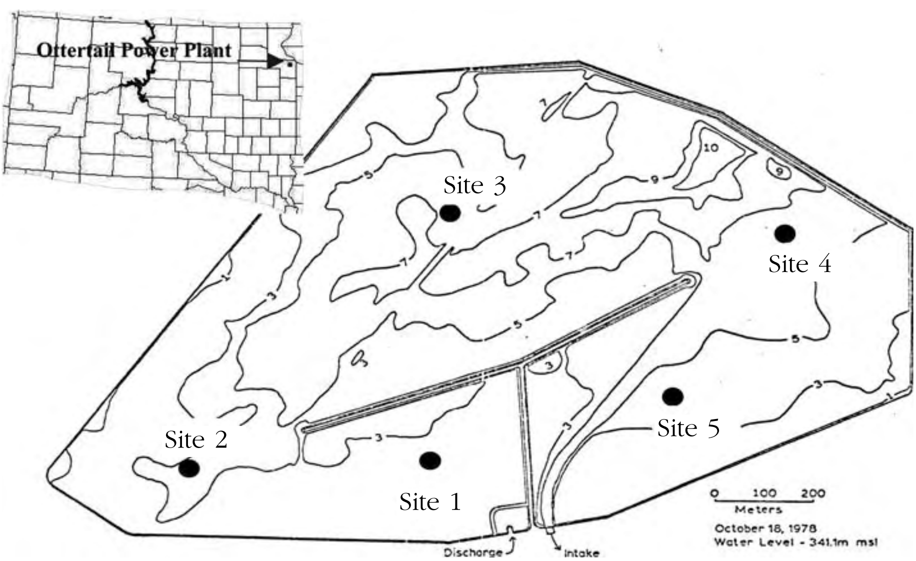

Figure 1. Sampling locations in the Ottertail cooling pond (Grant County, South Dakota)(modified from Wheeler 1979).

Total phosphorus, water transparency, chlorophyll a and total and relative abundance of phytoplankton were evaluated monthly from each site. Estimation of total phosphorus was preceded by acid persulfate digestion followed by a modified ascorbic acid treatment and spectrophotometric analysis (Hach Company, 1997).

Total Kjeldahl nitrogen (TKN) samples were collected on selected dates with other chemistry samples and processed by the South Dakota State University Water Quality Laboratory. Total nitrogen present in the cooling pond was determined by summing TKN and nitrate+nitrite.

Water transparency was determined using a Secchi disk from the shaded side of the boat at each site between 1000 hours and 1400 hours. Duplicate Secchi readings were taken from each site and date.

Chlorophyll samples were collected using a Van Dorn bottle. These samples were filtered onto glass fiber filters and frozen for later analysis. Frozen samples were extracted with 90% buffered acetone and corrected chlorophyll a determined spectrophotometrically following Eaton et al. (1995).

Waterfowl counts were provided by South Dakota Game, Fish and Parks and United States Fish and Wildlife Service. Pumping data for Big Stone Lake, bottom ash return and rural water use were obtained from Ottertail Power Plant personnel. Big Stone Lake total nitrogen and total phosphorus samples were taken three times during the two-year project (April, 1998 and March, April, 1999) and bottom ash return samples were taken during December, 1999. These samples were processed as outlined above.

Trophic State Index values were measured using Chlorophyll a, Secchi disk transparencies and total phosphorus (Carlson 1977). An overall site TSI value was obtained by averaging these values for each site and date.

Phytoplankton samples were collected with a Van Dorn bottle, transferred to darkened polypropylene bottles and preserved with Lugol's iodine (Lind 1979). Random subsamples were drawn from each sample and filtered onto membrane filter disks, cleared with immersion oil and counted following the membrane filter count method (Eaton et al. 1995).

DATA ANALYSIS

Loading estimates were generated using total nitrogen and total phosphorus chemistry data, monthly Big Stone Lake pumping volumes, average daily ash pond return volumes, average monthly rural water usage, average domestic wastewater total nitrogen and total phosphorus (Tchobanoglous and Schroeder 1985; Tchobanoglous et al. 1991), average winter waterfowl counts, and daily fecal output and fecal nutrient composition from Canada geese (Manny et al. 1974). Waterfowl loading estimates were calculated as weighted contributions by species relative to the average Canada goose *(Branta canadensis).* Waterfowl contributions were estimated for the period November through February, as these are the months during which high numbers were observed on the cooling pond. All loadings were estimated as annual contributions per square meter of pond surface.

Field data consist of separate monthly measurements for each parameter by depth, location and date over the period January 1998 to December 1999. Collected data were entered onto Excel spreadsheets and statistical summaries were estimated for each parameter by sampling location, season and depth.

RESULTS

Total nitrogen concentrations of the cooling pond ranged from 2.65 to 5.71 mg/L (mean=3.50 mg/L) while total phosphorus concentrations ranged from 0.32 to 4.40 mg/L (mean=1.10 mg/L). The total nitrogen:total phosphorus ratio ranged from 1.4 to 5.9 (mean=3.4).

Total nitrogen and phosphorus concentrations from all loading sources ranged from 1.9 to 2.63 and 0.09 to 0.77 mg/L, respectively (Table 1). Fly ash return flows contained the highest total nitrogen and phosphorus concentrations. However, greater volume contributions from Bigstone Lake and goose feces resulted in greater loadings of nitrogen and phosphorus from these sources. Bigstone Lake pumping contributed on average 4.8 g N/m^2/yr while goose feces contributed 1.7 g N/m^2/yr. In contrast, Bigstone Lake pumping contributed 0.23 g P/m^2/yr while goose feces contributed 0.54 g P/m^2/yr.

N:P ratios by mass within the cooling pond were similar to ratios observed from waterfowl and were much lower than those observed from water pumped from Big Stone Lake (Table 2).

Average Carlson Trophic State Index (TSI) values ranged from 64 to 104 and were lower from Secchi depth and chlorophyll a measurements than those calculated from total phosphorus concentrations (Table 3). TSI values gener-

Table 1. Average concentrations (mg/L) and estimated annual loadings (g/m^2/yr) of total nitrogen and total phosphorus from various sources to the Ottertail Power Plant cooling pond.

	Ave. Conc. (mg/L)		Estimated Annual Loadings (g/m^2/yr)	
	Nitrogen	**Phosphorus**	**Nitrogen**	**Phosphorus**
Ash Pond Return	2.63	0.77	-0.25	-0.61
Rural Water Use	0.40	0.012	0.025	0.082
Big Stone Lake	1.9	0.09	4.8	0.23
Waterfowl	1.9	0.09	1.7	0.54

Table 2. Average nitrogen:phosphorus ratios in the Ottertail Cooling pond, Big Stone Lake source water and goose feces.

Source	N:P Ratio (by mass)
Cooling Pond	3.4:1
Big Stone Lake Water	15.7:1
Goose Feces*	3.2:1

*Source: Manny et al. (1974)

Table 3. Carlson Trophic State Index values for the Ottertail cooling pond. Index values generated using field data for total phosphorus, chlorophyll a and Secchi depth.

Source of Data	TSI Value	Carlson Trophic Class
Total Phosphorus	104	Hypereutrophic
Chlorophyll a	64	Eutrophic
Secchi Depth	66	Eutrophic
Overall Average	78.2	Hypereutrophic

ated from Secchi and chlorophyll data suggest that the cooling pond is a eutrophic basin while total phosphorus TSI's suggest that this same basin is hypereutrophic. Overall TSI values averaged 78.3 and within the hypereutrophic range.

Twenty-three algal genera were found in Ottertail cooling pond samples. These genera comprised four phyla (Cyanobacteria, Chlorophyta, Chrysophyta and Euglenophyta). Chlorophyta contributed 10 genera (*Franceia* sp., *Micractinium* sp, *Pandorina* sp., *Pediastrum* sp., *Scenesdesmus* sp., *Selenastrum* sp., *Tetraedron* sp., *Ulothrix* sp., *Volvox* sp., and green unicells) followed by Chrysophyta (*Chaetoceros* sp., *Cocconeis* sp., *Cyclotella* sp., *Gyrosigma* sp., *Melosira* sp., *Navicula* sp., *Nitzschia* sp., *Stephanodiscus* sp. and an unknown pennate diatom), Cyanobacteria (*Anabaena* sp., *Lyngbya* sp., *Microcystis* sp. and *Oscillatoria* sp.) and Euglenophyta *Euglena* sp. Total phytoplankton counts ranged from 11,776 to 66,423 cells/ml. Chlorophyta (Fig. 2), Chrysophyta (Fig. 3) and Euglenophyta (Fig. 4) were found in greater abundance during winter months

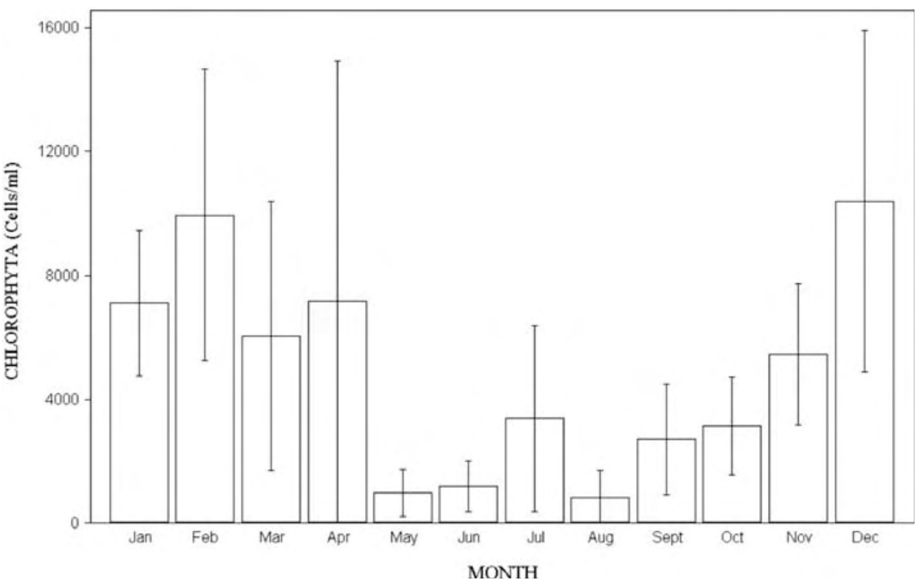

Figure 2. Mean (+/- 1 s.e.) abundance of Chlorophyta by month within the Ottertail Power Plant cooling pond.

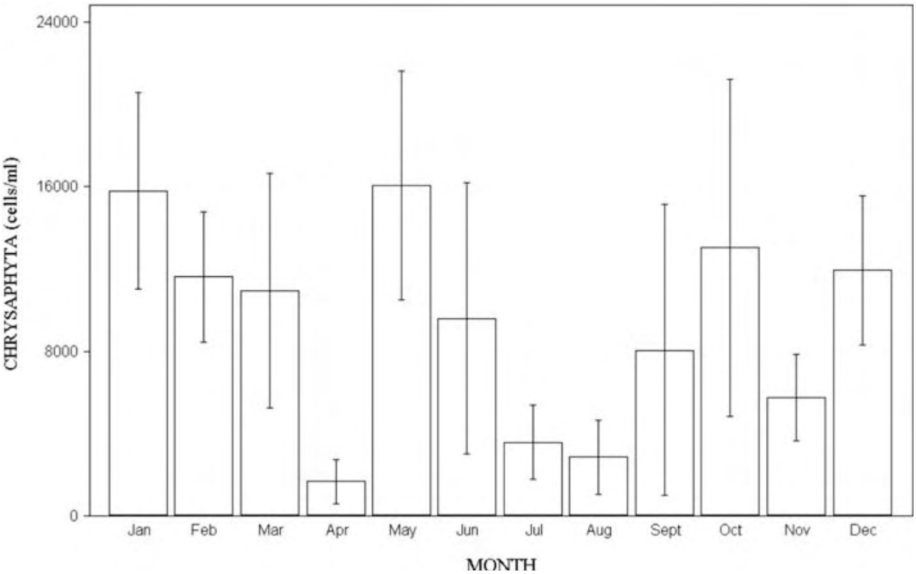

Figure 3. Mean (+/- 1 s.e.) abundance of Chrysophyta by month within the Ottertail Power Plant cooling pond.

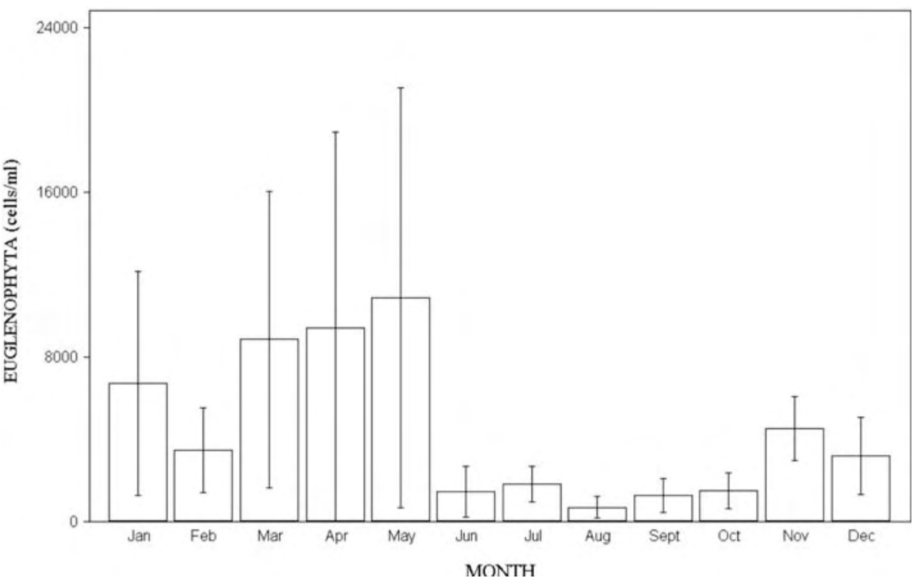

Figure 4. Mean (+/- 1 s.e.) abundance of Euglenophyta by month within the Ottertail Power Plant cooling pond.

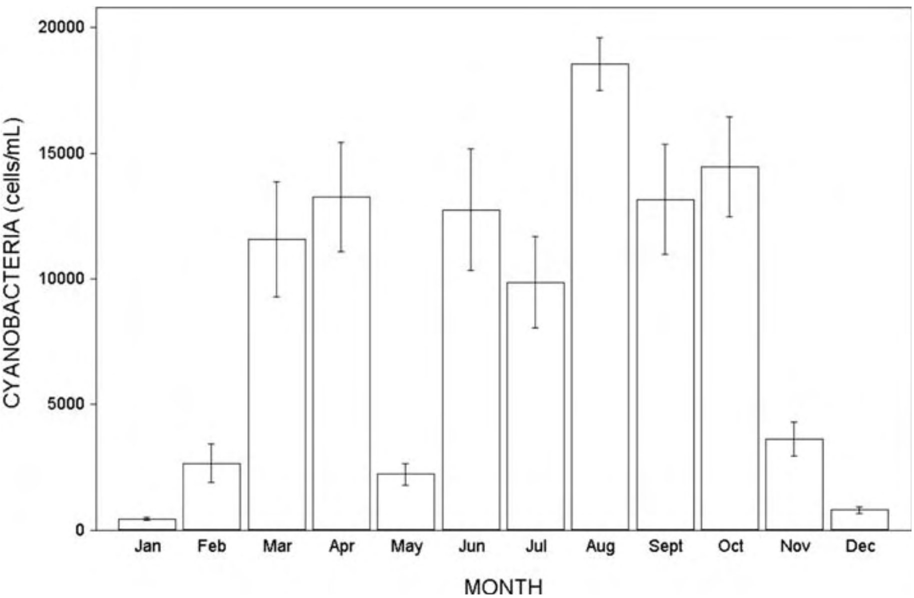

Figure 5. Mean (+/- 1 s.e.) abundance of Cyanobacteria by month within the Ottertail Power Plant cooling pond.

(range = 0 to 43,101 cells/ml) while Cyanobacteria dominated numerically during the summer months (range = 0 to 28,709 cells/ml) (Fig. 5) at all sites. No significant differences in algal unit counts were observed among sampling sites.

CONCLUSIONS

Lake basins, by definition, occupy lower elevations within a catchment. As a result, sedimentation, nutrient enrichment and changes in aquatic community structure are natural phenomenon throughout the life of a lake basin (Kalff 2001; Wetzel 2001). However, these processes are often accelerated following watershed development leading to rapid changes in physical, chemical and biological characteristics. Higher catchment erosion rates, basin sedimentation and nutrient enrichment enhance productivity and alter the composition of biotic communities within lake basins (Kallf 2002; Wetzel 2001). These changes may in-turn impair water quality for specific designated uses.

Cultural eutrophication has degraded water quality within the Big Stone cooling pond. Nutrient loading from Big Stone Lake and waterfowl have reduced nitrogen:phosphorus ratios, increased water column calcium concentrations, enhanced primary production, facilitated biogenic decalcification and altered algal community structure as compared to Big Stone Lake source water. In addition, high water temperatures throughout the year support high winter primary production and reduce oxygen solubility during summer months.

High water temperatures and decomposition during summer months result in oxygen deficit causing summer fish kills.

The Big Stone cooling pond functions as a hypereutrophic lake basin. However, this characterization is strongly influenced by high total phosphorus loadings. Algal biomass as measured by chlorophyll a and water transparency values suggest that this basin should be eutrophic. Sources of sediment and nutrients to the Big Stone cooling pond include the Bigstone Lake catchment, migrating waterfowl and impervious surfaces immediately surrounding the pond. Major sources of total nitrogen and phosphorus include water pumped from Big Stone Lake and waterfowl. Loading reductions from these sources may improve nitrogen:phosphorus ratios, lower critical algal nutrient levels and improve water quality for use by plant managers. In addition, it may be necessary to reduce cooling pond water temperatures and calcium loadings into the pond. High nutrient concentrations, low nitrogen:phosphorus ratios and high water temperatures all contribute to observed problems within the pond (algal blooms, summer fish kills, biogenic decalcification).

Water temperature, light, nutrients and herbivores may all exert some control over the composition and productivity of primary producers in lake basins (Kalff 2002; Wetzel 2001). However, phosphorus concentrations are often the most limiting resource to aquatic algae (Monson 1992; Schelske and Stoermer 1971). Most aquatic algae require a ratio of total nitrogen to total phosphorus approximately 7:1 (by mass) (Kalff 2002). Big Stone Lake, source of cooling pond water, demonstrated a ratio of 15.7:1 (by mass). Thus, phosphorus would be limiting relative to nitrogen in Big Stone Lake. However, nitrogen:phosphorus ratios within the cooling pond average 3.2:1 (by mass), very similar to the average reported in waterfowl feces (Manny et al. 1974). This low ratio suggests that algae within the cooling pond may be nitrogen limited.

Summer dominance of Cyanobacteria within the Ottertail cooling pond may reflect nitrogen limitation within the water column. Several species of Cyanobacteria are capable of fixing their own nitrogen (Smith 1983). This places them at a competitive advantage over other phytoplankton when N:P ratios are low (< 10:1) (Kalff 2002). In addition, Cyanobacteria are tolerant of warmer waters (Wetzel 2001) and low light conditions (Scheffer et al. 1997). Low nitrogen:phosphorus ratios, high water temperatures and greater biogenic shading were observed together in the cooling pond during the summer months. These conditions favor the establishment and maintenance of high Cyanobacteria production, a condition we observed in our phytoplankton data. High winter temperatures also favor greater winter production and enhance autochthonous loading of organic matter as compared to surrounding natural basins.

The cooling pond represents an important link in plant functionality. Protocols and strategies have been proposed to facilitate future monitoring of the pond and facilitate corrective actions to enhance pond integrity. Cold lime softening, microscreens, buffered alum, and controlled waterfowl hunting have all been proposed as possible management strategies. These strategies should be explored to address problems associated with nutrient enrichment and algal productivity. Short-term monitoring data would allow plant personnel to anticipate impending conflicts between pond water quality and plant operations. Limited monitoring should be conducted weekly and include measurements of water temperature, Secchi depth transparency, calcium concentrations and dissolved oxygen. Long-term monitoring data should be used to guide strategic management. Samples collected every 5 years might provide a baseline against which future management goals may be measured.

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DEPLOYMENT OF A MEMBRANE REFLECTOR IN ZERO-G

John Keefner, Angie Monheim and Lori Glover
South Dakota School of Mines & Technology
Rapid City, SD 57701

ABSTRACT

Thin membrane reflectors will have a large role in the next generation aerospace industry. Lightweight, flexible membranes will reduce cost for larger structures used for communication, imaging, and transportation in space. The goals of this project were to 1) Develop a first generation membrane test bed that can be continuously improved for later test flights; 2) To provide meaningful gravity release data for development of membrane space structures; 3) To provide SDSM&T students with an educational opportunity in aerospace engineering and science; and 4) To disseminate this information with a comprehensive outreach program to a broad student and public audience. The experiment took place aboard the KC-135A Reduced Gravity Laboratory at Ellington Field, Texas. An apparatus was constructed that would spin a reflecting membrane and a control grid on a spindle. A digital video camera recorded the behavior of the membrane under varying gravity and centrifugal forces. The data gathered from the flights was analyzed using imaging software. The results compared the distortion of the reflected image of the control grid off the membrane to the image of the control grid itself. The premise was that the amount of image distortion was proportional to the deviation from the desired surface profile. The results showed basic trends such as an increase in distortion with increased force on the membrane. However, a full quantitative analysis would require further work that is beyond the scope of the project at this time. The project was considered a success in that a membrane test bed was constructed and flown on the KC-135 and meaningful data were actualized in the process. SDSM&T students received an invaluable learning experience designing and constructing the project. The students have also had the opportunity to share their experience with many audiences. The experience has yielded insights for making precise measurements in a constantly changing environment such as the KC-135. These considerations will weigh heavily in any SDSM&T projects performed on the KC-135 in the future.

Keywords

KC-135 Reduced Gravity Membrane Deployment SDSM&T NASA

INTRODUCTION

Inflatable and membrane structures have been the highlight of interest for many NASA and DOD scientists regarding the future in space applications. The trend to reduce the cost of launch and design of space structures largely motivates this interest. Inflatable and membrane structures have the potential for significantly reduced launch mass and stowed volume. Applications for membrane and inflatable structures in space include optical and IR imaging, solar concentrators for solar power and propulsion, lunar and planetary habitats, sun shades, solar sails, and many other fields of study. These membrane structures may be from 10 - 100 m or more in breadth. Because the membranes are so thin and compliant, they have little stiffness to resist deflecting under their own weight. This characteristic makes it difficult to determine the deployment behavior and final shape of such membranes during ground tests on Earth.

This project, to study the final shape of a deployed membrane, was performed aboard the NASA's KC-135A Reduced Gravity airplane. The KC-135 flies in a parabolic trajectory that allows up to thirty seconds of weightlessness. The KC-135 provided a variable gravity platform, which allowed experiments to be performed under a variety of conditions including microgravity.

The objectives of this project include the following:

- To develop a first generation membrane test bed that can be continuously improved for later flight tests, including a possible space shuttle canister experiment,
- To provide meaningful gravity release data for development of membrane space structures,
- To provide SDSM&T students an educational opportunity in aerospace engineering and science,
- To disseminate this information with a comprehensive outreach program to a broad student and public audience.

TEST DESCRIPTION

SDSM&T students designed and flew the test article, which contained a model membrane reflector. The article was operated in both stationary and rotating modes. Video images, made with a digital video camera, captured the amount of distortion in the reflection of the image of the control grid. The amount of distortion could be compared between visual measurements made in microgravity and in normal gravity conditions. Similarly, the video capability of the camera allowed data to be collected when the article was rotating.

Images were made during two different operating conditions. In one condition, the membrane was stationary; in the other, it was rotating at a constant angular velocity. The latter case provided centrifugal forces on the membrane, which, in principal, modify its shape. Tension forces from the support bars or other were assumed constant and disregarded.

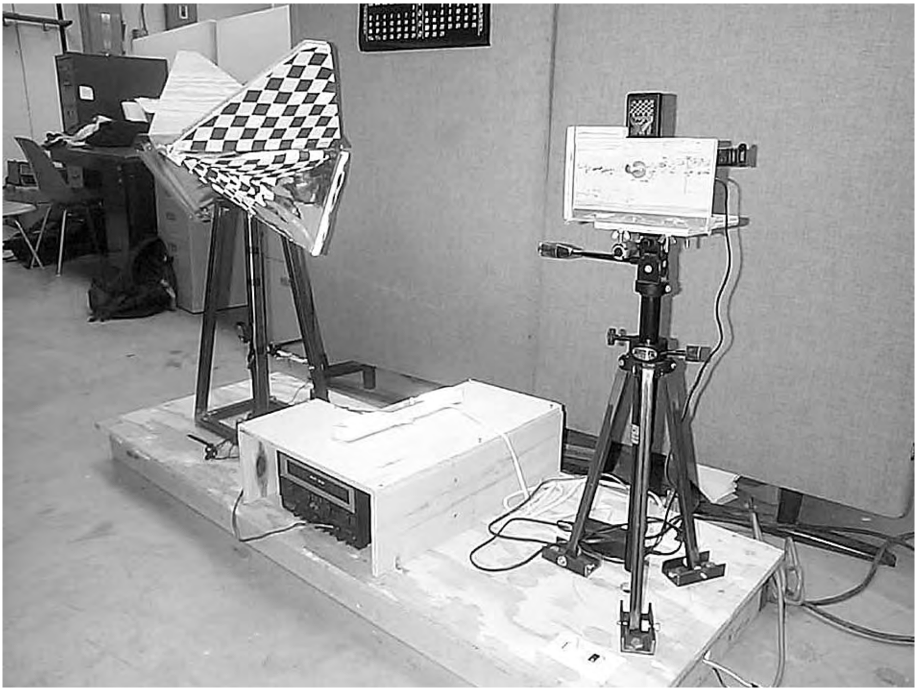

Figure 1. Experiment test bed without casing.

METHODS

The SDSM&T flight crews flew two times aboard the KC-135, which flies approximately forty parabolas per outing, with a maximum of thirty seconds of micro-gravity per parabola. The flight crews' responsibilities included inspecting and operating the video equipment and drive motor.

The data collected during the KC-135 flights included video footage of the membrane and grid together inside the test chamber. Still footage of the panels was taken during a break in parabolas to gather a baseline for the vibration conditions inside the plane during flight.

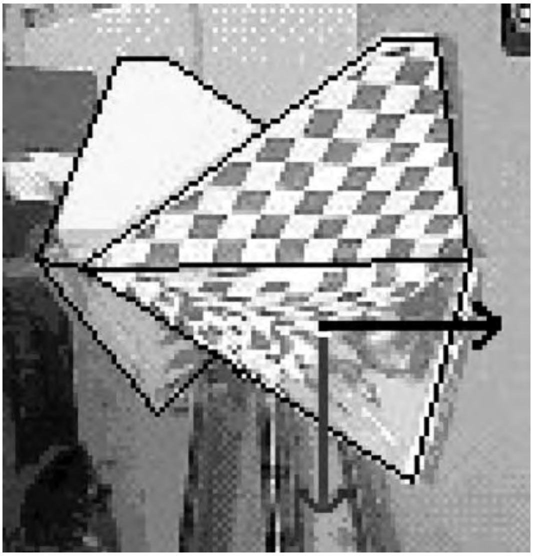

Figure 2. Forces acting on membrane. Black: centrifugal; gray: gravitational.

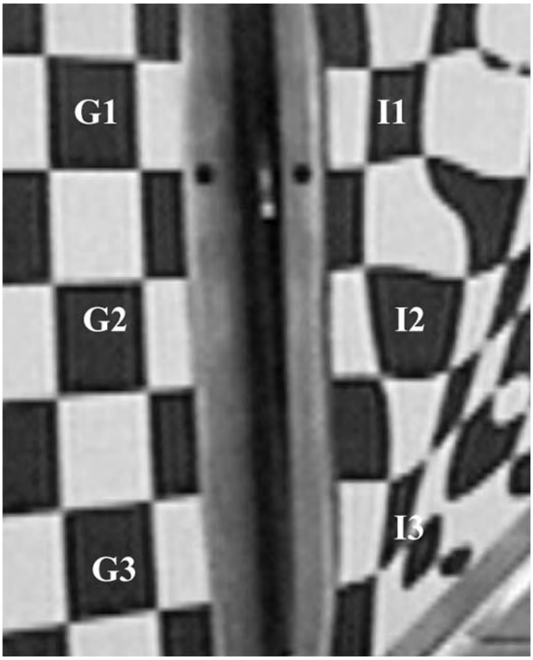

Figure 3. Close-up of control grid and reflected membrane images.

The data collection plan for flight day one was to record 10 parabolas, each at 60, 120, and 180 revolutions per minute. If problems were encountered during the flight, the alternate plan was to record still data for the remainder of the flight if the problem could not be easily fixed in flight. The plan for flight day two was determined from the data collected during the first flight. One hundred-eighty rpm and some 120 rpm data for day one was missed. So, flight day two would begin with 180 rpms, proceeding to 120 rpms, and ending with static data collection.

The camera provided 32 frames per second of images for analysis. Given that each flight lasted approximately an hour, the available video footage yielded over 230,000 images. In order to make the data more manageable for preliminary analysis, three frames were chosen from each parabola for analysis. These frames would be one image from the initial 2-G as the parabola began, one image from the time during microgravity, and one image from the final 2-G as the parabola finished. The specific frames used were chosen arbitrarily.

Each image contained all the boxes on the grid and their corresponding reflections on the membrane. A review of the video showed that three grid boxes in particular appeared to yield the most consistent reflections over each parabola. These three boxes and their corresponding reflection boxes became the choices for test points from which to begin the data analysis. For each image the same six test points were used - the three grid blocks and their corresponding reflected images. The control grid points, located on the left side of Figure 3, are labeled “G1, G2, or G3,” and the Membrane Reflection Image points are on the right side labeled “I1, I2, or I3.”

These test points were processed using Scion Image Software. Each image was first put through a threshold function to turn each pixel either black or white, determined by its original value. Next, the boxes were isolated by adding a small line of white at the middle of any connecting point between black boxes. This confined each box for the software so a pixel count of the area and the perimeter could be made. The areas and perimeters for each image and parabola were then recorded in Excel for analysis.

RESULTS

The three points were separately analyzed and plotted per trial versus the ratio of pixel change compared to the control grid. Control grid plots indicate that there is minimum change due to camera movement and the number of pixels captured per control grid image stays nearly constant.

Figures 4-6 show the trends of each point per trial at different constant angular velocities before, during, and after the thirty seconds of the microgravity period. The general trend was for the initial value to be smaller than the microgravity value. The higher value is most likely due to the motion of relaxation as gravity releases. And as gravity returns, the final values are consistently lower than the values during microgravity. However, the final value is usually not as low as the initial value. This is possibly an indication of a lag time as the membrane is still stretching to achieve the lowest value under gravity.

Another important trend that Figure 4 and Figure 5 illustrate is the increase in the Ratio of Area Change with increased rotation. At 60 rotations per minute, the Ratio of Area Change value is at its lowest point. It increases to 180 rpm where it is at its highest. The membrane, which normally sags due to gravity, has a slim reflective profile under higher gravity. As the rotation increases, this profile opens up and increases the reflective area, increasing the Ratio of Area that is reflected to the camera.

The data collected on the third set of points, G3 and I3, show deviant behavior. The trends followed by the other two points do not apply. Analysis of the video and pictures reveal that this particular box is located directly on a tension kink in the membrane. The surface at this point is nearly parallel to both gravity and the centrifugal forces, and the perpendicular surface area is minimized, reducing the effect of both forces on the membrane. This is the case with the similar values for all except the first set of 60 rpm values. The G3/I3 Day One, 60 rpm data may be the result of a vibration or some other anomaly.

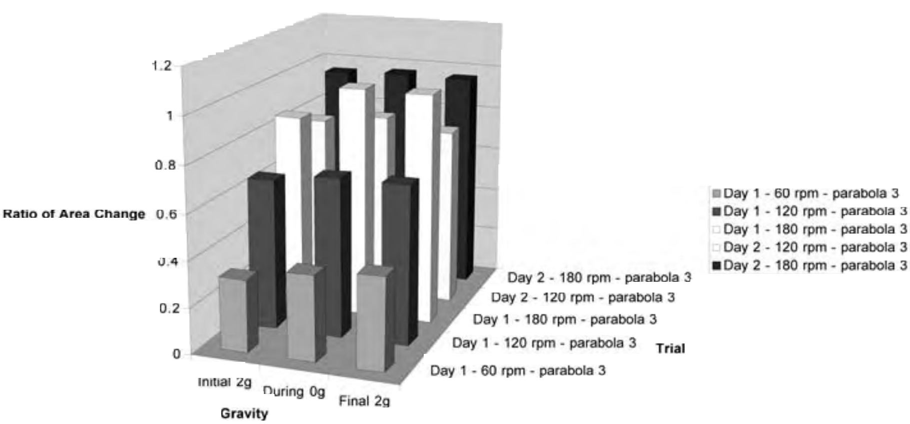

Figure 4. G1/I1 ratio of area change to gravity per trial.

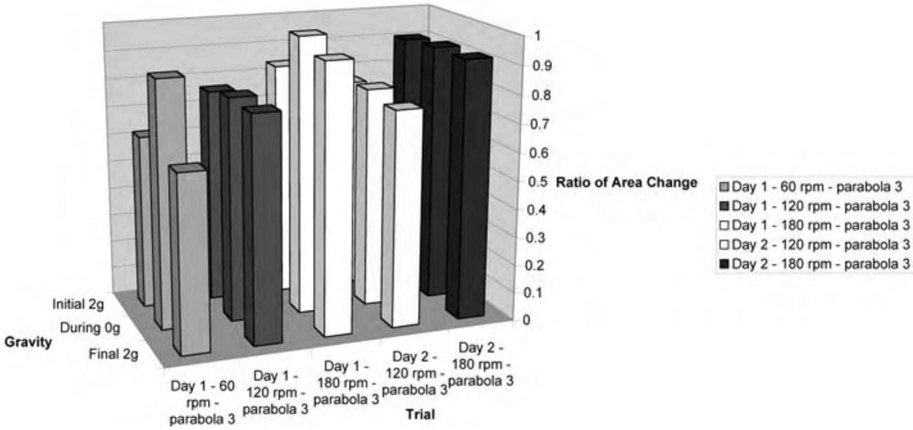

Figure 5. G2/I1 ratio of area change to gravity per trial.

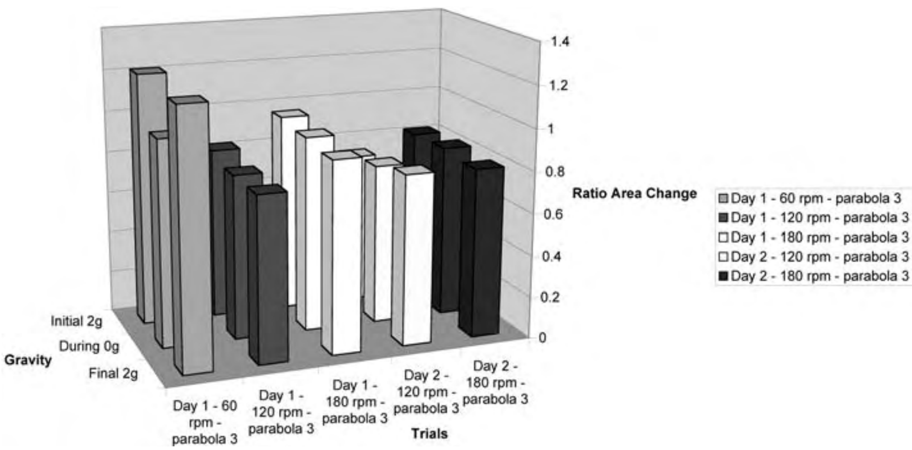

Figure 6. G3/I3 ratio of area change to gravity per trial.

CONCLUSIONS & RECOMMENDATIONS

Definite trends have been reflected in the data analyzed. The higher the gravity, the smaller the reflective profile of the membrane. The higher the rotation, the larger the reflective profile of the membrane. When the membrane is under gravity and spinning at fairly high rates of speed, one can expect competing forces to distort the membrane in different ways. This avenue of analysis hints at a calculus-based model. Further research could lead to a comprehensive calculus-based analysis.

One of the major problems that hindered construction and data analysis was the presence of tension kinks in the membrane. Several membrane reflectors were constructed in both South Dakota and Texas. Every reflector developed kinks after a period of time and proved sensitive to changes in temperature and weather. This tension interfered with proper reflection of the membrane and no doubt skewed the data significantly. To avoid this, the membrane could be placed on adjustable tensioners attached to a ring. In this manner, kinks could be easily removed. Experiments using different types of reflector material could also solve this problem. Whatever solution is ultimately developed, a better mounting scheme is required for the membrane reflector.

The scientific results from this experiment have shown that the membrane does change shape between normal gravity and microgravity. However, precise measurements showing how the membrane changes shape were not achieved. To accomplish these measurements, a refined test bed must be designed, and the data reduction method must be evaluated. Suggested improvements for future tests are listed below:

1) A better mounting scheme for the panels and grid to reduce movements,
2) Better adhesion methods for attaching the membrane to the frame,
3) Examination of the optimal membrane geometry for testing purposes,
4) Use of a still digital camera and a timing mechanism for increased resolution,
5) Use of strain gauges or other devices for measuring the deflections of the surface,
6) Isolation of the membrane and camera from external bumping of the test box,
7) Separation of centrifugal and gravitational measurements to maximize the effects of both,
8) An optimized method and software for data reduction.

The results from this project continue to be examined. By further data reduction and evaluation and closer examination of the testing procedures, additional ways to improve upon this first generation test will be identified.

This project was a success at many levels. SDSM&T students developed, constructed, and flew a working thin membrane experiment that yielded definitive results that may be used to prepare further membrane research. A comprehensive outreach program was prepared with the help of school Journalist Kari Larese. More than a dozen presentations have been made and various members of the KC-135 team have had the opportunity to interact with younger kids interested in science and engineering. Thousands of people have been made aware of the project through various articles and stories written from February to March of 2000.

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Flight Crew	**Ground Crew** * - alternate flyers
Louie Arguello (ChE)	Angie Monheim (Graduate Student & Team Coordinator)
Jed Brich (CEE)	* Lori Glover (ChE)
Alan Gertonson (ChE)	* Keith Flanegan (ChE)
Victoria Olson (ChE)	John Keefner (GeolE)
Kari Larese (Journalist)	Jed Padilla (Comp. Sci.)

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ANTLER DEVELOPMENT OF CAPTIVE SOUTH DAKOTA DEER

Lowell E. Schmitz and Jonathan A. Jenks
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

ABSTRACT

Antler development of 10 captive white-tailed deer *(Odocoileus virginianus)* was documented from fall 1997 through 2000. Fawns were maintained at the Wildlife and Fisheries Sciences Research Facility at South Dakota State University. When obtained, fawns were estimated to be less than one week old based on initial weights and hoove coloration (white or light colored). Five males were obtained from the Black Hills and the remaining five males originated from eastern South Dakota. All males exhibited "infant" antlers at 6 months-of-age. Basal diameter of antlers from Black Hills males increased an average of 7 (± 0.45) mm from 18 to 30 months-of-age, while males from eastern South Dakota increased an average of 8 (± 0.71) mm. Although the rate of increase was similar across regions of origin, males from the Black Hills had smaller ($P < 0.004$) antler basal diameters than males of the same age from eastern South Dakota. Based on growth rates of antlers, antler development of males from the Black Hills was about one year behind that of antlers of males from eastern South Dakota.

INTRODUCTION

Antlers are bony, secondary sexual characteristics commonly found on male cervids (McCorquodale et al. 1989). Males use antlers from September through December to deposit scent (Atkeson and Marchinton 1982), to intimidate other males (Benner and Bowyer 1988), and to attract potential mates (Sawyer et al. 1989).

Age, genetics, and nutrition are key factors in determining antler size (Hamel 1982). However, age is usually the factor most affecting size of antlers (Scribner et al. 1989). It has been estimated that 70% of all deer harvested during annual hunting seasons are 18 months-of-age or younger. Consequently, most males are harvested before reaching their full antler potential. Reduced antler size in younger animals is likely due to skeletal frame growth, which continues for the first 3 years of life and thus, limits nutrients available for antler development. While size and shape of antlers are hereditary, size also is dependent on nutrition.

Chronology of antler development begins with the development of two bony protrusions on the frontal skull bone, these protrusions are known as pedicles and are the foundations upon which antlers develop (Ullrey 1982). Some fawns may develop "infant" antlers at 6 months-of-age (Goss 1982). A male's first set of adult antlers can vary from small spikes or forkhorns, to as many as five points per beam. A male's second set of adult antlers will be generally larger than the first in spread, usually number of points, and also in total mass. Antlers continue to increase until males reach prime age, usually between 4 and 6 years of age. Antler characteristics have been documented for white-tailed deer in Mississippi *(Odocoileus virginianus virginianus;* Jacobson and Griffin 1982), Louisiana *(O. v. macrourus, O. v. mcilhennyi;* Schultz and Johnson 1992), Michigan *(O. v. borealis,* Ullrey 1982), and Texas *(O. v. texanus,* Harmel 1982). The objective of this study was to document antler growth and characteristics of captive South Dakota white-tailed deer *(O. v. dakotensis).*

MATERIALS AND METHODS

Antler development of 10 captive white-tailed deer was documented from fall 1997 through 2000. We obtained deer as fawns, which were believed to have been abandoned, from the South Dakota Department of Game Fish and Parks (SDGF&P). When obtained, fawns were estimated to be less than one week old based on initial weights and hoove coloration (white or light colored). Deer were maintained at the Wildlife and Fisheries Sciences Research Facility at South Dakota State University. Facilities and procedures for captive deer maintenance followed the recommendations of the American Society of Mammalogists (*Ad hoc* Committee for Animal care and Use 1998) and guidelines of the Institutional Animal Care and Use Committee at South Dakota State University (Project Approval No. 97-A016). Fawns were fed Advance Brand Powdered Lamb Milk Replacer (Milk Specialties Company, Dundee, Illinois, USA) mixed in a 4:1 ratio with warm water following a feeding schedule adapted from Buckland et al. (1975) (Table 1). Feeding was accomplished using a 591 ml (20 oz) plastic soft drink bottle with a rubber nipple. For the first 2 weeks, the fawn's anal area was wiped with a damp paper towel to encourage defecation during or after each feeding. Post-weaning, fawns were maintained on a pelleted ration (16% protein) (Table 2), and/or shelled corn offered *ad libitum.*

Table 1. Fawn white-tailed deer feeding schedule as adapted from Buckland et al. (1975).

Days after birth	Time of feedings	Amount fed/feeding (ml)
1-3	0600, 1000, 1400,1800, 2200	60
4-10	0600, 1000, 1400,1800, 2200	120
11-17	0600, 1000, 1400,1800, 2200	180
18-35	0600, 1000, 1800, 2200	240
36-42	0700, 1300, 1900	300
43-56	0700, 1900	300
57-84	1300	300
85	weaned	

Table 2. Composition of the base pelleted (6 mm pellets) diet fed post-weaning to white-tailed deer fawns obtained from the Black Hills and eastern South Dakota, 1997-2000.

Item	Percent Dry Matter
Alfalfa meal (Dehydrated 17%)	50.00
Corn cobs	10.00
Ground corn	26.60
Soybean meal (Soluble)	10.00
Cane molasses (Liquid)	2.00
Vitamin A 30000 units/gm	0.08
Vitamins A,D,E	0.02
Vitamin E 44.05 units/gm	0.10
Salt TM	0.50
Dicalcium Phosphorus	0.40
Soybean oil	0.30

Five male fawns were obtained from the Black Hills; the remaining 5 males were obtained from eastern South Dakota. We recorded number of points, basal diameters, and velvet shedding dates as well as antler shedding dates. We removed antlers at 18 and 30 months-of-age within a few days of velvet removal. Antlers were removed approximately 2.54 cm (1 inch) above the burr using a cable or hack saw. SYSTAT (SPSS 1998) was used to compare antler basal diameters.

RESULTS

All 10 males exhibited "infant antlers". These antlers were visible at 6 months-of-age and measured approximately 3 to 6 mm above the hairline. At 18 months-of-age all males had branched antlers. One September (± 2.9 days [SE]) was the mean velvet shedding date for males at 18 months-of-age. Three September (± 1.5 days) was the mean velvet shedding date for males at 30 months-of-age. Basal diameter of antlers increased from 18 to 30 months-of-age. Diameters of antlers of males from the Black Hills increased an average of 7 (± 0.45) mm whereas males from eastern South Dakota increased an average of 8 (± 0.71) mm. Although the rate of increase was similar, males from the Black Hills had significantly ($P < 0.004$) smaller antler basal diameters than males of the same age from eastern South Dakota (Table 3).

Over the course of 3 years, the 10 males in our study cast antlers between 24 January and 12 April with 11 March (± 6.55 days) as the mean shedding date for 1½ year old deer (n = 10), and the mean shedding date was 6 March (± 6.42 days) for the 2½ year olds (n = 10). Generally, antlers were cast within 6 days of each other (Left or Right). However, one male cast his second antler 78 days after shedding the first.

Table 3. Number of points and basal diameter of antlers at 18 and 30 months-of-age for captive white-tailed deer from the Black Hills and Eastern South Dakota.

Characteristic	Age[1]	Black Hills	Eastern South Dakota
Antler Points			
Left Beam	18	2.6 (0.4)	3.0 (0.3)
	30	4.0 (0.0)	4.4 (0.2)
Right Beam	18	2.2 (0.6)	3.0 (0.3)
	30	3.6 (0.4)	4.2 (0.5)
Antler Diameter[2]			
Left Beam	18	18.8 (0.7)	22.6 (0.7)
	30	26.4 (1.0)	31.2 (1.6)
Right Beam	18	18.8 (0.8)	22.6 (1.0)
	30	25.2 (1.2)	31.0 (1.4)

[1]Months.
[2]Basal diameters (mm) were measured 2.54 cm (1 inch) above burr.

DISCUSSION

All 10 captive males shed velvet between 15 August and 12 September. Mean velvet-shedding dates were 1 September for the 1½ year olds and 3 September for the 2½ year olds. These dates are earlier than those reported by Jacobson and Griffin (1982) in Mississippi (September 24) and Schultz and Johnson (1992) in Louisiana (16 September).

Our results for basal diameters of South Dakota deer were similar to those of Ullrey (1982) in Michigan (2.5-year-old males averaged 8-point antlers with 26-33 mm basal diameters) and slightly higher than those found by Harmel (1982) in Texas (1.5-year-old males, 17.8 - 21.9 mm basal diameters; 2.5-year-old males, 23.8 – 26.6 mm basal diameters).

Several factors affect when male deer cast antlers and deer from different regions can and do cast them at different times. It has also been noted that males that sustain an injury, such as being hit by a vehicle or sustaining a non-lethal wound during hunting season, will often cast antlers within a few weeks of the injury. Males used in this study cast antlers from late January until mid-March. This is later than dates reported by Chapman (1939, cited in Zagata and Moen 1974) in Ohio (December and January). Dates are similar to those reported by Hawkins et al. (1968) for southern Illinois (January – mid April).

A significant increase in antler development occurred between the ages of 18 and 30 months clearly demonstrating that South Dakota deer are able to produce large antlers. However, to grow large antlers, males must reach the age of 36 months prior to harvesting. Bucks will continue to increase both body size and antler development until full maturity at 4.5 to 6.5 years-of age.

Antler development of males from the Black Hills was approximately one year behind the development of antlers grown by males from eastern South Dakota. This result was consistent with body weights, which also were lower for Black Hills deer when compared to those from eastern South Dakota

(Schmitz 2000). Our results indicate that antler characteristics of South Dakota deer are comparable to populations in other states. Moreover, nutritional history can affect antler characteristics likely requiring an additional year before males attain maximum size.

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EVALUATION OF TURF-TYPE BUFFALOGRASS FOR LOW-INPUT TURF IN SOUTH DAKOTA

Leo C. Schleicher and Wayne R. Ness
Department of Horticulture, Forestry, Landscape and Parks
South Dakota State University
Brookings, SD 57007

ABSTRACT

Buffalograss, *Buchloë dactyloides* (Nutt) Engelm., is a warm-season grass species native to the Great Plains from Canada to Mexico. Improved turf-type buffalograss, developed through breeding programs, offers better turfgrass quality than native buffalograss stands and requires less water, fertilizer, maintenance, and energy input than more commonly used turfgrass species. The purpose of this study was to compare turfgrass characteristics among buffalograsses and evaluate the potential of buffalograss as a desirable low-input turfgrass species in South Dakota. Nine vegetatively propagated buffalograsses, plugged on 30.5 cm centers, and seven seeded buffalograss cultivars, seeded at 146 kg ha^{-1}, were evaluated over a 3-yr period in South Dakota. Turfgrass quality, turfgrass density, and genetic color were visually rated on a 1 to 9 scale, with 9 = best and 5 = acceptable. Vegetative-type buffalograsses established faster than seeded cultivars, but all buffalograsses were 100% established by the end of the first growing season. Vegetative-types '120', '61', and '118' rated highest in turfgrass quality (≥ 7.4) among registered or commercially available buffalograsses, while the turfgrass quality of 'Bison' and 'Sharps Improved' was unacceptable (< 5.0). Turfgrass quality of vegetative-type buffalograsses was greater (7.3) than seeded cultivars (5.6). Winter injury to '609', 62% in 1999 and 35% in 2000, was unacceptable. Turfgrass density of vegetative-type buffalograsses (7.7) was greater than density of seeded cultivars (5.2). Turfgrass density of NE 93-166, 120, and 61 was excellent (>8.6), but density of 'Texoka', Sharps Improved, and Bison was unacceptable (< 5.0). Although 118 rated highest in genetic color among all buffalograsses, seeded-types rated higher as a group than vegetative-type buffalograsses. Canopy height of unmowed turf ranged from 11.3 to 25.9 cm. Mean canopy height was tallest for Texoka and Bison and shortest for 118 and NE 91-181. Cultivars Bison and 609 showed no visual signs of dormancy as late as 7 Oct. 1998 and 23 Sept. 2000. All other buffalograsses exhibited some dormancy signs at one or both of these dates. Results exemplify the diversity in turfgrass characteristics among buffalograsses and indicate that buffalograss is a logical alternative for low maintenance turf use in South Dakota. Among buffalograsses included in this study, 61 appears to be the best commercially available buffalograss and 'Tatanka', 'Cody', and 'Sharpshooter' appear to be the best seeded selections.

INTRODUCTION

Buchloë dactyloides, or buffalograss, is a major component of the shortgrass prairie that extends across the Great Plains from Southern Canada to Central Mexico (Wenger 1943, Beetle 1950). This native, warm-season grass species has received increased attention because of its potential as an ecologically efficient alternative turfgrass compared to more commonly used cool-season turfgrasses (Riordan et al. 1996). Traditional cool-season turfgrasses like Kentucky bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) are better adapted to regions of greater annual precipitation located primarily east of South Dakota (Turgeon 2002). Previous research in the Central and Southern Great Plains has shown buffalograss to be an excellent turf for low-maintenance lawns, golf course roughs, parks, cemeteries, rights-of-ways, and industrial sites (Riordan et al. 1993, Gaussoin 1998).

Buffalograss has demonstrated superior drought tolerance, cold hardiness, and reduced fertility, mowing, and pesticide requirements compared to traditional turfgrasses (Johnson et al. 1997). Breeding programs have produced newer turf-type buffalograss cultivars with finer leaf texture, greater density, improved genetic color, and increased recuperative potential than older forage-type buffalograsses (Riordan et al. 1993).

The objective of this study was to compare turfgrass characteristics among experimental and commercially available buffalograsses and to evaluate the potential of buffalograss as a low-input alternative turfgrass for South Dakota. No previous research evaluating turf-type buffalograss in South Dakota could be found in the literature.

MATERIALS AND METHODS

Sixteen experimental or commercially available buffalograsses were established in 1.5 m x 1.5 m field plots in a randomized complete block design (RCBD) with three replicates at the N.E. Hansen Research Center near Brookings, S.D., in 1998. Cultivars Bison, Cody, Sharps Improved, Sharps Improved II, Sharpshooter, Texoka, and Tatanka were seeded at 146 kg ha^{-1} on 19 May. Cultivars 61, 609, 120, and 118 and experimentals NE 91-181, NE 93-166, NE 93-170, NE 93-181, and NE 95-19 were established on 26 May from 6.4 cm dia. pre-rooted plugs planted on 30.5 cm centers. NE 91-181, NE 93-170, and NE 93-181 are male clones, while 609, 61, 120, 118, NE 93-166, and NE 95-19 are female clones. Germplasm designated "NE" are experimental accessions from the University of Nebraska buffalograss breeding program. Cultivars 61, 609, Bison, Cody, Sharps Improved, Sharps Improved II, Sharpshooter, Texoka, and Tatanka are commercially available.

Supplemental irrigation was applied daily until seed germination, then as needed to encourage establishment. Following establishment, irrigation was applied once in July 1998 and once in August 1998. No irrigation was applied in 1999 or 2000. Buctril (bromoxynil) octanoic acid ester was applied on 3 June and 29 June in 1998 at 1.12 kg ha^{-1} for common purslane control; otherwise, weed control was performed by hand-pulling. A 12-24-12 starter fertilizer was applied at 49 kg N ha^{-1} on 3 June. Each year of the study, plots were mowed 1 to 2 times at 5 or 8.9 cm and fertilized in June and July at 49 kg N ha^{-1} with a 25-4-12 fertilizer.

Turfgrass quality, genetic color, and turfgrass density were evaluated on a 1 to 9 scale with 9 indicating the best. There was no statistical difference between years for genetic color so data were pooled. Winter injury and establishment were rated as percent of plot injured and percent of plot covered with buffalograss, respectively. Dormancy was evaluated on a 1 to 4 scale, with 4 indicating no sign of dormancy. Data were subjected to analysis of variance using the General Linear Model Procedure (SAS Institute 1991). Mean separations were calculated using Fishers Least Significant Difference test (LSD) at the 0.05 probability level.

RESULTS AND DISCUSSION

The negative impact of weed competition on buffalograss establishment in this study was similar to previous reports (Harivandi et al. 1995, Fry et al. 1997, Gaussoin 1998). Although bromoxynil controlled small weed seedlings postemergence, herbicide efficacy decreased substantially when applied several weeks after weed emergence and many hours of hand-pulling weeds were required in the initial year of establishment. Once plots became established with buffalograss, weed infestation was minimal and all cultivars were 100% established by 1 Aug. 1998. For commercial establishment, weed control by hand-pulling may not be necessary since pendimethalin and oxadiazon preemergence herbicides are labeled for use in vegetative buffalograss establishment and imazapic is labeled preemergence for seeded buffalograss establishment.

Collectively, vegetatively propagated buffalograsses rated higher in establishment rate, turfgrass density, and turfgrass quality compared to seeded cultivars (Table 1). Buffalograsses that establish faster may have decreased weed infestation initially; however, it is unclear if differences in this study are due to individual cultivar growth rates or differences between vegetative and seeded establishment methods. Adjusting seeding rate and/or the distance between vegetative plugs may alter the results obtained in this study.

Vegetative-types 61, 120, and 118 rated higher in turfgrass quality than all other commercially available buffalograsses (Table 2). Cultivars Sharpshooter, Cody, and Tatanka rated higher than all other seeded cultivars but not as high as vegetative-type buffalograsses except NE 93-170. Cultivars Sharps Improved and Bison were unacceptable (< 5).

Winter injury was acceptable for all buffalograsses except 609 which had 62% injury in 1999 and 35% injury in 2000. Cultivar 609 is a southern-adapted buffalograss, and similar injury has been reported in Lincoln, NE (Westerholt and Riordan 2000). NE 93-166, 61, and 120 rated higher in turfgrass density than all other buffalograsses except NE 93-181. Turfgrass density of Bison, Texoka, and Sharps Improved was unacceptable (< 5).

Table 1. Comparison of seeded vs. vegetative buffalograss types at the N.E. Hansen Research Facility, Brookings, SD, 1998-2000.

Type	Pct.[1] Estab.	Density[2]	Genetic[3] Color	Maximum[4] Canopy Ht.	TURFGRASS QUALITY[5] 1998	1999	2000	Mean
Vegetative	60.9	7.7	4.7	24.5	6.9	7.4	7.6	7.3
Seeded	44.8	5.2	5.4	31.0	5.5	5.7	5.2	5.5
Mean	53.9	6.6	5.0	27.7	6.3	6.7	6.6	6.5
LSD (0.05)	8.3	0.7	0.5	2.2	0.4	0.6	0.6	0.3

[1] Percent establishment 0-100; rated 7 Jul. 1998
[2] Density 1-9; 5 = acceptable, 9 = highest; rated 11 Jul. 2000
[3] Genetic color 1–9; 1 = bluish/gray, 9 = dark green; rated 7 Jul. 1998 and 28 May 1999
[4] Maximum canopy height (cm) measured during study
[5] Turfgrass visual quality 1–9; 1 = dead turf, 5 = acceptable, 9 = excellent

Table 2. Evaluation of commercial and experimental buffalograss at the N.E. Hansen Research Center, Brookings, SD, 1998-2000.

Cultivar	Genetic[1] Color	Turf[2] Density	WINTER INJURY[3] 1999	2000	FALL DORMANCY[4] 10/7/98	9/23/00	TURF QUALITY[5] 1998	1999	2000	Mean
‘120’	4.8	8.7	3.3	0.0	3.3	2.3	6.7	8.0	8.3	7.7
‘61’	4.5	9.0	0.0	0.0	3.7	2.0	6.7	8.0	8.0	7.6
NE 93-181	5.7	8.0	1.7	0.0	4.0	4.0	7.7	7.0	8.0	7.6
‘118’	6.7	7.7	8.3	0.0	4.0	2.3	7.0	7.3	8.0	7.4
NE 93-166	4.3	9.0	0.0	0.0	3.3	2.0	6.0	8.7	7.7	7.4
NE 95-19	5.2	7.0	0.0	0.0	3.7	2.3	6.7	7.7	7.7	7.3
‘609’	5.3	5.7	61.7	35.0	4.0	4.0	8.0	6.0	7.0	7.0
NE 91-181	4.5	7.3	0.0	0.0	2.7	2.0	7.0	7.0	6.7	6.9
NE 93-170	4.0	7.0	0.0	1.7	3.0	2.0	6.0	7.3	7.0	6.8
‘Sharpshooter’	5.7	6.7	1.7	0.0	4.0	3.3	6.0	7.0	6.3	6.4
‘Tatanka’	5.8	6.7	0.0	0.0	3.3	3.0	6.0	6.7	6.3	6.3
‘Cody’	5.5	6.0	3.3	1.7	3.3	3.0	6.0	6.7	6.0	6.2
‘Sharps Improved II’	5.5	5.0	8.3	0.0	4.0	3.7	5.7	5.7	5.7	5.7
‘Texoka’	5.7	4.7	0.0	0.0	4.0	3.7	5.0	5.0	5.0	5.0
‘Sharps Improved’	5.2	4.0	10.0	0.0	4.0	3.7	4.7	4.7	3.7	4.3
‘Bison’	5.2	3.7	6.3	0.0	4.0	4.0	5.0	4.0	3.7	4.2
Mean	6.5	6.6	6.5	2.4	3.6	3.0	6.3	6.7	6.7	6.5
LSD (0.05)	8.6	0.9	8.6	4.0	0.7	0.8	0.6	0.7	1.08	0.5

[1] Genetic color 1–9; 1 = bluish/gray, 9 = dark green
[2] Density 1-9; 9 = highest density
[3] Percent of plot injured; 0 = no injury, 100 = entire plot killed
[4] Dormancy 1–4; 1 = total plot dormant, 2 = plot nearly dormant, 3 = plot beginning dormancy, 4 = no sign of dormancy
[5] Visual quality 1–9; 1 = dead turf, 5 = acceptable, 9 = excellent

Vegetative-type 118 rated higher than all other buffalograsses in genetic color. Seeded cultivars, as a group, rated higher in genetic color than vegetative-type buffalograsses as a group. Vegetative-type 61 rated among the poorest in genetic color in this study; in contrast to excellent genetic color reported elsewhere (NTEP Buffalograss Report 2001, Westerholt and Riordan 2000). Native buffalograss color has been described as "gray-green", "grayish-green", and "green to blue-green" (Wenger 1943, Beetle 1950, Johnson et al. 1997), when compared to the more desirable dark green color typical of most cool-season turfgrasses. The range of color rating values from 1 to 9 in this study indicates the subjective preference for the more commonly desired green color. However, the color range from native blue-grey-green to dark green may have little impact on the desirability of a particular cultivar when all rating variables are considered together.

Short canopy height is desirable for low-input turf since mowing frequency may be decreased or eliminated without loss of aesthetic quality. During the 3-yr study, maximum canopy height among buffalograsses ranged from 11.3 to 31 cm when measured prior to mowing. Mean canopy height was tallest for Texoka and Bison and shortest for 118 and NE 91-181. A relative comparison of mean canopy height among buffalograsses in Figure 1 indicates a shorter canopy height of vegetative-type buffalograsses compared to seeded cultivars.

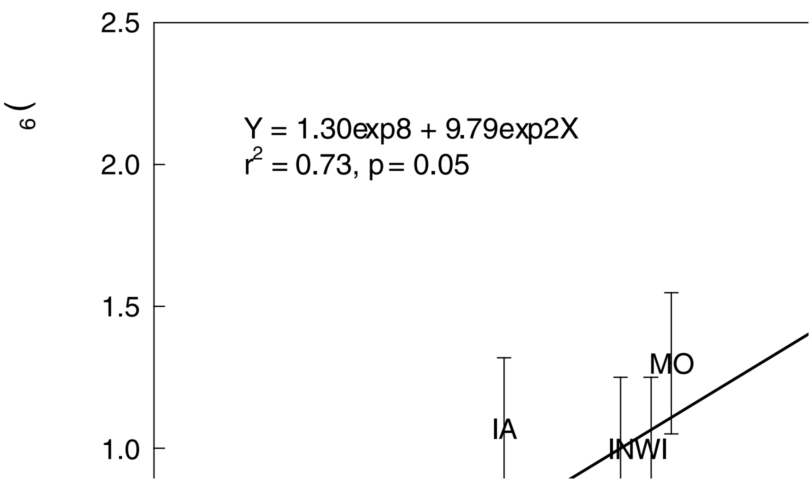

Figure 1. Relative comparison of canopy height among cultivars measured 86 days after mowing at 8.9 cm on 23 Sept. 1999, and 44 days after mowing at 5.1 cm on 21 Jun. 2000.

Buffalograsses retaining summer color into fall are generally more desirable compared to those that begin dormancy earlier. Bison and 609 showed no signs of dormancy as late as 7 Oct. and 23 Sept. in 1999 and 2000, respectively. However, 61, NE 93-166, NE 91-181, and NE 93-170 were nearly dormant on 23 Sept. in 2000. Delayed dormancy in some buffalograsses may indicate potential winter injury. Excluding 609, buffalograsses exhibiting no dormancy (4.0) on 7 Oct. 1999 averaged 5.2% winter injury the following spring while cultivars indicating at least some dormancy averaged 0.8% winter injury.

Results of this study indicate that turf-type buffalograsses can provide a sustainable, low-input alternative turf that is well suited to South Dakota. Compared to typical cool-season turfgrasses, buffalograss requires less mowing, water, fertilizer, and pesticides.

Differences among cultivars exemplify the diversity in buffalograss germplasm. Our results indicate that 61 would provide the highest quality turf among commercially available cultivars and that Tatanka, Cody, and Sharpshooter are the seeded cultivars of choice.

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FOOD HABITS OF COYOTES INHABITING THE BLACK HILLS AND SURROUNDING PRAIRIES IN WESTERN SOUTH DAKOTA

Jacquie R. Gerads
North Dakota Game and Fish Dept.
Bismarck, ND 58501

Jonathan A. Jenks and Bryan K. Watters
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

ABSTRACT

We examined the relationship between coyote *(Canis latrans)* food habits and relative density indices (RD) in the Black Hills and surrounding prairies (westcentral and northwest) of western South Dakota. Relative density indices (RD = # scats/km/day) were estimated, and 150 scats were collected along 57 fecal line transects from February – October 1998. Overall mean relative density indices were 57.9 in the Black Hills, 43.6 in the westcentral prairie, and 10.4 in the northwest prairie. Correction factors were used to associate relative frequencies of prey remains in feces to actual amount of prey consumed. In the Black Hills and prairie regions, mammals occurred most frequently, as measured by percent-of-scats, followed by vegetation, invertebrates, and birds. Mammals also comprised the greatest portion of coyote diets, as determined by fresh-weight-of-prey. Within the mammalian category, small mammals occurred most frequently, but white-tailed deer *(Odocoileus virginianus)* comprised the largest portion of diet by fresh weight in the Black Hills. This may be due to higher relative density indices of coyotes and increased vulnerability of a declining deer population in the Black Hills as compared to the surrounding prairie region. Conversely, small and medium-sized mammals occurred most frequently and comprised the largest portion of diet by fresh weight in the prairie region. An opportunistic predator such as the coyote may have adjusted its feeding strategy to meet local conditions in the Black Hills and prairie regions of South Dakota.

Keywords

Canis latrans, correction factors, coyote, diets, food habits, western South Dakota

INTRODUCTION

Coyotes are one of the most important and abundant predators in the prairie region of the central United States (Brillhart and Kaufman 1994). As a predator, the role of the coyote in the biological community holds great interest, particularly with respect to management issues of control and conservation (Caughley and Sinclair 1994). Tremendous effort has been directed toward understanding the effect of coyote predation on big game and domestic livestock (MacCracken and Uresk 1984). Understanding food habits and predator-prey dynamics is fundamental for determining the role of carnivores in ecosystems (Korschgen 1980). Numerous factors in the predator-prey relationship, e.g., abundance and availability of prey, play important roles in species ecology and may influence population dynamics of predators (Windberg 1995). Effects of predators on their prey populations are determined by their numerical and functional responses to prey densities (Solomon 1949).

Information gained from food habit studies can be used by wildlife managers to better understand preferred foods, to assess wildlife damage to crop and livestock, and to assess the role of nutrition in population dynamics. Coyotes are often associated with predation on domestic livestock (Connolly et al. 1976, Shivik et al. 1996), poultry, waterfowl (Sargeant et al. 1993, Sovada et al. 1995), and other wildlife species (Clark 1972). Furthermore, increased concern toward predators by ranchers and wildlife managers coincides with increasing predator densities.

As opportunistic predators, coyotes have the ability to change their diet both spatially and seasonally in response to changing prey availability (Clark 1972, Todd and Keith 1983, Parker 1986). Coyote food habits have been examined in many areas including the Black Hills (MacCracken and Uresk 1984), southwest North Dakota (Lewis et al. 1994), and Nebraska (Huebschman et al. 1997). However, food habit and predator density studies are limited in the prairie region of western South Dakota. The purpose of this study was to determine food habits of coyotes in the Black Hills and prairie regions of western South Dakota by incorporating correction factors from coyote feeding trials conducted by Kelly (1991). Furthermore, we wanted to examine the relationship between relative density indices and food habits of coyotes in the Black Hills and prairie regions of South Dakota.

STUDY AREA

Our study was conducted within two regions (i.e., Black Hills and prairie) of western South Dakota. The Black Hills region of South Dakota was comprised of portions of Lawrence, western Pennington, and Custer counties. The prairie region consisted of a westcentral study area represented by Haakon and north Jackson counties and a northwest study area located in Harding County (Fig. 1).

The Black Hills region is an isolated mountainous area in western South Dakota and northeastern Wyoming. Elevations in the Black Hills range from 973 to 2,202 m (Turner 1974). The Black Hills have both semi-arid continental and mountain climate types. Dominant overstory vegetation in the Black Hills consists of ponderosa pine *(Pinus ponderosa)* and white spruce *(Picea glauca)* interspersed with small stands of aspen *(Populus tremuloides)* and paper birch *(Betula papyrifera)* (Thilenius 1972). Primary understory vegetation

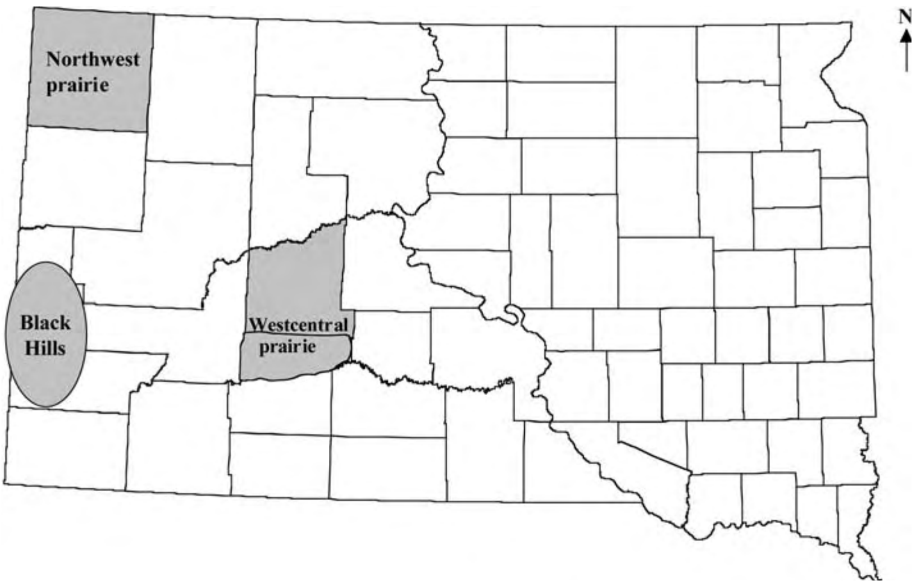

Figure 1. Location of Black Hills, northwest, and westcentral study areas located in western South Dakota.

consists of snowberry *(Symphoricarpos albus),* spiraea *(Spiraea betulifolia),* serviceberry *(Amelanchier alnifolia),* bearberry *(Arctostaphylos uva-ursi),* and juniper *(Juniperus communis).* Forests are managed by the USDA Black Hills National Forest primarily for timber production and livestock grazing. Common wildlife species in the Black Hills are deer (*Odocoileus* spp.), pronghorn *(Antilocapra americana),* elk *(Cervus elaphus),* wild turkey *(Meleagris gallopavo),* bighorn sheep *(Ovis canadensis),* mountain lions *(Felis concolor),* and golden eagles *(Aquila chrysaetos).*

Approximately 80% of the land in the westcentral and northwest prairie region is rangeland with the remaining land being cultivated crops, tame pasture, and hay (Faulkner 1997, Johnson 1988, Schlepp 1987). Common vegetation in the westcentral and northwest prairie regions includes western wheatgrass *(Agropyron smithii),* green needlegrass *(Stipa viridula),* blue grama *(Bouteloua gracilis),* and prairie Junegrass *(Koeleria pyramidata).* Dominant shrubs in the northwest prairie area include silver sagebrush *(Artemisia cana)* and big sagebrush *(A. tridentata).* Common wildlife species on the prairies are deer, pronghorn, grouse *(Tympanuchus phasianellus),* jackrabbit *(Lepus townsendii),* red fox *(Vulpes vulpes),* badger *(Taxidea taxus),* and prairie dogs *(Cynomus ludovicianus).*

METHODS

Coyote fecal samples were collected from 57 established fecal line transects located in western South Dakota (Gerads 2000) from February – October 1998. Samples from the westcentral and northwest prairies were analyzed together and separately. Collected coyote fecal samples were stored in a –80° C freezer for 24 hours and then oven dried at 60° C for 24 hours to kill eggs of *Echinococcus* spp. (Colli and Williams 1972). Each sample, along with an identification label, was secured in a ripstop nylon bag (18- x 18-cm), soaked in hot water for ≥ 48 hours (Johnson and Hansen 1979), and squeezed and kneaded to breakdown the fecal matrix (Springer and Smith 1981). A group of 50-bagged samples was washed in an automatic clothes washer and then dried in a clothes dryer (Johnson and Hansen 1979).

Food items were hand-separated into holding containers and each diagnostic part (e.g., hair and teeth) was counted by species. An electronic balance was used to weigh the amount of bone, hair, and other diagnostic parts by species (Kelly 1991). A roller press was used to obtain cuticular impressions of guard hairs on acetate strips (Bowyer and Curry 1993) and reference collections and other materials were used to identify food items (Adorjan and Kolenosky 1969, Jones and Manning 1992, Moore et al. 1974). Food items were separated into categories based on prey size and type (Huebschman et al. 1997). The mammal category was separated into five subcategories: 1) small-sized mammals, e.g., mice (*Peromyscus* spp.) and voles (*Microtus* spp.), 2) lagomorphs, 3) medium-sized mammals, e.g., raccoon *(Procyon lotor),* prairie dog, and pocket gopher *(Thomomys talpoides),* 4) deer/pronghorn, and 5) livestock, e.g., domestic cattle and bison *(Bison bison).* Other categories included birds, vegetation, invertebrates, and unknown.

Food habits were quantified by percent-of-scat (POS) and by percent-fresh-weight-of-prey (PFWP). Percent-of-scat (or frequency of occurrence) is the percent of a sample of fecal piles in which a prey species occurred (Kelly 1991) and describes how common an item is in a diet. Percent-of-scat was calculated using the formula: (# times prey species occurs / # fecal piles examined) x 100. Percent-fresh-weight-of-prey is measured by using 1) a correction for the amount of a prey item represented by its remains in a fecal sample, 2) how frequently a prey item occurred in a sample of fecal piles, and 3) the amount of a fecal pile attributable to each prey item (Kelly 1991). We used the tooth-detection model and visual estimates to apportion fecal pile contents and the kg-per-scat estimators (Kelly 1991). Because POS does not equate to percent of diet and detection rates of prey items in scats may vary with prey and/or meal size, correction factors from coyote feeding trials (Kelly 1991) were used to associate relative frequencies of prey remains in fecal piles to the actual amount of prey consumed using Program Scat 1.5 (Kelly and Garton 1993). Values based on PFWP correction factors are additive, not overlapping like POS values. Moreover, no correction factors are currently available for food items composed of vegetation or large food items such as bison and cattle. These large prey species exceeded the largest prey size allowable by the coyote regression model.

Relative densities of coyotes in western South Dakota were estimated using fecal line surveys (Gerads 2000). Overall mean relative density indices for coyotes were 57.9 in the Black Hills, 43.6 in the westcentral prairie, and 10.4 in the northwest prairie (Gerads 2000). Food habits and relative density indices of coyotes were qualitatively compared within and across study areas located in western South Dakota. Relative density (RD) of predators was determined using the formula: RD = (# fecal piles / 1.61 km / # days between collection periods) x 1000 (Gerads 2000).

RESULTS

A total of 100 fecal samples was analyzed from the Black Hills and 50 fecal samples from the prairie region; all samples were collected in 1998. Seasonal trends could not be evaluated for coyote diets due to the small number of samples analyzed in each month. Relative density indices were calculated for coyotes in the Black Hills and westcentral and northwest prairie regions for 1998.

Black Hills

Mammalian prey remains occurred most frequently (99.0 POS) in coyote diets in the Black Hills region in 1998, followed by vegetation (79.0 POS), invertebrates (32.0 POS), and birds (8.0 POS) (Table 1). Small-sized mammals, deer/pronghorn, and medium-sized mammals were among the most common categories of mammalian prey (76.0, 55.0, 25.0 POS, respectively). Most common small mammal species included voles *(Microtus* spp.) and mice *(Peromyscus* spp.), and medium-sized mammals included raccoon, prairie dogs, porcupine *(Erethizon dorsatum),* and northern pocket gopher. Less common species occurring in the fecal samples included birds (8.0 POS), lagomorphs (6.0 POS), and livestock, i.e., bison and cattle, (2.0 POS). Vegetation included wild plum *(Prunus americana)* and buffaloberry *(Shepherdia* spp.) and invertebrates consisted mainly of grasshoppers (Order Orthoptera).

According to PFWP calculations, mammals comprised the greatest part of the diet of coyotes in the Black Hills region (99.2 PFWP), followed by invertebrates (0.8 PFWP), and birds (<0.1 PFWP) (Table 1). Deer comprised the largest part of coyote diets within the mammalian category (64.4 PFWP), followed by small and medium-sized mammals (25.3 and 8.6 PFWP, respectively), and lagomorphs (0.9 PFWP). Although, livestock were a part of the diet, no correction factors were available to estimate PFWP.

Prairie region (westcentral and northwest)

Mammalian prey remains occurred most frequently (92.0 POS) in coyote diets in study areas located in the prairie region of western South Dakota in 1998, followed by vegetation (62.0 POS), invertebrates (28.0 POS), and birds (22.0 POS) (Table 1). Small-sized mammals occurred most frequently in the mammalian category (66.0 POS), followed by medium-sized mammals (38.0 POS), livestock (24.0 POS), lagomorphs (10.0 POS), and deer/pronghorn (4.0 POS). Voles, mice *(Peromyscus* spp., *Onychomys leucogaster, Zapus hudsonicus,* and *Reithrodontomys* spp.), pocket gophers, and prairie dogs were the most common mammalian prey items. Livestock consisted mainly of cattle and

Table 1. Annual percent-of scats (POS) and percent-fresh-weight-of-prey (PFWP) of food items found in coyote fecal samples collected February to October 1998 in the Black Hills and prairie regions of western South Dakota.

Study area	Food item	N	POS[a]	PFWP[b]
Black Hills	Mammals	99	99.0	99.2
	Small-sized mammals	76	76.0	25.3
	Lagomorphs	6	6.0	0.9
	Medium-sized mammals	25	25.0	8.6
	Deer/pronghorn	55	55.0	64.4
	Livestock	2	2.0	—[c]
	Birds	8	8.0	<0.1
	Invertebrates	32	32.0	0.8
	Vegetation	79	79.0	—
	Unknown	5	5.0	—
Prairie	Mammals	46	92.0	86.2
	Small-sized mammals	33	66.0	34.6
	Lagomorphs	5	10.0	8.4
	Medium-sized mammals	19	38.0	34.0
	Deer/pronghorn	2	4.0	9.2
	Livestock	12	24.0	—
	Birds	11	22.0	11.3
	Invertebrates	14	28.0	2.5
	Vegetation	31	62.0	—
	Unknown	5	10.0	—

[a] POS = (# times food item occurs / total # of fecal piles examined) x 100.
[b] PFWP was calculated using ratio and kg per scat estimators derived from coyote feeding trial data (Kelly 1991).
[c] No PFWP correction factors were available for livestock, vegetation, or unknown food items.

domestic sheep. Less common species included porcupine, raccoon, badger, and lagomorphs. Vegetation consumed included wild plum and grasses. Invertebrates consisted mainly of grasshoppers.

In 1998, PFWP of major categories for prey items of coyotes in the prairie region was 86.2 PFWP for mammals, followed by birds (11.3 PFWP), and invertebrates (2.5 PFWP) (Table 1). Small and medium-sized mammals (34.6 and 34.0 PFWP, respectively) comprised a large part of coyote diets within the mammalian category, followed by deer/pronghorn (9.2 PFWP), and lagomorphs (8.4 PFWP). Although livestock occurred in 24.0 POS, PFWP could not be calculated because no correction factors were available.

When dividing the prairie region into the westcentral and northwest study areas, small mammals were more common in the westcentral area (88.0 POS, 74.5 PFWP) whereas medium-sized mammals were more common in the northwest (56.0 POS, 43.6 PFWP) (Table 2). In the prairie areas, deer/pronghorn remains were found only in samples analyzed in the northwest study area.

Table 2. Annual percent-of scats (POS) and percent-fresh-weight-of-prey (PFWP) of food items found in coyote fecal samples collected February to October 1998 in west-central and northwest prairie regions of western South Dakota.

Study area	Food item	N	POS[a]	PFWP[b]
Westcentral	Mammals	24	96.0	85.7
	Small-sized mammals	22	88.0	74.5
	Lagomorphs	2	8.0	0.6
	Medium-sized mammals	5	20.0	10.6
	Deer/pronghorn	0	0.0	0.0
	Livestock	9	36.0	—[c]
	Birds	3	12.0	14.1
	Invertebrates	4	16.0	0.2
	Vegetation	12	40.0	—
	Unknown	0	0.0	—
Northwest	Mammals	22	88.0	86.5
	Small-sized mammals	11	44.0	18.2
	Lagomorphs	3	12.0	11.7
	Medium-sized mammals	14	56.0	43.6
	Deer/pronghorn	2	8.0	13.0
	Livestock	3	12.0	—
	Birds	8	32.0	10.1
	Invertebrates	10	40.0	3.4
	Vegetation	19	76.0	—
	Unknown	5	20.0	—

[a] POS = (# times food item occurs / total # of fecal piles examined) x 100.
[b] PFWP was calculated using ratio and kg per scat estimators derived from coyote feeding trial data (Kelly 1991).
[c] No PFWP correction factors were available for livestock, vegetation, or unknown food items.

DISCUSSION

Because POS (or frequency of occurrence) depends on the amount of food eaten, it tends to be more meaningful when reported with volume or weight expressed as a percentage of the sample (Korschgen 1980). Even though frequency data provide important information by measuring how pervasive a food item is in a diet, researchers tend to assume that frequency with which an item occurs within a scat corresponds to the amount of that item consumed. As prey species get larger, less of their mass consists of non-flesh components and therefore, fewer fecal samples are produced per unit weight (Kelly 1991). In other words, when using POS, small prey are overrepresented in biomass and underrepresented in numbers compared with larger prey. Kelly and Garton (1997) stressed the need for future consideration of the relationship between prey consumption and subsequent digestion. Additionally, Kelly and Garton (1997) cautioned against using the number of teeth or diagnostic bones to determine the number or amount of a prey represented by a fecal sample without addressing the variability in their recovery. Due to the variability in the recovery of bone and teeth and the lack of variability in the recovery of hair, we used teeth and bone to identify small rodents in coyote fecal samples, and then used a visual estimate of hair to apportion the fecal sample to the prey present as suggested by Kelly and Garton (1997).

Similar to other studies (Bowyer et al. 1983, Andelt et al. 1987, and Brillhart and Kaufman 1994), mammals were the most frequently occurring food item in coyote diets in all study areas located in western South Dakota. Also, the PFWP correction factors indicated that mammals comprised the majority of biomass in coyote diets in western South Dakota. In the Black Hills, small-sized mammals were the most common prey item. However, deer comprised the largest part of coyote diets. The POS results of this study were similar to those reported for other studies in western Montana (Reichel 1991) and in Yellowstone National Park (Murie 1940) in that voles were the most common coyote prey item. Also, MacCracken and Hansen (1987) and Ogle (1971) suggested that voles were more important than lagomorphs and/or deer in coyote diets. Hamlin et al. (1984) concluded that voles were a common food source for coyotes in eastern Montana only during years of high vole populations. Conversely, mice were a common food item in Minnesota (Berg and Chesness 1978) and the northwest prairie of South Dakota during our study. Andrews and Boggess (1978) concluded that mice, birds, and plants were most common in coyote diets during summer months in Iowa. Birds did not seem to be a major food source for coyotes in western South Dakota, nor were they in Minnesota (Berg and Chesness 1978). Fruits were common in coyote diets during berry ripening season in Minnesota and western South Dakota.

Other studies conducted in the Black Hills (MacCracken and Uresk 1984), southwestern North Dakota (Lewis et al. 1994), Nebraska (Huebshman et al. 1997), southwestern Oklahoma (Litvaitis and Shaw 1980), eastern Kansas (Brillhart and Kaufman 1994), and southwestern Colorado (Gese et al. 1988) demonstrated that deer were the most common food item of coyotes. Our results suggest that deer were not necessarily the most common prey item in the Black Hills, although they comprised the largest part of the total fresh weight of prey consumed. Most studies suggest that deer were more commonly found in fecal samples in late winter and spring, rodents during summer and fall, and insects and fruits in late summer and fall (MacCracken and Uresk 1984, Reichel 1991, Brillhart and Kaufman 1994, Huebschman et al. 1997). Berg and Chesness (1978) concluded that coyotes were more likely to take adult deer in January-March and fawns in April-July. Although deer were not the most frequent food item in western South Dakota, they were the second most frequent and interestingly, comprised the greatest part of coyote diets in the Black Hills based on PFWP correction factors. Small and medium-sized mammals comprised the greatest part of coyote diets in the prairie region based on PFWP correction factors.

Effects of predators on prey populations are determined in part by numerical (i.e., changes in reproduction, survival, immigration) and functional (i.e., changes in kill rates) responses to prey densities (Solomon 1949). Shifts in prey type and predation pressure may occur because of prey switching or other optimal foraging patterns (Patterson et al. 1998). These shifts may occur when the focus of a predator is switched from one prey type to another only after the "new" prey species becomes more abundant and provides more profitable hunting, or when numbers of the primary prey are low. Coyotes generally feed opportunistically on smaller mammals such as fawns of small ungulates, lagomorphs, and mice-size rodents (Kleiman and Brady 1978). However, in the presence of livestock, some coyotes may become efficient predators of domestic sheep (Connolly et al. 1976). Nevertheless, despite their presence, cattle and other livestock remains were negligible in fecal samples collected in study areas located in the Black Hills and other studies in this region (Lewis et al. 1994, MacCracken and Uresk 1984).

Compared to the Black Hills, deer/pronghorn were less frequent and small and medium-sized mammals more frequent in coyote diets in the northwest prairie. Reduction in the consumption of deer/pronghorn in the northwest prairie could be related to a decline in their abundance following the severe winter of 1996. Pronghorn numbers were reduced after the winter of 1996 (Schlueter 1999) such that coyotes may have switched their focus to more abundant and profitable prey, (i.e., small and medium-sized mammals). According to species richness data (V. Smith, South Dakota State University, Brookings, SD, unpublished data), small mammal diversity was moderate in the northwest prairie, moderate to high in the westcentral prairie, and highest in the Black Hills. Although we did not identify all food items to species, we did find at least 5 different species of small mammals in each of the study areas. Furthermore, because of low relative density indices of coyotes in the northwest prairie, group hunting for larger prey such as deer and pronghorn may have been more difficult; thus smaller prey may have been more profitable. Bowen (1981) indicated that packs were more successful than pairs or single coyotes in catching larger prey such as deer and that coyote group size increased in winter when large ungulates were in the diet.

Deer comprised the majority of coyote diets in the Black Hills but the lowest in the westcentral prairie. One possible explanation may be the high relative density indices of coyotes (Gerads 2000) and vulnerability of a declining white-tailed deer population in the Black Hills (Griffin 1994, DePerno et al. 2000). DePerno et al. (2000) stated that natural mortality (i.e., from coyotes, dogs, malnutrition, and sickness) of female white-tailed deer in the Black Hills was 71% with annual survival rates ranging from 50.3 to 62.1%. Conversely, Grassel (2000) concluded that existing forage quality was not limiting deer in the Missouri River Breaks region of westcentral South Dakota with annual survival ranging from 74.0 to 85.0%. This suggests that poorly nourished and weak deer in the Black Hills might be more susceptible to predation than were healthier deer in the westcentral prairie. Furthermore, coyotes will often take advantage of vulnerable deer (Hilton 1978) particularly in winter months. Perhaps with high coyote relative density indices and vulnerable deer in the Black Hills, coyote hunting strategies have been modified (e.g., group hunting). Patterson (1994) suggested that a critical factor in determining coyote killing rates of deer was their response to deer density and vulnerability. Unfortunately, it is impossible to determine if deer and livestock remains in coyote fecal samples are the result of direct predation or scavenging. However, anecdotal observations indicate that most coyote mortalities on adult deer in the Black Hills occur immediately post spring migration.

We were unable to investigate the numerous factors that can affect coyote foraging strategy and intensity of depredation in western South Dakota. Gier (1968) and Lemm (1973) stated that coyotes tend to attack more domestic livestock and poultry while raising young during summer months. In central Alberta, Todd and Keith (1976) demonstrated a positive relationship between coyote densities in winter and availability of dead livestock on agricultural land. Although food habits changed significantly between seasons, Bowyer et al. (1983) noted that coyote numbers did not change significantly suggesting coyotes are opportunistic feeders. We suggest that differences in coyote relative densities as well as vulnerable prey may explain differences in diets among our study areas. In addition to predator densities, habitat types, social status, prey abundance, and snow depth and hardness can significantly influence prey detection and hunting success by coyotes (Gese et al. 1996). Reichel (1991) suggested that even generalist predators would adjust their hunting strategies to accommodate local conditions.

MANAGEMENT RECOMMENDATIONS

Because ranching and hunting are important in South Dakota, ranchers and sportsmen are especially concerned with predation on livestock and game species. Increased concern toward predators by ranchers and wildlife managers coincides with increasing predator densities. Knowledge of abundance indices or trends in population abundance is useful for developing management programs and for understanding species ecology (Knowlton 1984). Relative density is an index of population abundance that may become useful to managers as multiple years of data are collected. This allows managers to monitor long-term seasonal and annual population trends. For instance, by using these indices, biologists may be able to monitor changes in density, reproduction, and/or predator-prey interactions.

Use of Program Scat 1.5 (Kelly 1991) provided a statistically valid representation of prey consumed by coyotes in various areas of western South Dakota. An accurate representation of prey consumed should prove worthwhile in helping to elucidate the underlying mechanisms of predator-prey dynamics. Future research needs to focus on all factors affecting coyote feeding strategies, including numerical and functional responses, social structure, prey abundance, detection and capture rates, habitat types, environmental conditions, and interspecific interactions. Furthermore, relationships between predator species, their food habits, and their influence on prey should be investigated to better understand and manage the community as a whole. Alternate prey population levels and cycles should be determined prior to decisions about whether or not to control coyotes to increase prey populations. Feeding trials are needed to develop applicable correction factors for larger prey items, e.g., elk, bison, cattle, and combinations of prey encountered in field conditions. It is important that the relationship between prey item recovered in fecal samples and the actual prey consumed be understood (Kelly 1991) before topics such as opportunistic feeding, optimal forage, competition among carnivores, and responses to changes in prey density can be addressed. Answering these types of questions can provide a more complete understanding of predator ecology and ultimately contribute to more efficient predator management strategies (Knowlton 1972).

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ENVIRONMENTAL CONTROLS ON FISH SPAWNING HABITAT IN SPEARFISH CREEK, BLACK HILLS, SD

Larry D. Stetler and Heidi L. Sieverding
Dept. of Geology & Geological Engineering
South Dakota School of Mines & Technology
Rapid City, SD 57701

ABSTRACT

Spearfish Creek, located in the northern Black Hills, SD, hosts the regions only naturally reproducing population of trout species. Success of the spawn is controlled by water conditions and availability of quality habitat. Spearfish Creek originates from springs emanating from the Mississippian Madison Limestone and as such, is supersaturated in calcium and magnesium. In summer, warm water temperatures promote precipitation of a calcium rind onto the bottom sediment effectively cementing them in place and making spawning difficult for Brown trout, a fall spawning fish. In winter, as water temperatures fall, calcium dissolution increases and the rind is weakened. In addition, algal growth occurring in winter coats the rind with biologic matter that when it decays, releases CO_2 and further weakens the cement rind. During the spring spawn, Rainbow trout have an increased habitat as much of the rind is shed from the sediment or destroyed by the fast moving water.

Groundwater models indicate that upwelling from the Deadwood aquifer occurs along portions of Spearfish Creek. At a constant temperature, these waters create warm spots in the winter and cool spots in the summer, further controlling the formation and distribution of the cement rind. The most favorable spawning habitat, which is cement-free, is located above the upwelling sites. Other favorable habitat is located at the confluence of Squaw Creek where a cement-free gravel delta is utilized both in fall and spring.

Keywords

Spearfish Creek, fish habitat, spawning, geochemistry, groundwater modeling, upwelling, calcite cementation

INTRODUCTION

Naturally reproducing trout in Spearfish Creek are limited in spawning success to the amount and location of available and suitable habitat. The purpose of this study was to determine geochemical controls and timing of the formation and destruction of a calcitic cement on channel bottom sediments in the main channel and identify impacts to available spawning habitat. The study was conducted with the cooperation of the SD Dept. of Game, Fish, and Parks.

STUDY LOCATION AND LOCAL CONDITIONS

The study area is located on Spearfish Creek between Homestake Mining Co. Hydroelectric Power Plant Number Two (Hydro No. 2) and Maurice intake (a diversion tunnel supplying Hydro No. 1 in Spearfish) and is about 10 miles south of the city of Spearfish, SD. (Fig. 1).

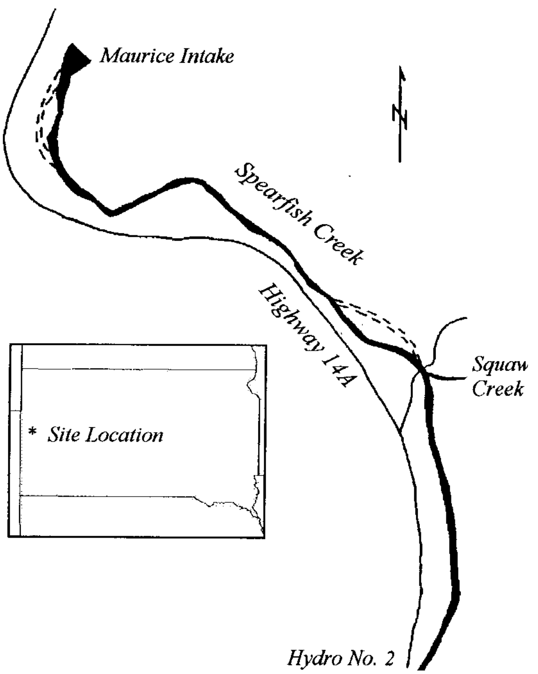

Figure 1. Study area location map.

There are two streams in the study area. The larger of the two, Spearfish Creek, originates from springs emanating from the Mississippian Madison Limestone. Flow in this stream is predominately northward. A shallow alluvial aquifer surrounds the surface flow in Spearfish Creek and contains both gaining and losing reaches. The smaller stream, Squaw Creek, enters Spearfish Creek about 0.5 km below Hydro No. 2. This creek sources from springs and seeps within the Cambrian Deadwood formation aquifer east of Spearfish Canyon and flows westward. This stream appears to be a gaining stream throughout its length.

Spearfish Creek has a single channel in the study reach with a sinuosity <1.11 (Mussetter 1997). The low sinuosity implies a mostly straight channel but it does meander through the bedrock of the canyon within which it flows. The main channel in Spearfish Creek consists primarily of cobbles and boulders with smaller sized gravels and pebbles filling the voids between the larger clasts. The dominate composition of the clasts is limestone. Squaw Creek consists of much the same sized clasts as Spearfish Creek but is composed mostly of sandstone derived from the Deadwood formation and igneous material derived from local intrusive bodies. Bank-attached gravel bars are located within the study area, mainly at the confluence of Squaw Creek, which delivers abundant gravel into the main channel. Small in-channel sediment bars are found immediately upstream of Maurice intake giving this reach of channel a braided appearance during low flow.

In the study area, the surface waters serve many functions: 1) Spearfish Creek and the associated shallow alluvial aquifer through which it flows constitute the drinking water source for the cities of Spearfish and Belle Fourche. Intake for the drinking water is about 3 km below Maurice intake. 2) Water is diverted out of the main channel to power two hydroelectric plants owned and operated by Homestake Mining Co. 3) The waterway is a popular recreational site for hiking and fishing.

Within this section of Spearfish Canyon, the geology is dominated by north-dipping Paleozoic-age strata and is capped by Holocene and recent alluvium along the stream channels. The Cambrian Deadwood formation is the oldest rock unit exposed and forms the steep canyon walls along the Squaw Creek drainage. It is the primary bedrock throughout the study area and underlies most of Spearfish Creek and its alluvium. Minimal exposures of Deadwood formation are seen in the main canyon. The overlying Ordovician Whitewood and Winnipeg formations are present at or very near the base of the canyon at Maurice intake. Above the base of the canyon walls near Maurice intake, the Devonian Englewood formation is present but is mostly covered by talus slopes. The main walls of Spearfish Canyon are formed from the massive limestone of the Mississippian Pahasapa (Madison) formation and are capped in the highest portions of the canyon by the Pennsylvanian Minnelusa formation. This massive cliff extends up to 800 feet above the stream level. West of Hydro No. 2, a thick sill of Tertiary phonolite has intruded into the Deadwood formation creating local changes in dip in the Deadwood. The youngest strata present in the canyon is Quaternary alluvium and colluvium that drape the canyon base and walls.

The primary landform in the study area is the prominence of Spearfish Canyon which is a structurally controlled canyon situated between a N-S extending structural lineament. To the south, the Fanny Peak Monocline forms a large fold in the Pahasapa formation. This trend is continued north of the Black Hills as the Belle Fourche Anticline folds the younger Mesozoic strata. The offset between these two features forms a deep, N-NE trending canyon in which Spearfish Creek flows (Lisenbee, 1985).

This reach of Spearfish Creek is inhabited by three trout species: *Salmo trutta* (Brown trout), *Oncorhynchus mykiss* (Rainbow trout), and *Salvelinus fontinalis* (Brook trout), all of which are non-native to the Black Hills. Recent fish census show that Brown trout are both the most abundant and the largest of the three species averaging 150-200 fish per 100 m of stream length and grow to an average of 256 mm in length. Rainbow trout populations have fluctuated during the past fifteen years between 40 and >200 fish per 100 m with an average size of 106 mm. Brook trout average <5 per 100 m and any fish over 100 mm is rare (SD GFP, 2001).

The study area has been managed by the South Dakota Department of Game, Fish, and Parks since 1985 as a catch-and-release fishery in order to protect a unique, self-sustaining Rainbow trout population (SD GFP, 2001). The policy was most recently modified in January 1997 allowing a daily harvest of five Brown or Brook trout, of which only one fish could be over fourteen inches in length. All Rainbow trout captured must be released. The effectiveness of this policy is that this reach of Spearfish Creek has not been stocked since the establishment of the catch-and-release policy in 1985.

Fish populations are monitored through an annual electro-shocking program conducted at specific site locations. To complete the census, a 100 m section of the creek is netted to prevent fish from escaping or entering the area. Using an electro-shocking method, three length-passes are made of the site where hand-held nets are used to scoop up the temporarily paralyzed fish. These fish are held in holding tanks until they can be individually identified, weighed, and measured for each pass. A statistical technique uses the reduction in number of captured fish per pass to estimate the total fish population within the section. These data provide a good picture of the success of natural spawning of the trout species living in Spearfish Creek.

STUDY METHODS

The water in Spearfish Creek is super-saturated in calcium and magnesium from dissolution of limestone as it flows through the Pahasapa formation. In Spearfish Creek, calcite is precipitating on bottom sediment due to this oversaturation. According to Krauskoph and Bird (1995), the chemical equation that governs calcite precipitation and dissolution is:

$$Ca^{2+} + 2HCO_3^- \longleftrightarrow CaCO_3 + H_2CO_3 \qquad (1)$$

The process of precipitation appears to be driven by water temperature fluctuations since the solubility of calcite increases as temperature decreases. This means that during summer, calcite is precipitated forming a 'cement' rind on the basal sediments and during winter, the calcite rind is weakened and/or dissolved. Moreover, the rind appears to consist of alternating layers (Fig. 2). Algal growth during the winter forms a thin green-black organic layer which alternates with an ~1/8 inch thick layer of calcite that forms during the summer. The warmer the summer is, the thicker the rind becomes. Evidence obtained from samples support the hypothesis that as the algal layer decays, the lowermost calcite layer (that nearest the sediment surface) is weakened from both temperature dissolution and release of CO_2 from the decomposition process of organic material. The solubility of calcite depends on the CO_2 present within the system since the carbon dioxide concentration helps to determine the concentration of dissolved H_2CO_3 (carbonic acid) by the reaction (Krauskoph and Bird 1995),

$$H_2O_{(l)} + CO_{2(g)} \longleftrightarrow H_2CO_{3(aq)}. \qquad (2)$$

These processes create planes of weakness within the rind structure. In early spring, clasts in all portions of the channel begin to show a 'shedding' of the rind (Fig. 3) and many clasts are no longer cemented to the substrate. Shedding of the rind continues until warmer water temperatures promote calcite crystallization. Any particular rind may persist for several seasons before being destroyed. As a result of these reactions, the maximum thickness of the rind is typically limited to less than 2.0 cm.

Figure 2. Alternating layers of calcitic rind from Spearfish Creek. The dark color layers contain algal growth. Note the dissolution occurring near the bottom, which is the part of the rind that would be in contact with the sediment.

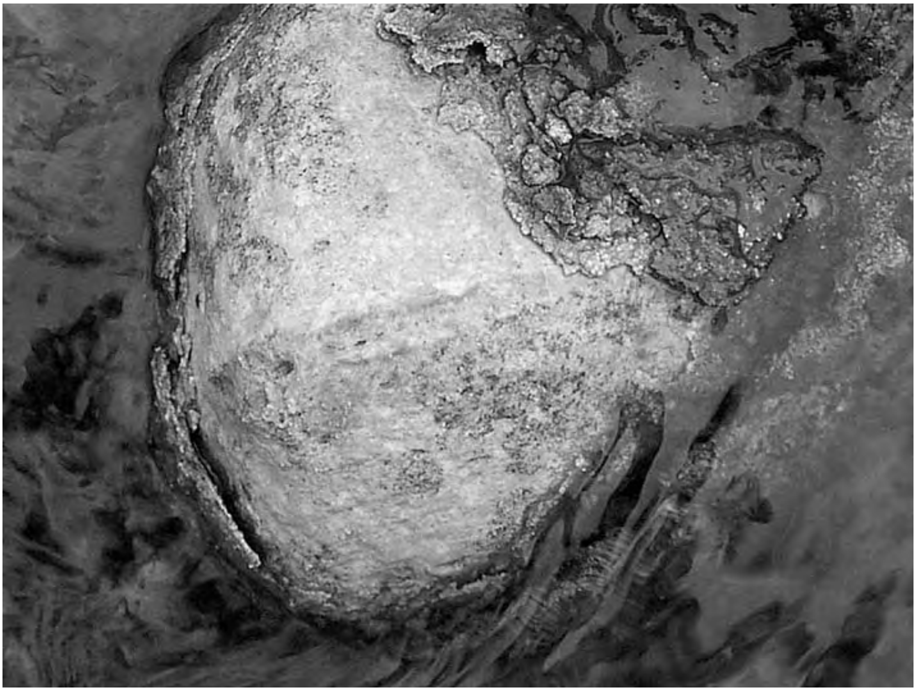

Figure 3. Limestone boulder in Spearfish Creek shedding its calcitic rind. Note the scaling of the rind and the clean upper surface.

Ground-water temperature is approximately 10°C and remains fairly consistent between summer and winter, however, surface water temperatures show large seasonal changes (Fig. 4). It is the continual upwelling of constant temperature groundwater into the main channel that creates warm 'spots' in the winter and cool 'spots' during the summer. It is these cool 'spots' that are significant to the calcite precipitation; by reducing the temperature of the water and therefore, the saturation of the calcium, calcite precipitation is reduced. The location this is most evident is immediately upstream from Maurice intake where sediments were disturbed approximately two years ago during a fish-habitat improvement project (Mussetter 1997). In comparison to other upstream locations where the sediments were also recently disturbed, the rind upstream of Maurice intake is visibly thinner (<1mm) and has been attributed to the upwelling water from the Deadwood aquifer which underlies this area. By comparison, the rind is thickest (>1 cm) near Hydro No. 2 where no evidence of upwelling occurs.

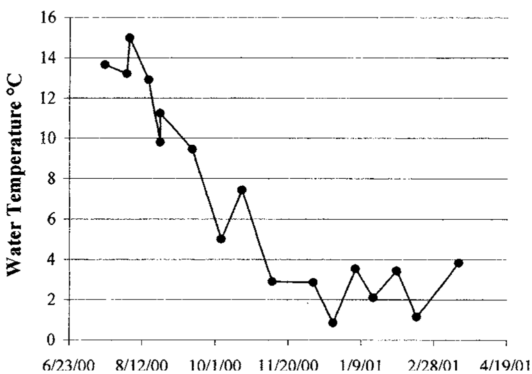

Figure 4. Water temperature variations in Spearfish Creek from summer to winter.

Three formations in the immediate area contain aquifers; the Pahasapa, Minnelusa, and Deadwood formations. However, local and regional Tertiary intrusive activity has produced fractures in many other units creating a situation where, for example, the Winnipeg formation, which would normally function as an aquitard, is present as an aquifer. This situation has produced areas of upwelling as well as loss zones within the main channel of Spearfish Creek. The overall ground-water flow direction for the primary aquifers is NW (Strobel et al., 2000).

Data on all local wells were acquired from the United State Geologic Survey (USGS) database. Subsurface flow were classified into two categories based on water-level elevation, geologic unit, and topographic location: 1) flow controlled by Pahasapa/Minnelusa aquifers, and 2) flows controlled by the Deadwood aquifer. Visual ModFlow was used to create regional potentiometric maps for each of these layers. Figure 5 was created using observed seeps and spring locations within the study area and indicates that both Squaw Creek and Spearfish Creek are gaining water from the Deadwood aquifer controlled layer.

Additionally, seepage may be also be occurring from the Pahasapa/Minnelusa aquifer controlled layer in the immediate area of Maurice intake. Several seeps were also observed in the Deadwood formation within Squaw Creek

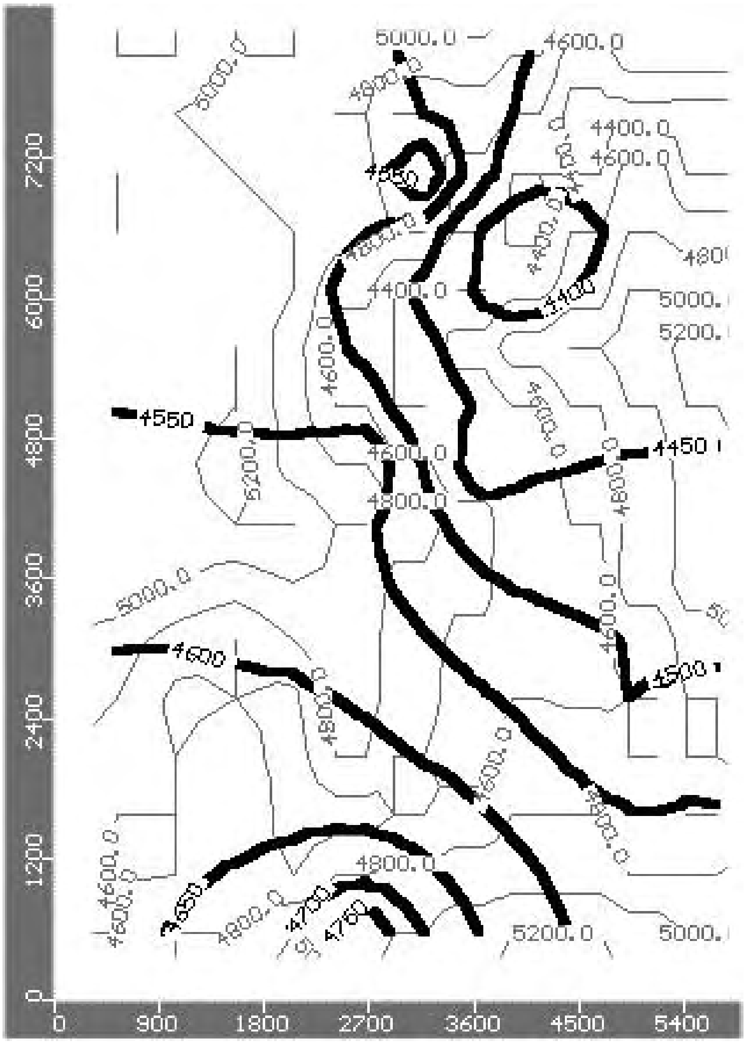

Figure 5. Groundwater model showing Potentiometric surface and upwelling above Maurice intake (4400' contour).

Canyon. No visual seeps or springs were observed from the Pahasapa or Minnelusa formations along the canyon walls. This was not surprising since any seeps that would be present would be covered by colluvium and alluvium near the base of the canyon.

Within the main channel there are three primary locations of upwelling water: below Maurice intake, seven meters upstream from Maurice intake, and on the south side of Squaw Creek Canyon. The source of upwelling below Maurice intake appears to be from both the alluvial and Deadwood aquifers. Approximately seven meters upstream from Maurice intake a measurable difference in water temperature exists as well as a difference in the thickness of the calcitic rind, further indicating a zone of upwelling. Large areas of gravel bars remain cement free throughout the year. Based on chemistry and temperature, the source of this ground-water appears to be the Deadwood aquifer. In Squaw Creek Canyon, springs and seeps along the south side are due to down-cutting of Squaw Creek into the Deadwood formation which penetrates the upper aquifer.

SUMMARY

Understanding the chemical processes leading to formation and destruction of the calcitic rind is an important step to understanding where spawning trout find available habitat in Spearfish Creek. It is evident that the calcite rind is not a continuous process but fluctuates between precipitation and dissolution as a function of water temperature, upwelling of groundwater, and algal growth and decay. Spawning trout require non-cemented gravel, cool rapidly flowing water over the gravel, and water flow through the gravel. In Spearfish Creek the most favorable locations during the fall spawning run are at the confluence of Squaw Creek and immediately above Maurice intake. At both locations, visual evidence for habitat consists of large areas of cement free gravel bars located in rapidly flowing water. At the Squaw Creek confluence, the location of the gravel delta within the main channel forces the flow through the gravel and the groundwater models indicate that above Maurice intake, upwelling groundwater supplies the through flow. Subsequent habitat may be sporadically distributed in the main channel.

During the spring spawn, breakdown of the rind (and free movement of gravel) from large regions within the channel support a greater extent of available habitat. Whether all of these areas are utilized for spawning activities is not yet known.

Results from this study indicate that the interaction between surface and groundwater plays a critical role in the location of cement free sediment and subsequently, available spawning habitat. Secondly, the annual growth of algae during winter and the weakening of the rind, both due to algae and cold water temperatures, promotes destruction of the rind during the spring spawning season. As a result, there is an increase in habitat in the spring.

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FORAGING ECOLOGY OF RING-NECKED PHEASANTS RECORDED IN THE STABLE ISOTOPE SIGNATURE OF FEATHERS

Jesse D. Munkvold, Craig N. Spencer, Michael E. Chapman,
Lincoln P. Likness, and Sara E. Cody
Biology Department
Augustana College
Sioux Falls, SD 57197

ABSTRACT

Thirty six male ring-necked pheasants *(Phasianus colchinus)* were harvested in South Dakota and Wisconsin from a variety of habitats supporting differing plant communities. Feeding habits of the birds were evaluated by visually identifying gross crop contents and stable isotope ratios of carbon ($^{13}C/^{12}C$) from different regions of tail feathers. Carbon isotope ratios are useful tracers in food webs since the isotopic signals of ingested food become incorporated and expressed in the tissues of consumers.

We found that pheasant crop contents are significantly correlated with the $\delta^{13}C$ values of the calamus (Fall growth) of the feather. Their was no significant correlation between the $\delta^{13}C$ of the rachis (Summer growth) and crop contents. The findings demonstrate that crop content analysis is accurate only over short periods of time, whereas, stable isotope analysis of feathers can show diet changes over several months. Our study also found that pheasants shift their diet toward a higher C_4 plant consumption in the Fall as compared to Summer. The significance of pheasant diet shifting appears to depend on land-use and C_4 plant source availability. When $\delta^{13}C$ values are compared to C4 crop land-use, a significant logarithmic relationship exists. The pheasant diet appears to be saturated in C_4 at approximately 40% C_4 crop land-use. The techniques used may have applications for non-destructive diet studies in pheasants and help provide information for pheasant habitat management.

INTRODUCTION

Ring-necked pheasants *(Phasianus colchicus)* are known to feed on a wide variety of sources. They prefer plants, especially agricultural grain such as corn and soybeans, as well as a variety of seeds of weeds and grasses, buds and soft parts of herbaceous plants (Trautman 1982). Pheasant populations tend to thrive in mixed habitats that include grain fields interspersed with areas of heavier cover supporting permanent vegetation such as native grasses and cattails. In the present study, we were interested in studying seasonal patterns in pheasant foraging habits. Traditional dietary studies involve examining crop contents from birds (Trautman 1982). The crop is a membranous sac utilized to store excess granules of food until digestion can ensue (Welty 1962). However, crop content analyses provide only a snapshot of recent food ingestion. Furthermore, food ingestion is not necessarily synonymous with food assimilation.

An increasing number of studies are using stable isotope analysis of various tissues as a tool for diet reconstruction (Tieszen 1994). The technique has been used substantially in migratory birds to trace origins and relationships (Chamberlain et al. 1997; Hobson et al. 1998), in mammals to trace seasonal diet changes (Ben-David et al. 1997), and in seabirds as a measure of environment and habitat conditions (Furness and Camphuysen 1997). Chamberlain et al. (1997) used stable isotope data from feather samples of black-throated blue warblers *(Dendroica caerulescens)* to trace bird migration patterns. Romanek et al. (2000), analyzed stable isotopes of feathers from wood storks *(Mycteria americana)* to identify foraging areas, since differences in isotopic signature of the feathers could be traced to differences in food sources being consumed when the feathers were being produced.

Stable isotopes are best utilized as tracers in food webs when there are measurable differences in isotopic ratios between different food sources. Many food web studies make use of the fact that C_3 and C_4 plants have distinct carbon isotope signatures (Hobson 1999). Such differences result from differential fractionation of stable carbon isotopes during photosynthesis by C_3 and C_4 plants (O'Leary 1988).

In the present study we attempted to reconstruct pheasant foraging habits using stable isotope analysis of tail feathers together with more traditional analysis of crop contents. We chose to analyze feathers since previous studies indicated that the isotopic composition of different regions of a feather reflect the foods and water consumed by the bird at the time that portion of the feather was being produced (Chamberlain et al. 1997). Although stable isotope studies have been conducted on a variety of bird species, we are not aware of any such studies using pheasants.

In the present study, we first set out to confirm whether the recent diet of pheasants, indicated by crop content analysis, would be reflected in isotope ratios of recently synthesized portions (the calamus) of the tail feathers. We expected that birds feeding primarily on C_3 food sources would have more negative $\delta^{13}C$ values than birds feeding on predominantly C_4 food sources (Fig. 1). Secondly, by analyzing various parts of the feather we hoped to be able to reconstruct the pheasant diet over the course of the year. The study was conducted on pheasants collected from a wide variety of habitats in Codington, Jones, Moody, and Spink counties, South Dakota and St. Croix county, Wisconsin.

METHODS

Male pheasants were collected via upland hunting techniques from October 21 - November 11, 2001. Birds were collected from a wide range of habitats. After each bird was collected, the general plant cover-type within a one half-mile (804.65m) radius of the collection site was recorded. Following col-

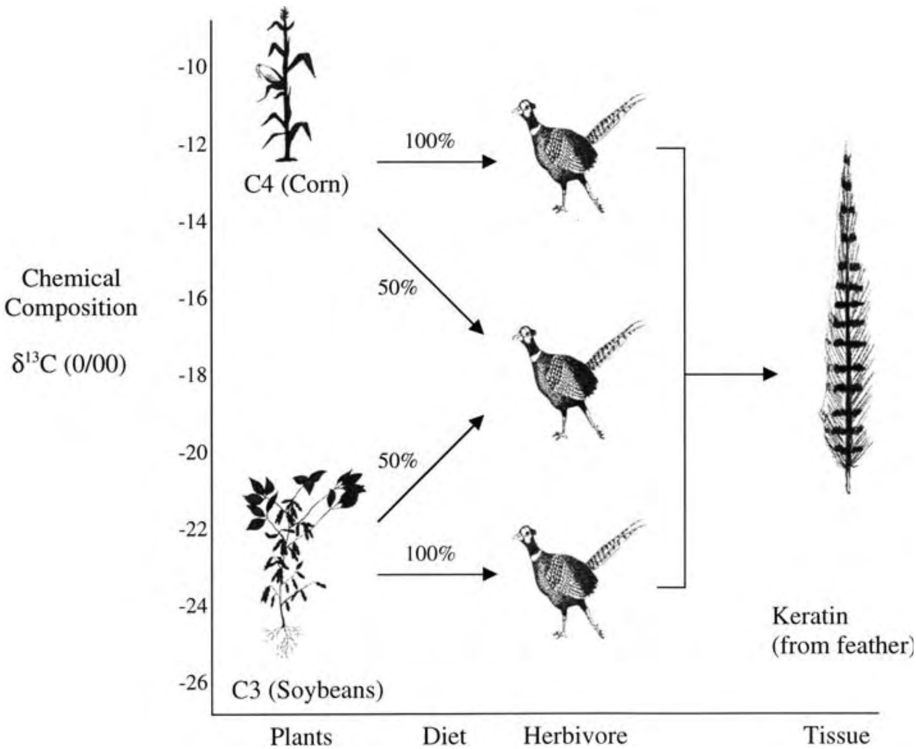

Figure 1. The general relationship between pheasant diet and $\delta^{13}C$ values as taken from the feather. The $\delta^{13}C$ values of the feather can be expected to change according to the ratio of C_3 and C_4 plants in the pheasant diet. Fractionation factors are not figured into the general $\delta^{13}C$ estimates.

lection, the crop of each bird was removed along with the three longest tail feathers. The crop contents were removed in the field and stored in Whirlpak bags using 80% ethanol for preservation.

The tail feathers were allowed to air-dry in the lab for several days to one week. The feathers were then cleaned with 100% ethanol and prepared for chemical analysis. The calamus, which is the proximal and most recently synthesized portion of the feather, was prepared by removing the proximal one centimeter tip of the keratinous feather quill beginning one-half centimeter above the base of the feather. This sample was sliced and cut into small pieces using a sharp blade and stored in 1.5 mL micro-tubes.

The rachis, which is the distal and oldest synthesized portion of the feather, was prepared in a slightly different fashion. First, the feathery veins or colored portions of the feather, were removed using scissors or simply peeling the veins free from the shaft. The first and most distant five centimeters of the rachis were cut and discarded. The second five centimeters of keratin were used for the distal sample analysis. This portion was diced into pieces using scissors and then stored in 1.5 mL micro-tubes.

Small cuttings of keratin from the pheasant tail feathers were loaded in tin cups and weighed on a Cahn C-30 microbalance. These samples, with standards of known composition for $\delta^{13}C$, %N, and %C, were placed in an autosampler and introduced to a Carlo Erba NA 1500 elemental analyzer. The samples were fully combusted at 1030°C in a stream of pure oxygen and oxidative catalysts and reduced on pure copper wires at 650°C. Gases were separated on a chromatographic column and water was removed with a chemical trap. After peaks were detected and analyzed with a thermal conductivity detector, the gases, primarily CO_2, N_2, and the helium carrier gas, were passed to the sample inlet of a VG SIRA 10 dual inlet isotope ratio mass spectrometer through a stainless steel capillary. The CO_2 was cryogenically purified, admitted to the analyzer, and compared to a CO_2 reference gas of known isotopic composition to calculate an isotopic value. Stable carbon isotope ratios, $\delta^{13}C$, were measured relative to PDB, the Pee Dee Belemite scale.

RESULTS AND DISCUSSION

Pheasant tail feathers elongate as they grow which makes them useful timelines for studying dietary changes. Tail feathers are molted annually in the ring-necked pheasant, and like hair, the new feathers grow from the base not from the tip (Welty 1962). The calamus is the basal portion of the tail feather and contains the most recently synthesized keratin in the feather. The rachis is the distal portion of the feather near the tip and it represents the oldest part of the feather. The rachis in our mature tail feathers was most likely synthesized in early to mid-summer shortly after molting, while the calamus was synthesized in later summer or early fall. The condition of the feathers during sample collection in October indicated that tail feather growth had recently ceased in most of the birds. A few of the feathers still had an active blood supply, but most had already dried up, indicating the feather growth had ceased.

Crop content versus isotope ratio of feathers

The $\delta^{13}C$ of the feather calamus showed close correlation with the crop contents (Fig. 2). Birds with crops containing only C_4 plant material had a mean $\delta^{13}C$ value of –15.99 ‰. By contrast, birds with crops containing only C_3 plant material had significantly a lower mean $\delta^{13}C$ value of –20.99 ‰ ($p<0.05$). $\delta^{13}C$ ratios for modern corn, the predominate C_4 plant in the pheasant diet, in general are –11.2 ‰ (Tieszen and Fagre 1993). Typical $\delta^{13}C$ ratios for modern soybeans are not available, but an average value for C_3 plants is –27.1‰ (O'Leary 1988). Birds with crop contents containing a mixture of C_3 and C_4 food sources were intermediate between the other two groups, although with a mean $\delta^{13}C$ of -16.5 ‰ our analyses would suggest that these birds likely had been feeding on food sources heavily weighted towards C_4 plants. Although the crop contents on the day of sample collection contained significant C_3 material, the isotope data suggests that these birds may in fact have recently been feeding heavily on C_4 plant matter. This is one possible advantage of diet analysis us-

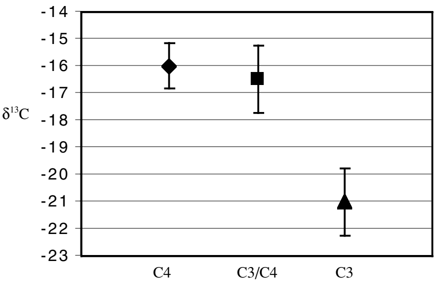

Figure 2. The relationship between the crop contents and mean $\delta^{13}C$ levels of the calamus (proximal feather portion). Those birds labeled with C_4 had only C_4 plant sources within their dissected crop. The birds labeled as C_3 had only C_3 plant sources in their respective crops and birds labeled C_3/C_4 had an unquantified mixture of both C_3 and C_4 plant material in their crops. The standard error bars show the standard error around the mean, calculated as the standard deviation divided by the square root of the sample size. A one-way ANOVA showed a significant difference between groups. A Tukey's HSD post-hoc test shows that at α=0.05, 3.954 $\delta^{13}C$ must separate samples in order for them to be significantly different. A difference was found between birds labeled C_4 and C_3 and also birds labeled C_3 and C_3/C_4. The difference between C_4 and C_3/C_4 was found to be insignificant.

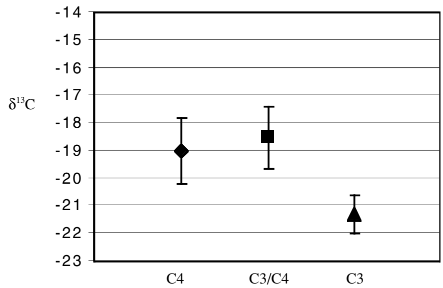

Figure 3. The relationship between the crop contents and mean $\delta^{13}C$ levels of the rachis (distal feather portion). Those birds labeled with C_4 had only C_4 plant sources within their dissected crop. The birds labeled as C_3 had only C_3 plant sources in their respective crops and birds labeled C_3/C_4 had an unquantified mixture of both C_3 and C_4 plant material in their crops. The standard error bars show the standard error around the mean, calculated as the standard deviation divided by the square root of the sample size. A one-way ANOVA gave a p-value of 0.17, indicating that no significant differences existed between groups. The insignificance suggests that changes in diet over longer periods of time make stable isotope analysis a more accurate option than crop contents for evaluating the pheasant diet.

ing stable isotope mass spectrometry. Though crop contents may indicate daily diet, they do not reflect the diet over a more extended period of time.

In contrast to data from the calamus, $\delta^{13}C$ from the older part of the feather (rachis) did not correlate as well with crop contents (Fig. 3). There were no significant differences in $\delta^{13}C$ among the three groups (p=0.17). This result was not unexpected since the rachis was synthesized in early to mid-summer. As such, its isotopic composition would be expected to reflect food sources ingested in June, not the Fall when our crops contents were analyzed. The fact that we obtained different statistical results when using $\delta^{13}C$ from the rachis versus calamus provides a hint that the pheasant diet may have shifted over the course of the growing season. A more direct examination of this possibility follows next.

Comparison of isotope ratios of the rachis and the calamus

Calamus samples had significantly higher $\delta^{13}C$ values than rachis samples, $p<0.001$ (Fig. 4). This difference was consistent across all four counties, although the effect was more pronounced in some areas than others. The increase in $\delta^{13}C$ in the younger, calamus portion of the feather is consistent with increased consumption of C_4 plants, such as corn, in late summer and early Fall when the calamus was actively growing. Earlier in the season, our isotope data provide evidence that the birds made greater use of C_3 food sources. The availability of mature corn kernels in the Fall may be the most significant factor contributing to the shift of isotope signature in the calamus (Fig. 4). It is well known that corn kernels are a significant food source for pheasants in the fall and winter (Trautman 1982). Thus it seems reasonable that pheasants might make use of a variety of food sources (C_3 and C_4) in early to mid-summer, but as agricultural crops ripened in the Fall, the pheasants would switch to a diet favoring corn, a C_4 plant.

As noted earlier, the seasonal shift in $\delta^{13}C$ was more pronounced in some counties than others (Fig. 4). These differences most likely are related to differences in plant and crop cover in the various counties. Birds from Jones County had the lowest $\delta^{13}C$ values, which is consistent with a higher concentration of C_3 plants in the diet. This is not surprising since Jones County does not support a lot of corn production. Land use in this county, located west of the Missouri River, is dominated by pasture lands with lesser amounts of row crop agriculture. By contrast, Moody and Spink Counties, located east of the Missouri, are dominated by row crops including significant amounts of corn. The elevated $\delta^{13}C$ values in calamus samples, so pronounced in Moody County birds may be explained by marked increases in corn consumption in the Fall. We do not have an explanation for the less dramatic increase in $\delta^{13}C$ in the calamus of birds from Spink Country.

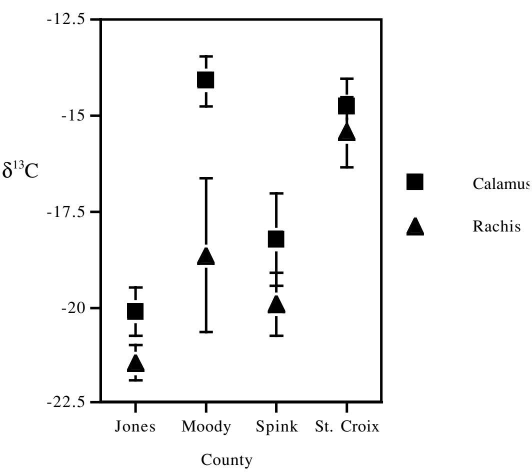

Figure 4. The differences between the averages of the $\delta^{13}C$ levels for the calamus (proximal portion) and the rachis (distal portion) between birds from the same county. Paired sample t-tests showed significant differences with a p-value of < 0.001 for all birds combined.

Isotope ratios of birds from St. Croix County, Wisconsin, were distinct from the South Dakota birds (Fig. 4). The mean $\delta^{13}C$ of rachis samples from Wisconsin was -15.43 ‰, which was elevated compared to rachis samples from South Dakota where mean values ranged from –21.44 ‰ in Jones County to –18.64‰ in Moody County (Fig. 4). Not only were the rachis values higher in Wisconsin birds, but there was no significant difference in $\delta^{13}C$ between rachis and calamus samples (p=0.348).

One explanation for the marked differences in $\delta^{13}C$ from the Wisconsin samples may relate to differences in plant cover. Our study areas in South Dakota lie in the prairie whereas St. Croix County, located in west central Wisconsin, is characterized by mixed forests and crop lands. Thus the corn fields in St. Croix County are not bordered by grasslands as in South Dakota, but rather by forests. In South Dakota, pheasants are frequently observed making considerable use of grassland habitat as well as crop lands. Pheasants are not generally associated with forest habitats, a view supported by our isotope data. Trees are C_3 plants with $\delta^{13}C$ values similar to other C_3 plants. The elevated $\delta^{13}C$ values in the Wisconsin birds (-15.43‰) provides strong evidence that these birds did not rely on trees or forest insects as food sources (Fig. 4). The lack of surrounding grasslands in Wisconsin may result in pheasants relying more on crop lands for food. Thus corn may have been the dominant food source for pheasants, not only in the Fall, but throughout the summer. Prior to ripening of the corn in the Fall, the pheasants may have fed directly on corn leaves and/or indirectly through consumption of herbivorous insects associated with corn. In either case, increased reliance on the C_4 corn plant as a food source throughout the growing season could explain the elevated $\delta^{13}C$ found in both the rachis and calamus of the St. Croix County pheasants, as well as the absence of a late season isotopic shift, so evident in the South Dakota birds (Fig. 4).

^{13}C Content in Pheasants as Related to Land Use

When available, pheasants appear to make heavy use of C_4 crops as a food source, as supported by our isotope and crop content data, personal observations in the field, as well as literature studies (Trautman 1982). The relationship between pheasants and C_4 crops was examined further by plotting the percentage of C_4 crop cover within a one-half mile radius (804.65m) around each of our study birds against the $\delta^{13}C$ levels from the birds (Fig. 5). Though all C_4 crops were included in the analysis, corn was the predominate C_4 food source seen during visual crop content evaluation. Only four birds had C_4 plant material in the crop other than corn.

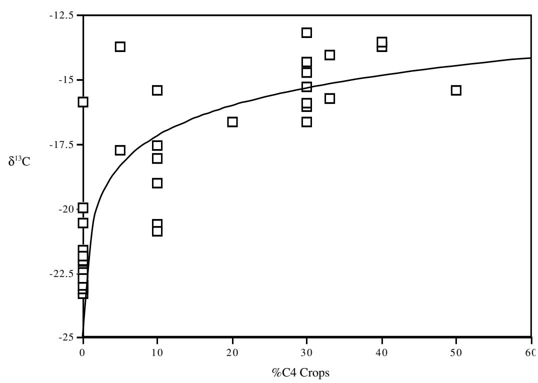

Figure 5. The relationship between the $\delta^{13}C$ levels from the calamus (proximal feather portion) and the percent of C_4 plant usage for a one-half mile (804.67 meters) radius around the sample. The relationship is significantly logarithmic as shown by a logarithmic transformation and regression analysis. The R^2 value for the relationship was found to be 0.64 and p<<0.01.

Pheasants harvested from areas without any corn cover had relatively low $\delta^{13}C$ levels in the calamus (Fig. 5). With increasing corn cover, $\delta^{13}C$ values increased (Fig. 5). The resulting logarithmic relationship was highly significant ($p<0.001$) and provides further evidence that pheasants make increasing use of corn in their diet as this C_4 plant becomes more available in the surrounding habitat.

Smith (1999) reported that the average home range for pheasants varies from as little as 35 hectares to 150 hectares. Each of our study area included 203.4 hectares, a large enough area to include the reported pheasant range. We are confident that the pheasants sampled were consistently feeding within our study range.

Though all C_4 crops were included in the study, corn was by far the most prevalent C_4 crop and will thus be used from now on to represent C_4 crop land use. The relationship between corn crop cover and pheasant isotope ratios shows evidence of saturation beginning at a level around 30-40% corn cover (Fig. 5). Thus when corn cover in the immediate vicinity of the birds reaches 30-40%, it appears that the pheasants reach a maximum for corn ingestion and assimilation. Extrapolating from our data, we would not expect a bird collected from an area supporting 100% corn cover to differ significantly in isotopic composition from pheasants living is an area with 50% corn cover.

According to the published data regarding $\delta^{13}C$, -11.2‰ is the typical $\delta^{13}C$ value for modern maize (Tieszen and Fagre 1993). Our data suggest that the maximum $\delta^{13}C$ for feathers from pheasants that are maximizing their intake of corn is only -14 or -15‰ (Fig. 5). Though no fractionation studies have been done on pheasants, it can be assumed that ^{13}C fractionation in the feather would be similar to birds with comparable diets. Hobson and Clark (1992) found that crows raised on a corn based diet had a +3.5‰ fractionation mean between the feather and diet. By assuming similar fractionation it can be reasoned that a pheasant feather with a $\delta^{13}C$ of -14‰ resulted from a diet with a –17.5‰ value. One possible explanation could be that pheasants, though they may prefer corn as a food source, may still mix in other foods (C_3 source) even when corn is highly available. This could also explain $\delta^{13}C$ ratios in pheasant feathers, which are more positive than what would be expected if they were feeding entirely on C_3 sources.

CONCLUSION AND RECOMMENDATIONS

The results presented show the numerous possibilities for stable isotope analysis to evaluate the pheasant diet and movement. Past studies evaluating the pheasant diet have relied on crop content analysis, requiring large scale destructive sampling techniques. Although destructive sampling techniques were used in this study, a nondestructive approach could feasibly be used in future studies. The combination of $\delta^{13}C$ stable isotope analysis with that of ^{15}N analysis would provide a deeper level of insight into the exact composition of the pheasant diet. This work would need to be strictly evaluated due to the less consistent nature of ^{15}N incorporation into tissue when other biotic stresses are prevalent (Hobson et al. 1993). A controlled experiment involving captive pheasants raised on diets with varying composition would help to establish a normal standard for the $\delta^{13}C$ expected in the tail feather as related to diet composition.

The usefulness and applicability of stable isotope data can be used in conjunction with other data to determine complex relationships between animals and their habitat. The importance of corn to the diet and overall fitness of snowgeese *(Chen caerulescens)* in relation to population has been evaluated by $\delta^{13}C$ analysis (Hobson 1999). Similar studies may be applicable to pheasants living in the varied habitat and bird population ranges of South Dakota. Isotope data could also be evaluated in conjunction with remote sensing to provide information on bird movement patterns and range.

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COMPUTATIONAL CHEMISTRY OF THE PORPHYRIN RING SYSTEM

Kari Lunder and Arlen Viste
Department of Chemistry
Augustana College
Sioux Falls, SD 57197

ABSTRACT

Jaguar 4, Gaussian 98, and gOpenMol were used to study the porphyrin ring system. (Schrˆdinger 2000, Gaussian 1999, Laaksonen 2000) Jaguar was used to perform computational activities on the porphyrin ring system. This molecule is one of the most prevalent bioinorganic molecules. (Marechal 2000, Siegbahn 1999, Siegbahn 2000) Jaguar performed very well with an effective core potential and a symmetry limitation. An oxygen molecule was added to the iron atom to examine the physical properties of the ring with the bound oxygen. The effects of a cyano group and a carbon monoxide group were also analyzed. The molecular orbitals, density, and electrostatic potential were

Keywords

Porphyrin, heme, Jaguar, Gaussian, quantum chemistry

INTRODUCTION

The porphyrin ring system has long been an interest to bioinorganic chemists because of iron center. This is the functional aspect of the heme group. This interesting system is found in many differenent proteins in the body. This iron center contributes to the electron chain transport by the oxidation and reduction of the iron center. When the iron is in the +2 oxidation state, it is firmly bound in the ring system. When the iron is in the +3 oxidation state, it is out of the ring as a free ion that is capable of being reduced and bound back into the ring system. This project explored the properties of the ring system and later add bound molecules (carbon monoxide, oxygen, and cyanide) to study the physical properties of the system with the different molecules bound. The project initially started using Gaussian, attempting an ONIOM multi-layer calculation. (Marechal, 2000) The project eventually moved to another computational program, Jaguar 4.0. The whole ring system was geometry optimized using a LAV1S* basis set. The density functional method was recommended by Siegbahn. (Siegbahn, 2000) The density and the electrostatic potential were calculated and displayed. The molecular orbitals were also calculated and displayed using gOpenMol. (Laaksonen, 2000)

METHODS

Hyper Chem

All of the necessary molecules were first built in HyperChem and converted to readable files for Gaussian and Jaguar. (Hypercube, 2000, Gaussian, 1999, Schrödinger, 2000)

Gaussian

A multi-layer ONIOM calculation was attempted with a molecular mechanics calculations on the ring system and a STO-3G basis set on the Fe-N bonds. This was attempted several times, but even with a process with parameters that were similar to ones successful in Jaguar 4.0 (LANL2DZ basis set in Gaussian), it still failed in Gaussian. Unfortunately, our approach in Gaussian was not sophisticated enough to handle a system in which a transition metal was introduced. (Gaussian, 1999) The next step was to move onto another program.

Jaguar 4.0

In Jaguar we did not locate a counterpart to the ONIOM hybrid QM/MM method of Gaussian. (Schrödinger, 2000, Gaussian, 1999) In Jaguar, density functional calculations were chosen instead, Becke 3:P86; this is Perdew's density functional that has a gradient correction along with Becke's three parameter (exact Hartree-Fock wavefunction, Slater local exchange functional, and Becke's 1988 non-local gradient correction). This method was picked for a faster convergence. The system was optimized using a LAV1S* basis set because of the effective core potential, chosen because of the substantial number of electrons in the system. This ECP method only optimized the valence electrons of the iron and a total analytic optimization on the rest of the structure with a STO-3G basis set. 100 iterations was required for the total optimization with an initial guess using ligand field theory. A GVB-DIIS convergence was recommened for faster convergence so that was also used in the calculation. The energy convergence was loosened to 1E-03. An oxygen molecule was added to the porphyrin ring system to study the different physical properties that occurred. It is suspected that iron atom comes out of the plane when it is not bound, but it is in the plane of the ring when oxygen is bound. That question was not answered directly, because in order to calculate the original porphyrin ring, the symmetry had to be restricted. A cyanide group and a carbon monoxide group were added to the iron and calculated. These molecules were calculated and eventually converged to optimized structures. Using the *.in files that were generated after each run, the potential and the density and the molecular orbitals were calculated.

gOpenMol

gOpenMol is able to use the *.out files generated from Jaguar to create visual plots of the electrostatic potential, density, and molecular orbitals. (Laaksonen, 2000) The coordinates were imported from Jaguar and converted to readable files for gOpenMol. The *.plt files were made into readable *.gom files. These were plotted on a contour map with red for the positive wavefunction and blue for the negative wavefunction.

RESULTS AND DISCUSSION

Geometry

Table 1. Iron porphyrin complex, calculated as low spin molecule.

Bond Lengths	Fe-N	Fe-O	Fe-C
Iron Porphryin	1.956818		
Iron Porphryin with oxygen	1.892339	1.80703	
Iron Porphryin with carbon monoxide	1.968281		3.0168
Iron Porphryin with cyanide	2.022941		2.3479
Iron Porphryin with carbon monoxide, solvated	2.016842		2.27685
Iron Porphryin with cyanide, solvated	2.016807		1.93230.

Table 2. Iron porphyrin complex, calculated as low spin molecule.

Bond Angles	N-Fe-N	Fe-X-L (X=C,O L=N,O)
Iron Porphryin	89.93	
Iron Porphryin with oxygen	88.93	121.39
Iron Porphryin with carbon monixide	90.00	
Iron Porphryin with cyanide	89.21	
Iron Porphryin with carbon monoxide, solvated	89.34	180.00
Iron Porphryin with cyanide, solvated	89.68	179.77

Experimentally, iron bound to oxygen is typically about 1.8 A. An iron to carbon bond is typically 1.8-2.0 A. This is considerably different than what is represented in Table 1. Next, calculations were carried out for the iron porphyrin complex bound to CO, and the Fe-C bond distance shortened considerably for the solvated molecule in comparison with gas phase.

Iron Porphyrin Molecular Orbitals

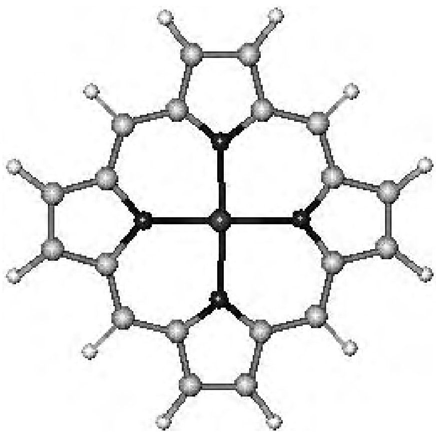

Figure 1. Fe porphyrin structure.

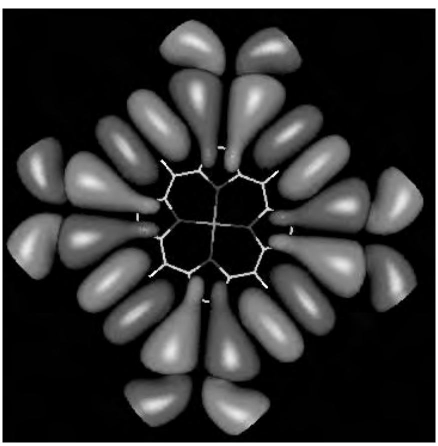

Figure 2. Fe porphyrin HOMO.

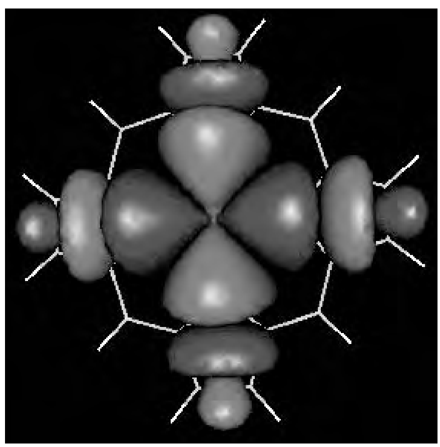

Figure 3. Fe porphyrin LUMO.

Molecular Orbitals of Iron Porphyrin with Oxygen Bound

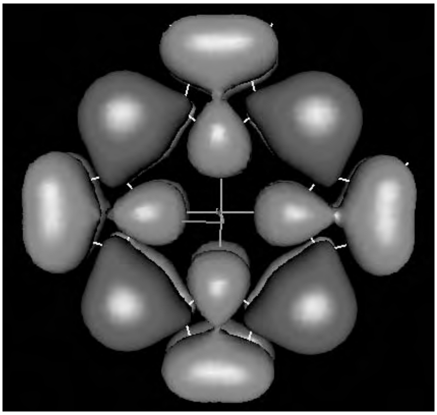

Figure 4. Fe porphyrin O_2 HOMO.

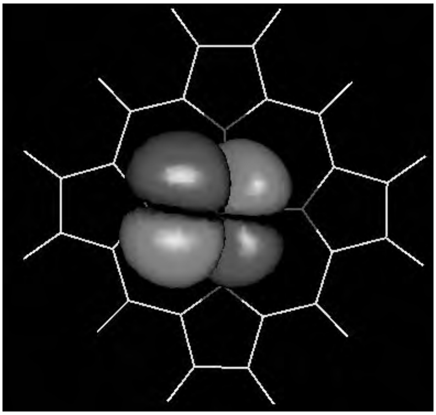

Figure 5. Fe porphyrin O_2 LUMO.

Note: the LUMO is predominantly on the O_2 ligand.

Iron Porphyrin with Carbon Monoxide Bound

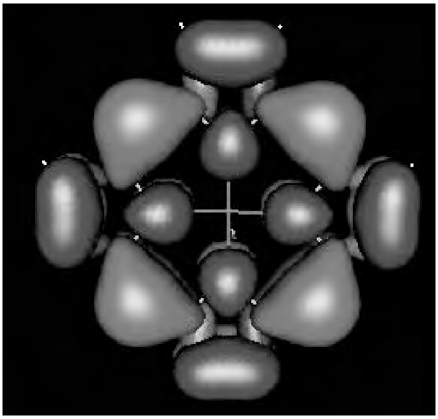

Figure 6. Fe porphyrin CO HOMO.

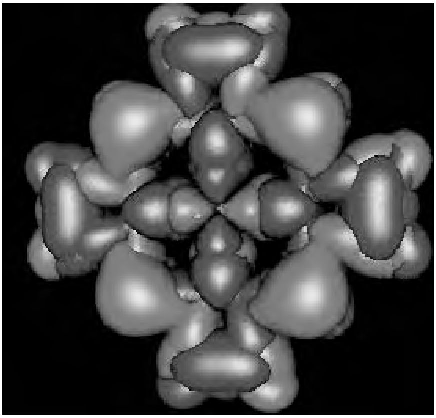

Figure 7. Fe porphyrin CO LUMO.

CONCLUSION

The heme group is one of the most widely studied bioinorganic molecules. It is considerably more complex in its actual environment, but the point of interest to the bioinorganic chemist is the iron center. This is the center for the oxidation and reduction that is needed to perform many biological tasks. Jaguar 4.0 performed very well with an effective core potential. The capability of Jaguar to use an initial guess based on ligand field theory is quite helpful and effective. In the gas phase the carbon monoxide group and the cyanide group tended to come away from the iron that it was supposed to be bound. This was surprising so a solvent calculation was run. Jaguar calculated a shorter Fe-C distance for the solvated molecule than for the isolated gas phase molecule.

Further computational procedures would be needed to explore the bonding of the carbon monoxide, the oxygen, and the cyanide group to understand what is actually going on. This project explored the geometries of the different molecules and the molecular orbitals were viewed in gOpenMol.

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IMPLEMENTING JAGUAR 4.0 IN THE UNDERGRADUATE LABORATORY: A COMPUTATIONAL INVESTIGATION OF THE NICKEL-IRON HYDROGENASE

Crystal Cunningham, Arlen Viste, and Gary Earl
Department of Chemistry
Augustana College
Sioux Falls, SD 57197

ABSTRACT

The family of metalloproteins called hydrogenase catalyze the reaction $H_2 \leftrightarrow 2H^+ + 2e^-$. The active site of the enzyme contains two metal atoms, iron and nickel. Several iron-sulfur clusters surround the active site and participate in electron transfer. The reaction mechanism of this enzyme has been extensively studied both experimentally and theoretically. Two detailed theoretical analyses (Shuqiang 1999, Pavlov 1998) prompted the current investigation. Density Functional Theory (DFT) methods were used to investigate the active site and iron-sulfur clusters in various redox, protonated, and spin states. The DFT results were in good agreement with experimental values of bond lengths and bond angles. The calculations were performed using Jaguar 4.0 and gOpenMol was used to view plots of the electron density, electrostatic potential, and molecular orbitals. (Schrödinger 2000, Laaksonen 2000) This paper suggests a smooth convergence of structures of this type in the Jaguar software system. Another result of this effort proved Jaguar 4.0 to be efficient in the undergraduate laboratory for the computational exploration of heavy metal atoms.

Keywords

Hydrogenase, metalloproteins, Jaguar, DFT

INTRODUCTION

The driving force for ATP formation in sulfur reducing microorganisms is the oxidation of H_2

$$H_2 \leftrightarrow 2H^+ + 2e^-$$

The reaction results in a pH gradient that gives rise to ATP via ATPase (Pavlov, 1998). There are three metalloprotein and one novel organic hydrogenase (Thauer, 1996) that catalyze the oxidation reaction. Both the Fe-only and Ni-Fe enzymes complex with an iron-sulfur thiocubane structure (Td symmetry) that assists in electron transfer. The Fe-S clusters provide electron transfer pathways to and from the active site, the H-cluster. Molecular hydrogen binds to the Fe atom in the H-cluster. This initial binding begins a complicated series of redox reactions which eventually yield the two electrons and protons formed from H_2.

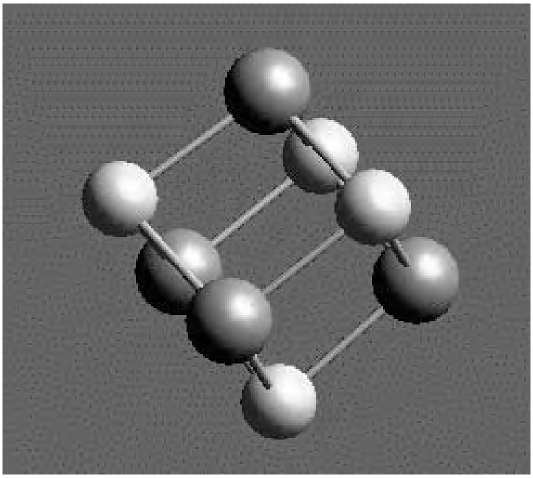

Figure 1. Thiocubane Fe_4S_4 cluster from Jaguar. S lighter, Fe darker.

X-ray diffraction has provided the structures of both the Fe-only (Peters, 1998) and Ni-Fe hydrogenase (Amara, 1999). The proteins were isolated from the bacterium *Desulfovibrio desulfuricans* a sulfate reducing bacterium. The resolved crystal structures show that the Ni-Fe H-cluster contains bridging sulfur ligands between the Fe and Ni. In addition to the two bridging sulfur atoms, Ni has two cysteinethiolate ligands. The infrared studies show three diatomic ligands located on the Fe atom (Pavlov, 1998): one CN^- and two CO molecules. When the sixth ligand, molecular hydrogen, binds the Fe atom takes an octahedral geometry. The thiocubane and the H-cluster from the D. gigas are depicted in Figures 1 and 2.

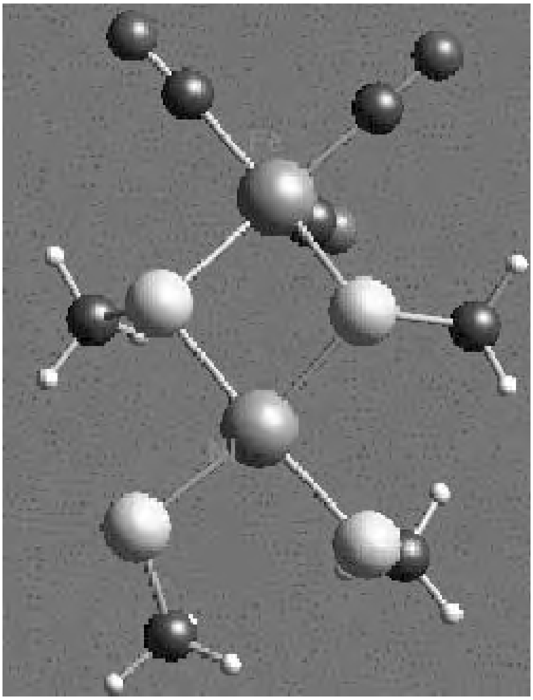

Figure 2. Jaguar image of active site of Ni-Fe hydrogenase, reduced state.

EPR data gives evidence of several accessible states of the enzyme (1). Detailed computational studies by Pavlov *et al* (Pavlov, 1998) and Suquiang Niu et al (Niue, 1999) propose mechanistic schemes for this enzyme based on the EPR, NMR and X-Ray data. Suitable species for the experimental results were proposed by Shuquiang Niu *et al.* This work prompted the current investigation to employ Jaguar 4.0 (Schrödinger, 2000) and gOpenMol (Laaksonen, 2000) computational software in the undergraduate laboratory to better understand the complexity of enzyme catalysis through the use of computational modeling.

The use of an accurate *ab initio* approach to study this system is very challenging considering the number of heavy metal atoms in the enzyme. The thiocubane structure and the H-cluster are considered to be too large of systems to obtain realistic results using *ab initio* methods. On the other hand, various density functional theory (DFT) methods overcome this many body problem. The accuracy of the DFT method weighs heavily on which method is employed. This research used a Local Density Approximation (LDA) to study the thiocubane structure and a Non-Local Density hybrid to study the H-cluster of the Ni-Fe hydrogenase. Several studies have shown that DFT methods have the capacity to treat these larger biochemical systems with the accuracy of *ab initio* calculations (Siegbahn, 2000).

COMPUTATIONAL METHODS

The Jaguar 4.0 Computational program was used for all calculations. The calculations were carried out under SuSE 6.4 Linux on a PC.

Thiocubane Optimization

DFT calculations used a SCF local density approximation Slater VWN, with the LACVP** basis set This basis set gives an effective core potential(ECP) for the iron and provides a 6-31G** basis set for all other electrons. The HF initial guess was that of Ligand Field Theory. The SCF level shift was set to 2 using the GVB-DIIS convergence scheme with an ultrafine accuracy level. An *&atomic* file was added to the Jaguar input in order to complete the calculation. In geometry optimization, bond angles were frozen to maintain the cubic structure but the bond lengths were allowed to optimize.

Ni-Fe H-Cluster Optimization

The Ni-Fe hydrogenase (Fig. 2) was optimized with a net molecular charge of -2 and in the triplet state. The same LACVP** basis set used for the thiocubane optimizations was used for these optimizations. The specific DFT theory used was the Becke three-parameter hybrid exchange functional and the Lee-Yang-Parr correlations functional (B3LYP). This optimization also required the use of an *&atomic* section. This species has both Fe and Ni in the +2 oxidation state and possesses triplet multiplicity. Two other species were also optimized. The first species was a bridged Ni-H-Fe complex. This bridging structure contained Fe^{+2} and Ni^{+3}, the molecular charge was -1 and a doublet multiplicity was designated. The bridging hydrogen was assigned a -1 charge and the terminal sulfur was protonated.

Transition state search

An attempt was made to find a possible transition state for movement of H from a bridging position Fe-H-Ni to and S-H position. The quadratic synchronous transit (QST) search was used first since both product and reactant input are known. The second method employed was the linear synchronous transit (LST) search. For this search the most recent structure and its corresponding Hessian provided by QST were used as the proposed transition state. The optimizer can now search along the linear path to the product.

RESULTS AND DISCUSSION

The thiocubane structure Fe_4S_4 structure is shown in Figure 1. In the optimization, bond angles were left fixed but bond lengths were varied. In comparison with crystallographic distances of Mak for Fe_4S_4, our calculated Fe-S distance is 2.10 vs 2.22 Å, calculated S-S 3.54 vs 3.49 Å, but calculated Fe-Fe 3.30 vs 2.67 Å. (Mak, 1992). Calcilated Fe-S in $[Fe_4S_4]^{+1}$ and $[Fe_4S_4]^{-1}$ were 2.86 and 2.85 Å.

The Ni-Fe hydrogenase (Fig. 2) has both Fe and Ni in the +2 oxidation state and possesses triplet multiplicity. Two other species were also optimized. The first species was a bridged Ni-H-Fe complex. This bridging structure contained Fe^{+2} and Ni^{+3}, the molecular charge was -1 and a doublet multiplicity was designated. The bridging hydrogen was assigned a -1 charge and the terminal sulfur was protonated. The third species contained Fe^{+2} and Ni^{+1}. The molecular charge was also -1 in the doublet state. This species had both terminal sulfurs protonated. These species were proposed by Shuquiang Niu *et al* as intermediate structures of active site species. The two latter species, Ni-Fe(II,III) and Ni-Fe(II,I) are shown in Figures 3 and 4 respectively. Figure 5 shows the electron density surface of the hydride bridged structure (of Fig. 3), colored with the electrostatic potential.

The transition state search did not fully succeed. However Figure 6 shows the closest approximation reached in this study.

The final distance between the transferring hydride ion and the S3 atom is 2.32 angstroms. This short distance places the hydride ion in a bridging position between the S1 and S3 atoms

The LST search gave rise to a structure in which the CO ligand on the Fe atom became bent toward the Ni atom. This was similar to the investigation by Pavlov *et al* in which the CN- ligand bent toward the Ni atom. (Pavlov, 1998).

CONCLUSION

This work concludes that the thiocubane structure and its redox states can be successfully investigated using DFT methods in a time efficient manner appropriate for the undergraduate laboratory.

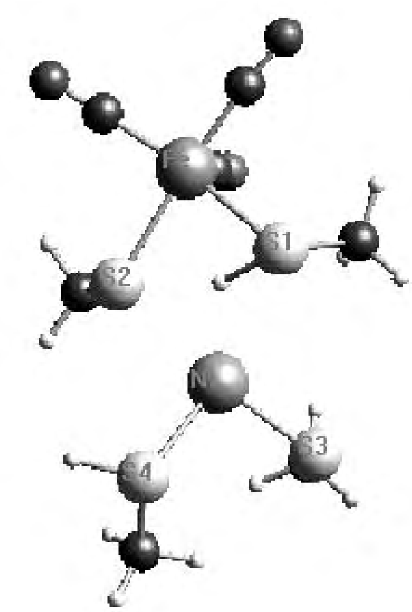

Figure 3. Hydride bridged Fe-Ni-S4 cluster.

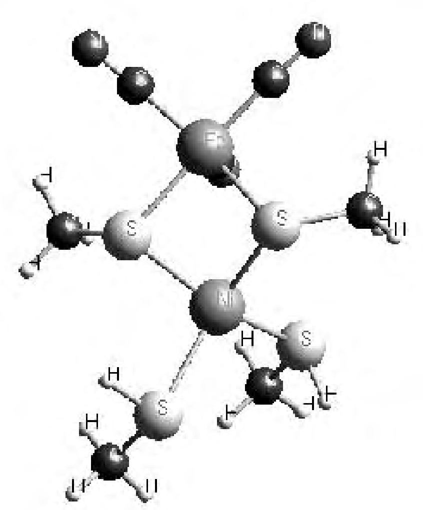

Figure 4. Fe-Ni-S4 cluster with both H on S.

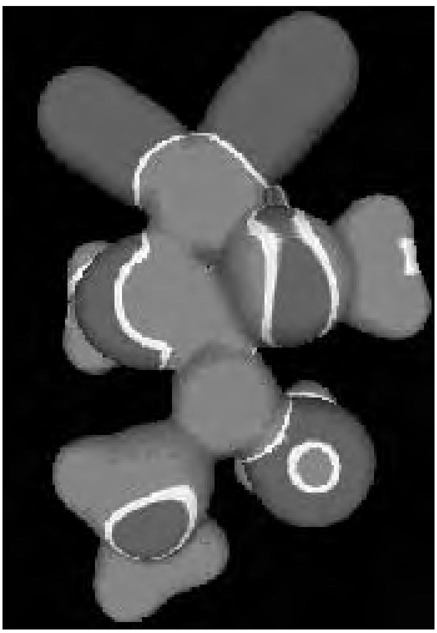

Figure 5. Hydride bridged cluster (from Fig. 3) with electrostatic potential colored on the electron density.

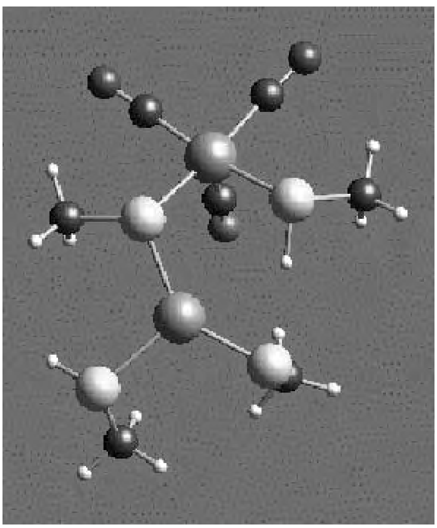

Figure 6. Transition state search.

Plots of the electrostatic potential and electron densities of the H-Cluster show it to be a spin delocalized system. DFT methods give insight into the structure and reactivity patterns of the H-Cluster of the hydrogenase enzyme and can be a useful tool to study enzyme structure and mechanisms. This work optimized two thermodynamically stable structures in the H_2 cleavage cycle. A partial transition state between these two structures suggests that the hydride ion is transferred to a bridging sulfur atom. During this transfer the Ni-S bond breaks and bending of the CO ligand occurs.

One of the reasons for the difficulty in locating the transition state is that the structure labeled as product was optimized in a way that placed the hydride ion on the back-side of the sulfur. It may be possible to rotate the hydrogen on the S3 atom and use this structure as the product target and then make a transition to the structure in Figure 4. Another option to consider is that the hydride transfer might not be a single-step concerted process but might instead occur by a two step process. Further investigations should shed light on the location of the transition state and further use of Jaguar in the laboratory.

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INTRODUCTORY BAND STRUCTURE CALCULATIONS IN THE UNDERGRADUATE QUANTUM CHEMISTRY ENVIRONMENT

Teresa M. McConville and Arlen Viste
Department of Chemistry
Augustana College
Sioux Falls, SD 57197

ABSTRACT

Recently BICON-CEDiT software became available, which carries out band structure calculations on one, two, and three-dimensional periodic structures, in an extended H¸ckel approach (Calzaferri 2000). The work reported here was undertaken to utilize and test this software package in an undergraduate chemistry environment. In addition to standard examples such as polyacetylene and graphite, we report the application of the software to a chain of iodine atoms such as found in the familiar intensely colored blue-black starch-iodine complex of analytical chemistry, which treated as a one-dimensional periodic system.

Keywords

BICON-CEDiT, band structure, starch-iodine complex

INTRODUCTION

The electronic structure of crystalline solids is treated by band theory, which is related to molecular orbital treatments of small molecules but takes into account the translational symmetry of the crystal. (Hoffman 1988, Burdett 1995). Undergraduate physical chemistry texts tend to treat this topic very briefly (Atkins 1998 p. 418-420). Among quantum chemistry texts, Lowe provides a chapter on the topic (Lowe 1993). Recently BICON-CEDiT software became available, which carries out band structure calculations on one, two, and three-dimensional periodic structures, in an extended Hückel approach (Calzaferri 2000). The software is descended in part from QCPE 571 (Whangbo 1989). The work reported here was undertaken to utilize and test this software package in an undergraduate chemistry environment. After running standard test examples such as polyacetylene and graphite, we report the application of the software to a chain of iodine atoms such as found in the familiar intensely colored blue-black starch-iodine complex of analytical chemistry, which we treat as a one-dimensional periodic system.

METHODS

The BICON-CEDiT software package was downloaded from the University of Bern, Switzerland. (Calzaferri, 2000). It was installed on a PC under Windows NT 4.0. An oddity of the software is that the graphical display of results from this software page requires that the display be set to 256 colors. The 32-bit binary distribution of the software is stated to require Windows NT 4.0, and this seems to be the case. (Calzaferri, 2000) We tried briefly and unsuccessfully to use it under Windows ME. The software comes with several sample data sets. The manual, which is fairly thorough and helpful, uses the data set for alternating all-trans-polyacetylene to orient the new user in a "Quick Start." The program manual and the sample data sets provided adequate guidance to prepared input files for the graphite and iodine chains which we investigated with the software. Irfanview, a freeware graphics utility, served conveniently to capture screen images and save them as jpg files. (Irfanview 2001)

RESULTS AND DISCUSSION

All-trans-polyacetylene is one of the standard examples for which input data files are provided in the BICON-CEDiT software package. The polymer chain is taken to be planar, two-dimensional, with translational repetition in one dimension only. The resulting band structure is shown in Figure 1. The density of states and crystal orbital overlap population are shown in Figure 2. Note the

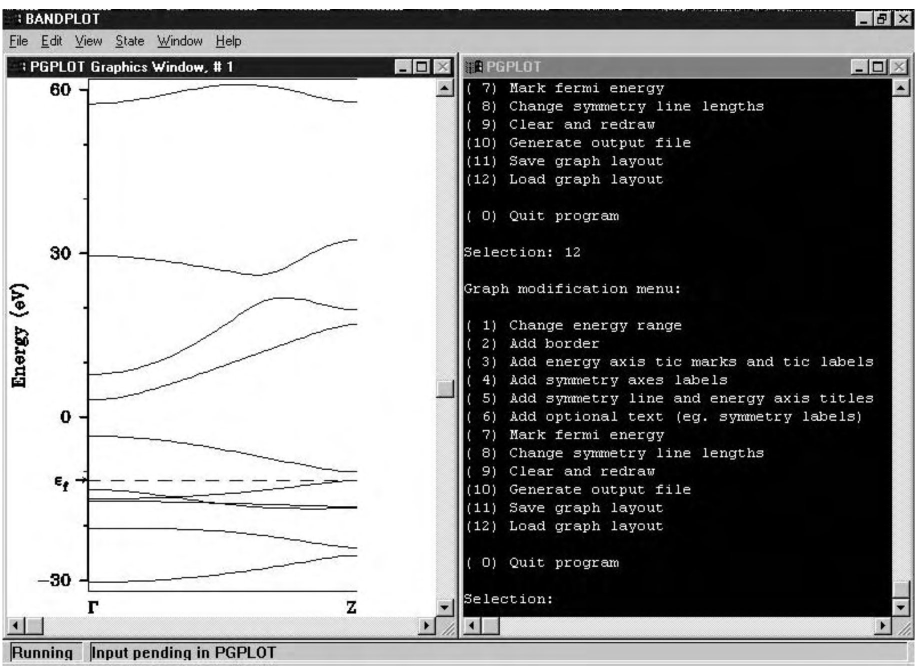

Figure 1. Band structure for all-trans-polyacetylene.

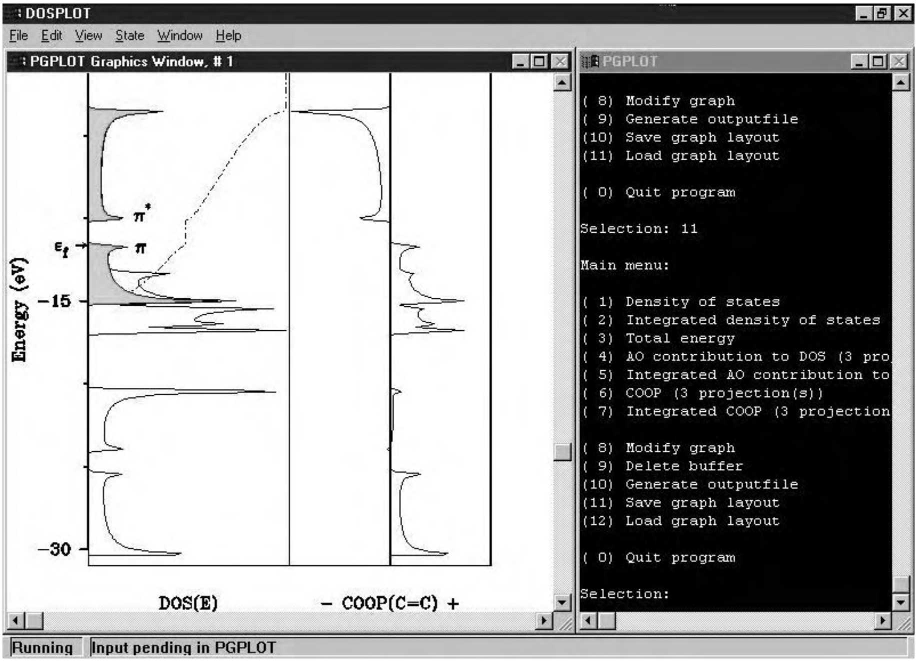

Figure 2. Density of states and crystal orbital overlap population for all-trans-polyacetylene. Note the Fermi level, marked as ε_f. For a chemist, this may be regarded as the position of the highest occupied molecular orbital (HOMO). The unequal CC bond lengths in the polymer chain correspond unequal C-C and C=C bond lengths, or may be regarded as a Peierls distortion (Hoffman, 1988).

Fermi level, marked as f. For a chemist, this may be regarded as the position of the highest occupied molecular orbital (HOMO). The unequal CC bond lengths in the polymer chain correspond unequal C-C and C=C bond lengths, or may be regarded as a Peierls distortion. (Hoffman, 1988)

Graphite. One layer of the graphite structure may be regarded as a system with two translation vectors, the edges of a two-dimensional unit cell. One trial version of a band structure calculated for 2-dimensional graphite is shown in Figure 3.

Iodine chains. The electronic structure of chains of iodine atoms has been discussed by Kertesz and Vonderviszt. (Kertesz, 1982) Such chains occur in the starch-iodine complex, familiar as the endpoint of iodimetric titrations in analytical chemistry. A short segment of an iodine chain running down the interior of a helical starch chain was modeled in HyperChem, and was displayed in gOpenMol. (Hypercube, 2000, Laaksonen, 2001) This rough model is shown in Figure 4. The helix is probably somewhat more tightly coiled than suggested here. One calculation of a symmetrically spaced I_3 chain gives the band structure shown in Figure 5. The corresponding density of states (DOS) and crystal orbital overlap (COOP) plots are shown in Figure 6. Peierls distortion is

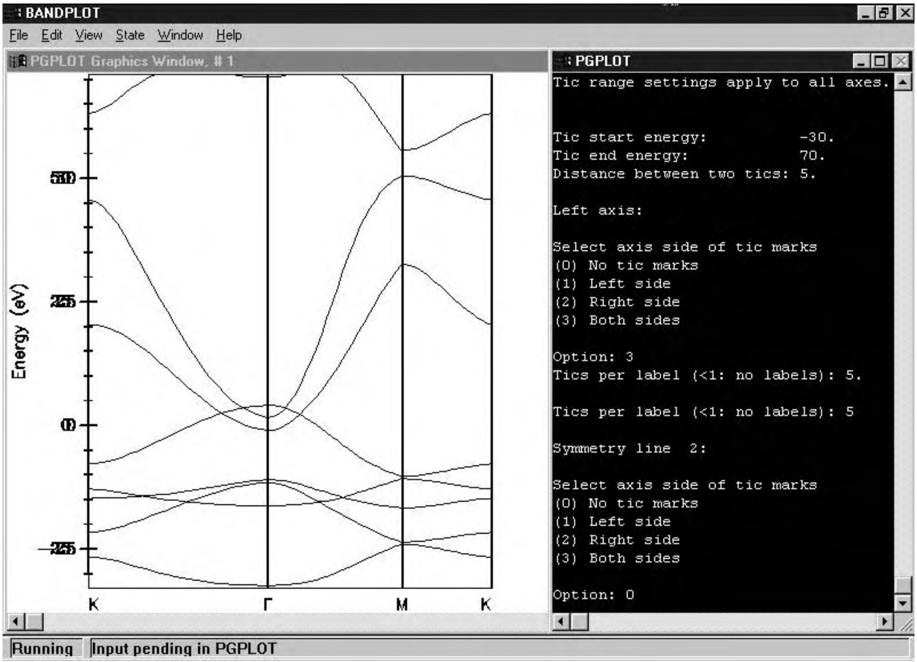

Figure 3. Band structure for two-dimensional graphite layer.

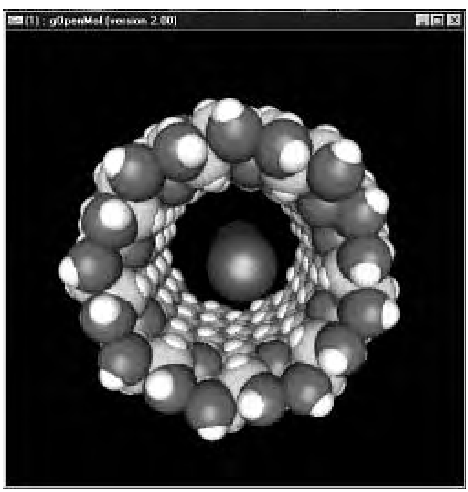

Figure 4. Segment of starch-iodine complex modeled in HyperChem and gOpnMol.

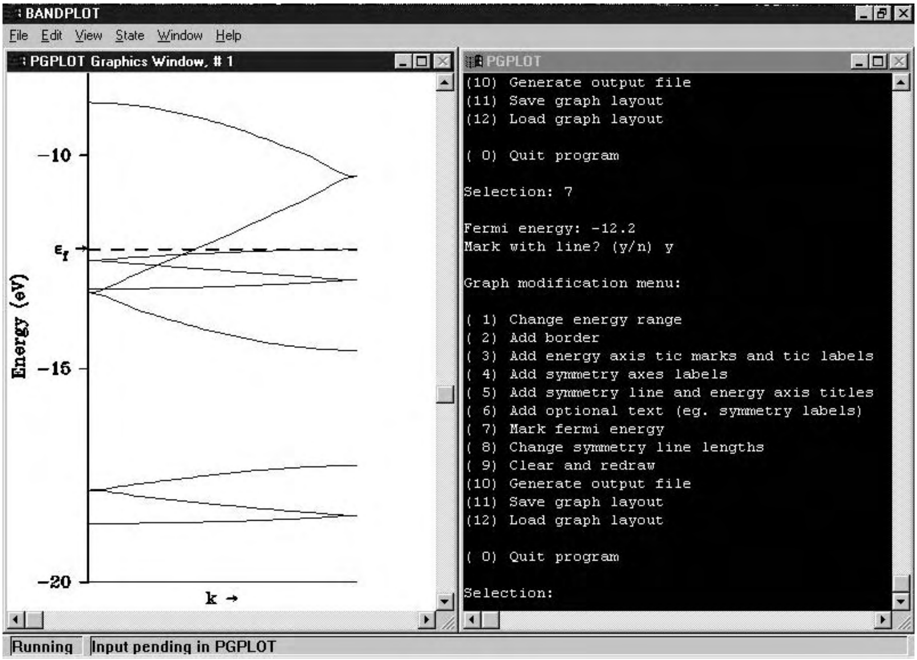

Figure 5. Band structure calculated for uniformly spaced I_3 chain.

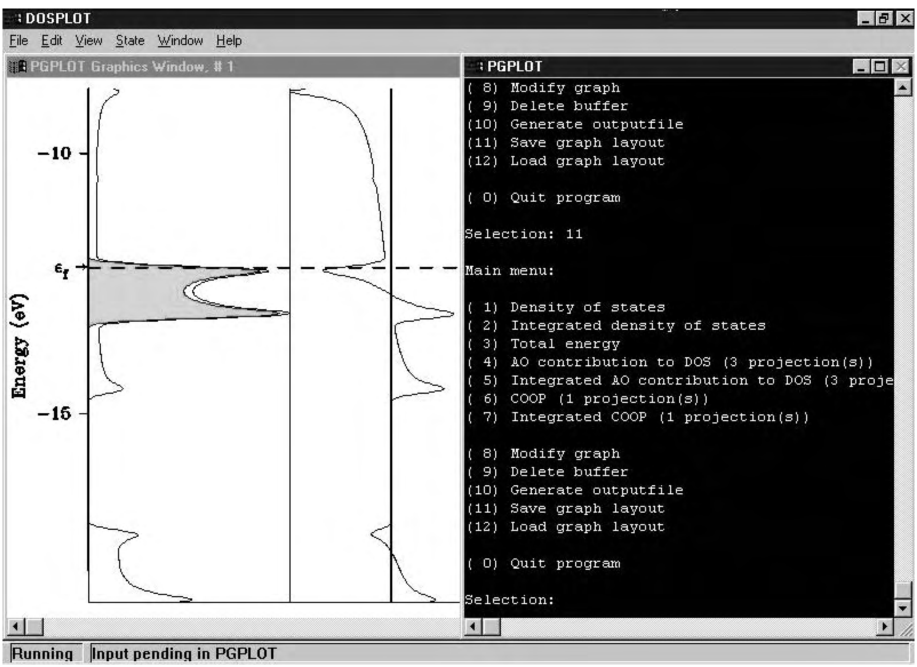

Figure 6. Density of states (DOS) and crystal orbital overlap (COOP) plots for uniform I3 chain.

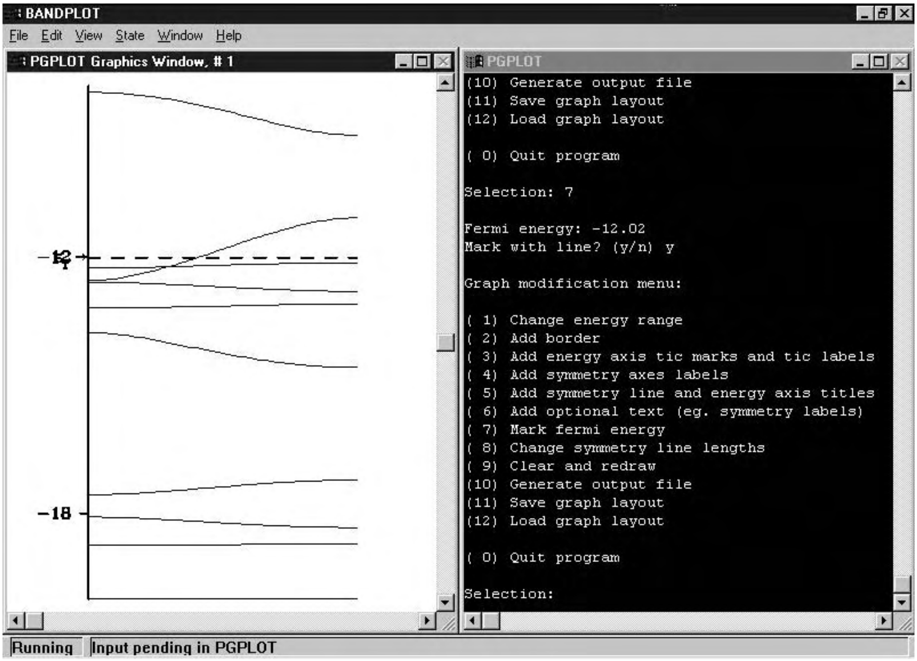

Figure 7. Band structure for an I_3 chain distorted to unequal bond lengths.

of course expected to lead to inequalities of I-I bond lengths, opening up a band gap. A structure deliberately distorted along these lines gives a band plot such as that shown in Figure 7.

CONCLUSION

The BICON-CEDiT software is quite useful for exploring band structures of systems with translational symmetry. In this study the software was applied to all-trans-polyacetylene, a graphite layer, and iodine chains related to the starch-iodine complex. There is a significant learning curve, as with most worthwhile software. However the calculations and especially their graphical output enrich the perceptions of electronic structure which are familiar to chemists. We suggest that this software package may be quite a useful tool in undergraduate Physical Chemistry or Quantum Chemistry Courses.

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ACKNOWLEDGMENTS

We thank the developers of BICON-CEDiT for access to this software package. Thanks also to Augustana College and its Department of Chemistry for software and hardware support.

IMPLEMENTING AND EXPLORING WebMO AS A WEB-BASED UNDERGRADUATE QUANTUM CHEMISTRY ENVIRONMENT

Per Haakon Thrane-Nielsen and Arlen Viste
Augustana College
Sioux Falls, SD 57197

ABSTRACT

WebMO is a web-based environment for working with such major quantum chemistry packages as Gaussian, GAMESS, and MOPAC (Hope 2000). Hope College generously encourages the free licensing of the WebMO software for installation elsewhere. This paper reports the process of installing, testing, adjusting, and applying the WebMO software package at Augustana College (WebMO Augustana 2001). Initial installation implemented work with Gaussian 94 through WebMO on an IBM RS/6000 computer under the Aix 4.3. Attention next turned to working with GAMESS through WebMO. We have not chosen to implement MOPAC thus far. In this environment, WebMO has been successfully applied to small organic molecules, such as ethene, C_2H_4 in GAMESS and allene, C_3H_4 in Gaussian 94..

Keywords

WebMO, quantum chemistry, GAMESS, Gaussian

INTRODUCTION

Interesting Web-based tools related to quantum chemistry are beginning to appear. At an introductory level, The Simple Hückel Molecular Orbital Theory Calculator, implemented as a Java applet, is based at the University of Calgary (Hückel MO 2000). MolSurf, based at the University of Erlangen, provides visualization of molecular surfaces in a VRML environment (Molsurf 2001). WebMO is a web-based environment for working with such major quantum chemistry packages as Gaussian, GAMESS, and MOPAC (Hope 2001).

METHODS

Hope College generously encourages the free licensing of the WebMO software for installation elsewhere. We have downloaded WebMO from the Hope College web site, and have installed the software package on an IBM RS/6000 computer under Aix 4.3.3 as the Unix operating system. Gaussian 94 has been installed on this computer for several years (Gaussian 2001). As part of the current work, GAMESS was downloaded, compiled, and installed on the RS/6000 as well (Gordon 2001). In WebMO, building a molecule is with a visual editor, based on a Java applet.

RESULTS AND DISCUSSION

Installation of the WebMO software was relatively straightforward. (WebMO Augustana 2001) Compilation of GAMESS is well documented and was successful. Installation of GAMESS under WebMO required more detailed attention than Gaussian 94. In both cases a template file needed to be converted from Ascii DOS to Unix format.

Using the Augustana installation of WebMO, quantum chemistry calculations have been carried out on some small organic molecules, One example is ethene, C_2H_4. Using GAMESS an *ab initio* 6-31G(d) MO calculation was done for geometry optimization and vibrational frequencies. The calculated infrared spectrum is shown as Figure 1.

A WebMO Java applet displays the normal modes of vibration. An example is the strong band at 1095 cm^{-1} shown in Figure 2.

A second example is allene, C_3H_4 or $H_2C{=}C{=}CH_2$. Using Gaussian 94 an *ab initio* 6- 31G(d) MO calculation was done for geometry optimization and vibrational frequencies. The calculated infrared spectrum is shown as Figure 3.

The normal mode of vibration for the strong band at 2214 cm-1 shown in Figure 4.

WebMO currently does not include provision for graphical display of probability density contour surfaces for molecular orbitals or total electron density. However with some further

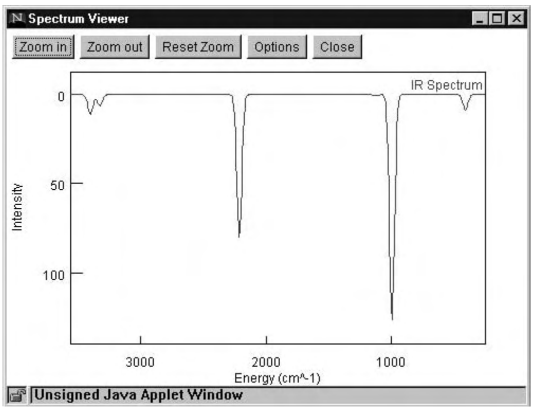

Figure 1. C_2H_4 GAMESS 6-31G(d) IR spectrum.

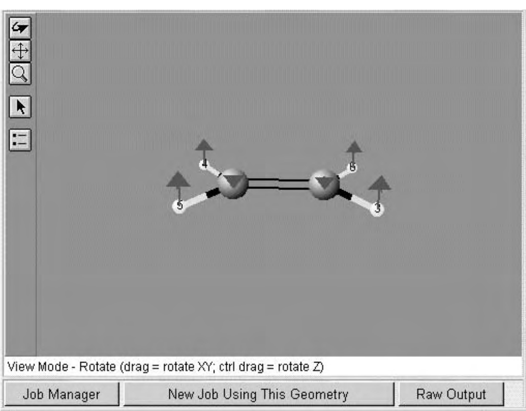

Figure 2. C_2H_4 GAMESS 6-31G(d) normal mode calculated at 1095 cm^{-1}.

effort, such surfaces can be displayed in separate visualization software such as Molekel or gOpenMol. (Molekel, 2001, Laaksonen, 2000) As an example, the electron density surface of allene, with electrostatic potential, in shown in Figure 5, as rendered by Molekel. In WebMo, it is possible to add keywords such as POP=FULL to a Gaussian 94 run, so that Molekel can produce such surfaces for molecular orbitals, electron density, and electrostatic potential.

CONCLUSION

WebMO has been successfully installed on and IBM RS/6000 computer at Augustana College (SD). It has been tested and successfully applied to quantum chemistry calculations on small organic molecules, such as ethene and allene, It is a useful tool, particularly for students in an undergraduate Chemistry academic environment. The Hope College developers of this software have done a valuable service for the academic community.

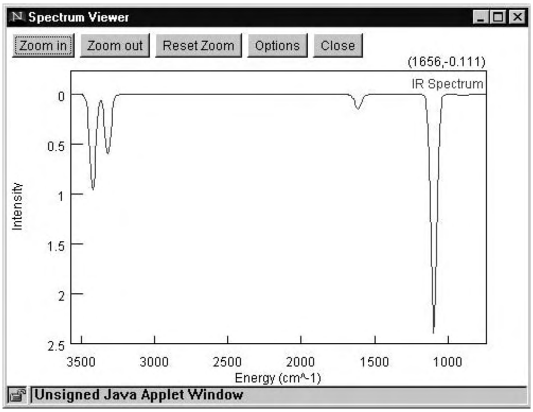

Figure 3. Allene Gaussian 94 6-31G(d) IR spectrum.

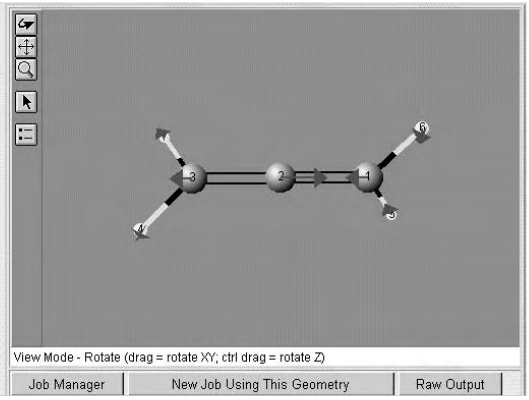

Figure 4. Allene Gaussian 94 6-31G(d) normal mode calculated at 2214 cm^{-1}.

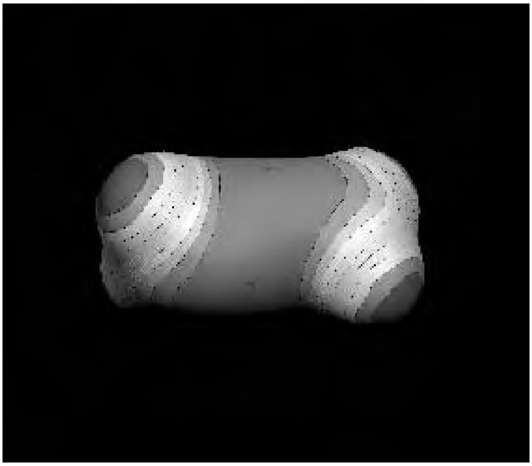

Figure 5. Allene electron density with electrostatic potential, from Gaussian 94 and Molekel.

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ACKNOWLEDGMENTS

We thank Hope College for their public-spirited development provision of the WebMO software package. Thanks also to Augustana College and its Department of Chemistry for software and hardware support.

IMPLEMENTING MacGAMESS AND MacMolPlt ON A MAC G4

Andrew W. Aspaas and Arlen Viste
Department of Chemistry
Augustana College
Sioux Falls, SD 57197

ABSTRACT

MacGAMESS is a Macintosh port of GAMESS, which is a computational quantum chemistry software package. (Bode 2000, Gordon 2000) MacGAMESS and its visualization companion MacMolPlt have been downloaded, installed, and tested as part of this project. Versions of GAMESS are available for a number of computer platforms, including Unix, Windows, and Mac. The Mac version is particularly cnvenient for ease of visualization of results.

Keywords

MacGAMESS, MacMolPlt, quantum chemistry, GAMESS

INTRODUCTION

GAMESS is an acronym for General Atomic and Molecular Electronic Structure System GAMESS was created by the team of the National Resources for Computations in Chemistry project from 1977 to 1981 at the Lawrence Berkeley Laboratory, and was a combination of several computational chemistry programs. The program was later modified and improved at the University of North Dakota until 1992, when its operations were moved to the Ames Lab at the Iowa State University. The project of converting GAMESS to the Macintosh was supervised by Brett Bode at the Ames Lab, who continues to update and maintain the program. It is freely available by registration at the MacGAMESS webpage. (Bode 2000) MacMolPlt was also designed by Brett Bode at the Ames Lab, and can be freely downloaded. (Bode 2000a) It is freely available by registration at the MacGAMESS webpage, MacMolPlt was also designed by Brett Bode at the Ames Lab. It makes extensive use of QuickDraw 3D, an Apple Computer technology that allows for the fast and efficient rendering of 3D models with photo-quality lights, shadows, and transparency in real-time. This makes for the molecules and plots viewed in MacMolPlt to be very visually stunning, and rotatable in real-time with the mouse.

METHODS

MacGAMESS and MacMolPlt have been downloaded and installed on a Mac G4 at Augustana College in this project. the amount of RAM allocated to MacMolPlt was increased by highlighting the program, choosing “Get Info...” from the “File” menu, and increasing the preferred size to 10,000K. MacMolPlt needs a larger memory allocation when large 3D models are to be saved or copied nto memory for use in other programs. This is a program for computing ab initio quantum chemistry calculations up to the 6-311G* basis set, using energy, gradient, and hessian run types. The hessian run type allows for normal modes of vibration to be calculated. MacMolPlt is an intricate visualization program which makes use of the files MacGAMESS outputs. It also has a convenient graphical MacGAMESS input builder, to easily create the input files necessary for MacGAMESS to run its calculations. It makes extensive use of QuickDraw 3D, an Apple Computer technology that allows for the fast and efficient rendering of 3D models with photo-quality lights, shadows, and transparency in real-time. This makes for the molecules and plots viewed in MacMolPlt to be very visually stunning, and rotatable in real-time with the mouse.

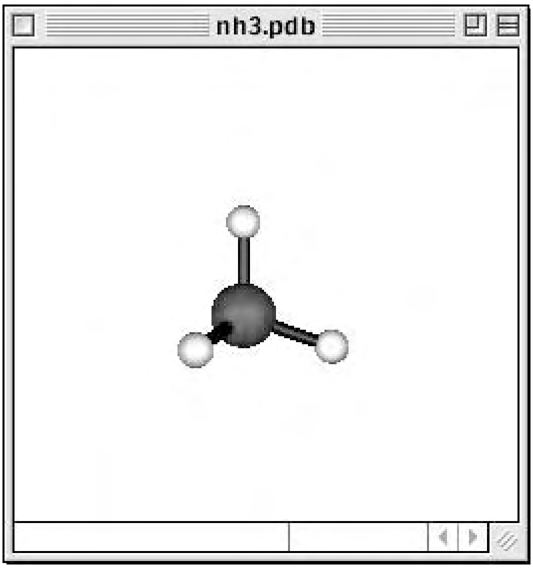

Fig. 1. NH_3 input in MacMolPlt.

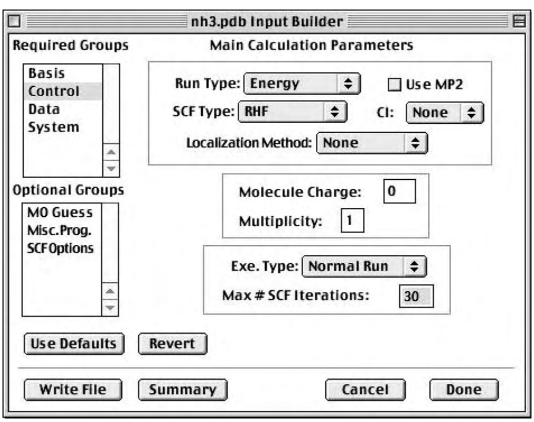

Fig. 2. MacGAMESS Control screen.

RESULTS AND DISCUSSION

MacGAMESS and MacMolPlt have been tested on small molecules, and a web-based manual has been developed. (Aspaas 2000) In testing the software, the ammonia molecule is used extensively in the manual and report to illustrate the capabilities of the software, including surfaces and vibrations. Using HyperChem on a PC in the Augustana Chemistry Department computer lab, a model of ammonia, NH_3 was built, and its geometry was optimized using AM1. This molecule was exported from HyperChem as a Brookhaven PDB file (extention *.ENT). The extension was then renamed to *.PDB, the standard extension for this type of files. The file was transferred to inst, Augustana's private FTP server, so it could be transferred to the Macintosh with MacMolPlt and MacGAMESS on it. The file was downloaded onto the Macintosh, and was dropped on top of the MacMolPlt icon. (Using the Macintosh operating system, the function of dropping a file onto a program is a shortcut to opening the program and opening that file within the program.) To turn rendering on, "Use QuickDraw 3D" was selected from the "Display" menu. The molecule was shown in the MacMolPlt window as in Figure 1.

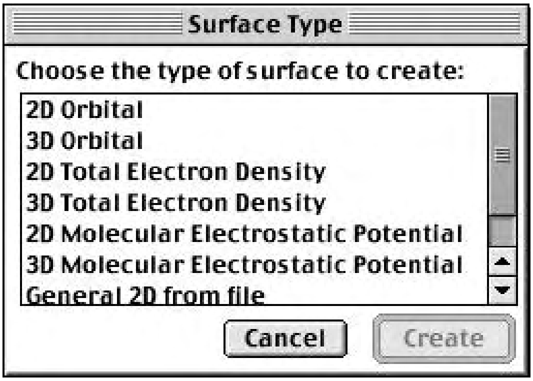

Fig. 3. Available surfaces for display.

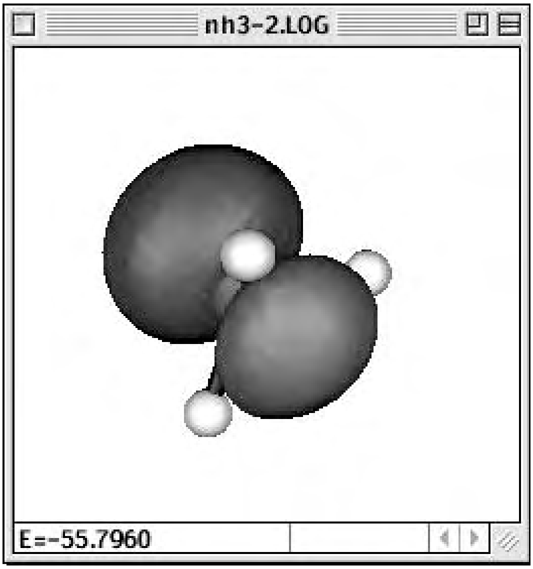

Fig. 4. NH_3 MO #5.

Next, the MacGAMESS input file was prepared. That screen was accessed by following "Windows > nh3.pdb > Input Builder." The first screen that comes up is the Control screen, as shown in Figure 2.

Similarly Basis and Data screens are worked through. Clicking on "Write File" creates the necessary input file with the molecule's information and the parameters for the run. This file is saved as a *.inp file. This file was run through MacGAMESS by dropping it onto the MacGAMESS icon. A dialog was presented while MacGAMESS was running: Depending on the complexity of the molecule and the speed of the computer, MacGAMESS will run for 30 sec-

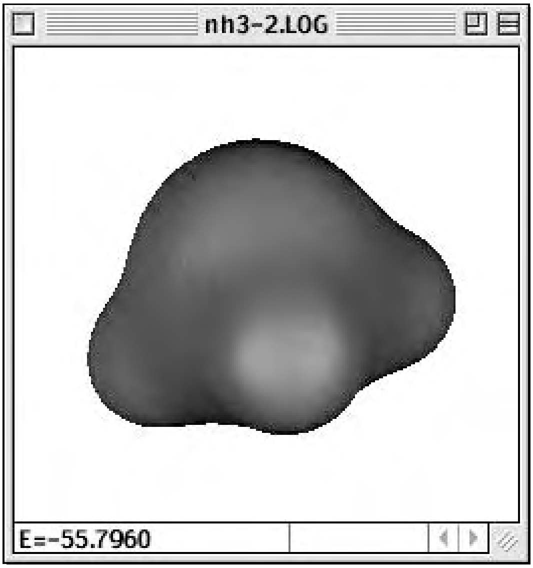

Fig. 5. NH_3 Total Electron Density.

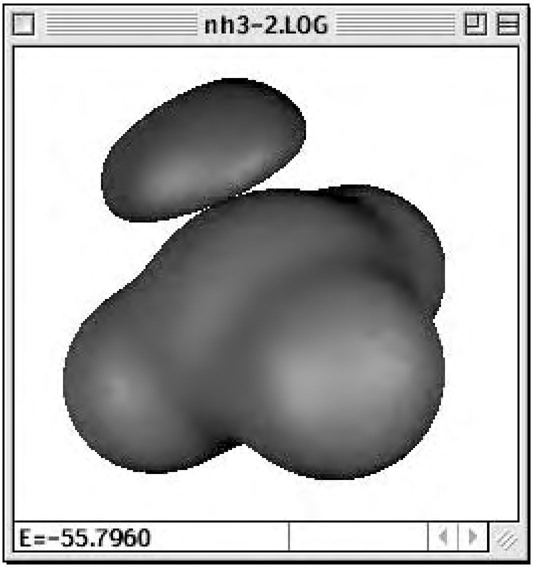

Fig. 6. NH_3 Molecular Electrostatic Potential.

onds to several minutes. However, if MacGAMESS immediately quits when the run starts, an error probably occured and the user should check the *.LOG file that was outputted for an explanation of the error. Common errors may be choosing a point group other than C1, or choosing a basis set that does not support 1 or more of the atoms in your molecule. When finished, MacGAMESS created a *.DAT and a *.LOG file. To visulaize the results, the *.LOG file was dropped onto the MacMolPlt icon. This opens the molecule with its quantum data into MacMolPlt. To see the results "Windows > nh3.LOG > Surfaces" was chosen. A list of available surfaces was presented as in Figure 3.

Selecting 3D Orbital, clicking Create, and choosing MO #5 produced the MO surface in Figure 4. Other choices include plotting 3D Total Electron Density in Figure 5 and 3D Molecular Electrostatic Potential in Figure 6.

MacGAMESS and MacMolPlt also readily calculate and visually display the normal modes of vibration of a molecule. The various images in MacMolPlt can also be exported readily as PICT or JPEG files. The latter format is directly useable on a web page.

CONCLUSION

MacGAMESS and MacMolPlt is a very useful pair of programs for quantum chemistry calculations. MacMolPlt has far more features that were not explored in this investigation, and MacGAMESS has a tremendous amount of parameters that are not provided for in the MacMolPlt input builder. Certainly the future will bring much more versatility to both of these programs. Basic operating instructions based on this study are posted on the web. (Aspaas 2001)

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ACKNOWLEDGMENTS

We thank the GAMESS developers, particularly Brett Bode, for access to the MacGAMESS and MacMolPlt software packages. Thanks also to Augustana College and its Department of Chemistry for software and hardware support.

REASSESSMENT OF THE AFFINITIES OF THE EXTINCT GENUS *CYLINDRACANTHUS* (OSTEICHTHYES)

David C. Parris and Barbara Smith Grandstaff
Bureau of Natural History
New Jersey State Museum
Trenton, NJ 08625-0530

Gorden L. Bell,Jr.
Guadalupe Mountains National Park
Salt Flat, TX 79847

ABSTRACT

The perplexing fossil genus *Cylindracanthus* has long been a taxonomic problem. Virtually a form genus of ribbed spine-like marine fish fossils (Cretaceous-Eocene), it has only recently been definitively shown to be rostral, based on bilateral symmetry and the presence of teeth. Best-known from circum-Atlantic sites, the first South Dakota specimen revealed the teeth for the first time and gave impetus for this review. Although the study is on-going, an emergent concept of relationships of the genus is now hypothesized, as well as potential biostratigraphic utility.

Traditionally *Cylindracanthus* was discussed in relation to the billfishes (marlins and swordfishes), particularly by those who considered the fossils to be rostral fragments. Aside from the anatomical considerations, such a relationship is awkward for biostratigraphic and evolutionary reasons. The extant billfish are highly derived Perciformes, an order that is virtually confined to the Cenozoic. *Cylindracanthus* and associated genera originated during the Cretaceous, which would place them among the earliest perciform genera, if correctly referred. In fact, they are in some respects even more derived than the living billfish, presumably with a skeleton entirely of cartilage except for the rostrum. (Extant billfish are bony, not cartilaginous.) It is thus unlikely that *Cylindracanthus* would have appeared so much earlier than supposedly related forms which are less derived.

Ancestral Acipenseriformes (sturgeons and related forms) appeared in the geologic record at about the same time in the Cretaceous as did *Cylindracanthus* , and a significant number of acipenseriforms survived the Cretaceous/Tertiary extinction event, as did *Cylindracanthus*. All of the living members of the order have tendencies toward projecting rostral development, and all are highly cartilaginous. As many taxonomic groups of fishes have produced experiments in bill-like projections of the rostrum, it is reasonable to speculate that *Cylindracanthus* was such an experiment among the acipenseriforms, with which all known features are consistent. Of known actinopterygians, only

Acipenseriformes have a projecting rostrum entirely anterior to the mouth, and this appears to have been the case in *Cylindracanthus* as well.

Among these features are the teeth, now known from the South Dakota specimen, which resemble those of juvenile *Polyodon* and of the various toothed species and growth stages of *Acipenser*. The same specimen exhibits insertion grooves with the bones posterior to the rostrum which resemble the insertion grooves in Acipenseriformes. The ventral rostral bones, cylindrical in Polyodontidae, are comparable to *Cylindracanthus*, particularly if homology to the vomer (generally a tooth-bearing element) is hypothesized. Microscopic structures and chemical analyses are thus far consistent with such a reference.

The teeth of *Cylindracanthus* were vestigial at the earliest known appearance of the genus, but became even more so during the course of evolution. This aspect may have some biostratigraphic value when more fully studied. Presumably *Cylindracanthus* became extinct when Eocene billed fishes of more modern aspect, such as *Blochius,* became too competitive for survival of similar, but archaic, forms.

Keywords

Fossil Fish, Acipenseriformes, Cretaceous, South Dakota

INTRODUCTION

Few fossil vertebrates have challenged understanding as much as has the fossil fish genus *Cylindracanthus* Agassiz. From the time it was first described (Agassiz, 1843) it was effectively a form taxon of cylindrical spines of Cretaceous through Eocene age. Easily recognized and fairly common in marine sediments from both sides of the Atlantic Ocean (Casier,1966; Lauginiger,1984; Robb,1989; Russell,1987), the specimens were nonetheless invariably incomplete and unassociated with any other skeletal material. Even the anatomical position of *Cylindracanthus* specimens remained unresolved. A possible relationship to the genus *Blochius* (of the Monte Bolca fauna of Italy) was advocated by Woodward (1917) and more or less accepted by many subsequent authorities (Fierstine, 1974). That hypothesis was the last major advance in knowledge; most subsequent publications have been notes of occurrence or discussions of form species and supposedly related form genera. Whether the genus was chondrichthyan or osteichthyan was still to some degree debatable.

It is somewhat unusual for a single specimen of a fossil taxon to clarify relationships after many years of confusion. This is particularly true when the specimen comes from a lithic unit which is notorious for poorly preserved fossils. It is thus with some bemusement that we describe a specimen of *Cylindracanthus* which is very helpful to interpretations of the genus, and effectively raises its status from form taxon to biologic taxon.

In the course of describing this specimen, we have assembled others of good quality and have re-examined the genus thoroughly. We began to question traditional assignments of *Cylindracanthus* (including those which we had been formerly willing to accept), based on both stratigraphic and anatomical grounds. The new anatomical evidence suggests affinities to the Acipenseriformes, the sturgeon-like fishes, a hypothesis that we develop in detail herein.

AREA OF INVESTIGATION

Cylindracanthus has a wide distribution, but is particularly well known from circum-Atlantic sites of Cretaceous and Eocene age. Our comparative materials have been primarily from North America, both Cretaceous and Eocene sites. Of particular interest is the specimen from South Dakota, first publicly announced by Parris *et al.* (1996), which extended the range of the genus to the Western Interior. Other specimens included within this study are from the Atlantic and Gulf Coast states from New Jersey to Texas.

METHODS

Much of our investigation has consisted of examination of fossil specimens to determine the presence or absence of teeth and tooth bases or remnants. This generally included gross examination followed by binocular microscopy, recorded notes, sketches and in some cases, photographs. We have also attempted to determine whether the fossils consist of acellular (massive) bone, but have not yet prepared thin sections specifically for this purpose, only examining existing sections and broken ends of specimens. Examination of recent acipenseriform specimens included inspection of prepared complete skulls and skeletons and of liquid-preserved entire specimens, under binocular microscopy.

RESULTS

Systematic Paleontology

Genus *Cylindracanthus* Leidy 1856

Type Species: *Cylindracanthus rectus* Agassiz 1843
Amended Diagnosis: Osteichthyan fish known primarily from cylindrical rostrum, gradually tapering and possessing longitudinal ridges corresponding to wedge-shaped sector of the rostrum. Bilateral symmetry often reflected in median partition of a central cavity and in paired grooves which may bear teeth or tooth bases.

Type Species: *Cylindracanthus ornatus* Leidy 1856
Amended Diagnosis: Rostrum bearing 32 to 55 longitudinal ridges, some pairs uniting into single ones toward the narrow end. Teeth or tooth remnants, when present, spaced about 10 per centimeter of rostrum length.

Referred Specimen: SDSM 30638, a fragment of rostrum with teeth. Repository is Museum of Geology, South Dakota School of Mines and Technology (Fig. 1).

Provenience: Pierre Formation, Verendrye Member, from Locality V952 in Hyde County, South Dakota, with precise locality data on file at South Dakota School of Mines and Technology (SDSM). Precise stratum is two meters above the designated iron-stained layer, a marker bed in the lower Verendrye Member noted in the stratigraphy of Hanczaryk *et al.* (1996).

Age: Cretaceous, Campanian.

Description: Restored length of the specimen is 261 mm and its diameter varies from 7.8 mm to 12.9 mm. The number of longitudinal ridges varies from 21 to 44. In cross-section, the specimen exhibits vaguely the familiar double cavity described by Leidy (1856) and subsequently illustrated by various authors, including Fowler (1911) and Schultz (1987).

The remarkable aspect of SDSM 30638 is that it bears well-developed teeth, the first specimen known to us to retain them. The teeth are typically acrodont and appear to be composed of vitrodentine. Curved strongly at the bases, the teeth are oriented with a long axis at an acute angle with the long axis of the rostrum, pointing toward its larger diameter, the presumed basal or posterior end. The teeth do not rise significantly above the groove in which they are placed, thus they could scarcely serve as barb retainers in the generally ex-

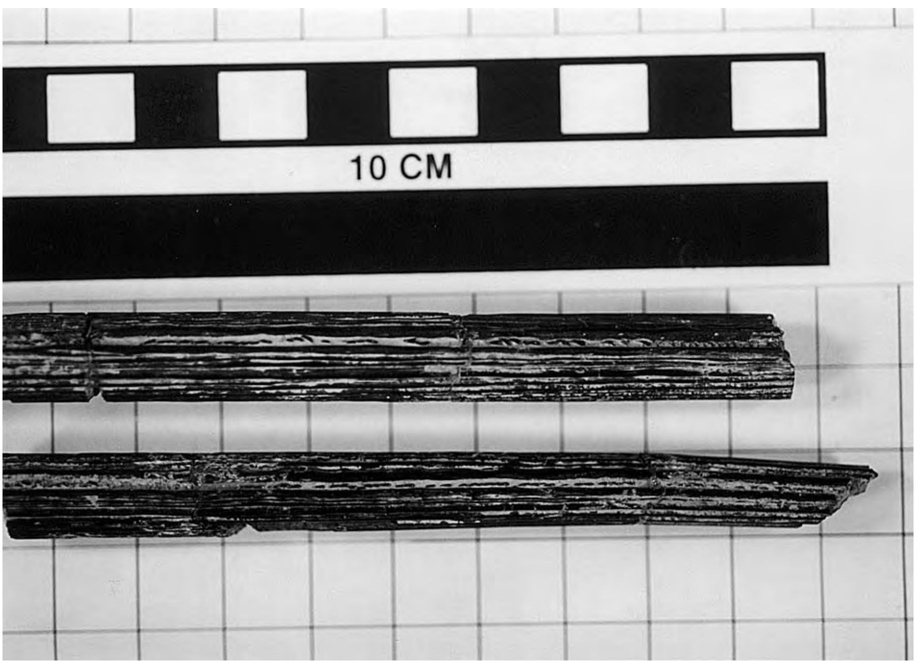

Figure 1. *Cylindracanthus ornatus* Leidy. SDSM 30638, partial rostrum from the Verendrye Member, Pierre Formation, (Cretaceous,Campanian), Locality V952, Hyde County, SD.

pected manner. Indeed, the apex of each tooth overlaps the basal portion of the adjacent more posterior tooth. They are of regular size (approximately two mm long), and are spaced quite evenly at 10-11 per centimeter. They are translucent and appear to have internal open structure, but have closed pointed tips (so presumably did not serve as venom-conducting fangs). Some replacement teeth are visible, emerging beside the functional row, so it may be presumed that regular tooth replacement followed shedding or losses from the main row. There are six to fifteen ridges between the tooth rows.

One other conspicuous feature of SDSM 30638 is a sulcate groove on the surface which we interpret to be the dorsal side. The bilateral symmetry plane passes through it and the two tooth rows are paired closer to the other side. This sulcus, positioned at one end, appears to expand toward the base of the specimen and may represent the insertion of another pair of skeletal elements.

Another specimen with teeth preserved has been noted in the collections of the Alabama State Museum, catalogued as ASM-PV 994.2.111, and which has been loaned to us for inclusion in this study (Fig. 2). Also referable to the species *Cylindracanthus ornatus,* it is from the Bluffport Marl Member of the Demopolis Chalk in Marengo County, Alabama. (Precise locality information is known and catalogued.) It is quite similar to the South Dakota specimen in general form, with a number of loose teeth preserved in matrix within the ventral grooves. The teeth are no different from those in the South Dakota specimen.

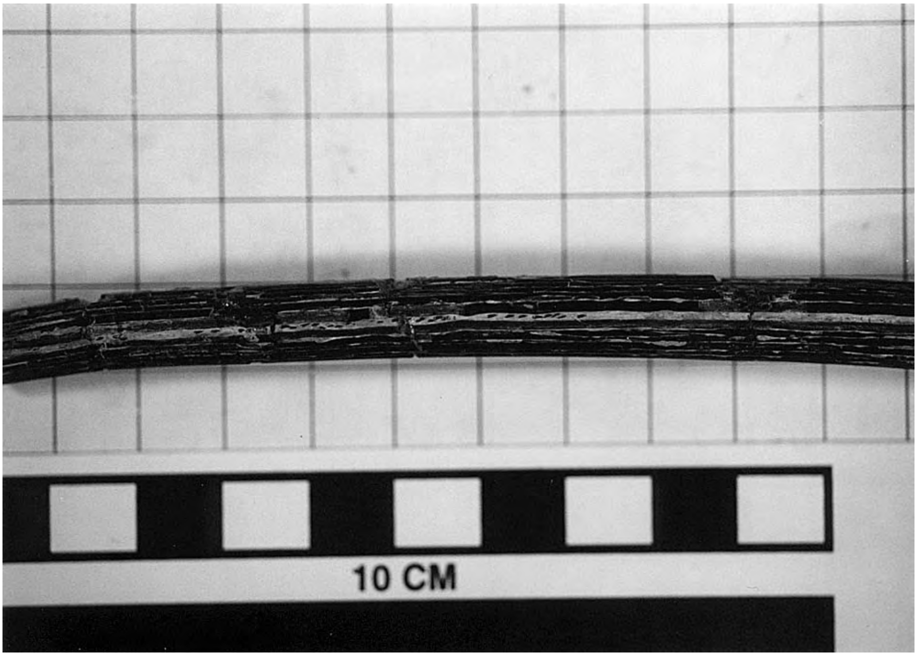

Figure 2. *Cylindracanthus ornatus* Leidy. ASM-PV 994.2.111, partial rostrum from the Bluffport Marl Member, Demopolis Chalk, (Cretaceous), Marengo County, AL. Precise locality information on file.

Comparisons

The type material of *Cylindracanthus ornatus* (Fig. 3) was made available for comparison by the repository, the Academy of Natural Sciences of Philadelphia (ANSP). Leidy (1856) described the species from three fragments, ANSP 5186-5188. Additional description was contributed by Fowler (1911), whose notations on the number of ridges remain as part of the specific diagnosis. However, his description of the genus indicates absence of denticles, when in fact all three fragments show evidence of two rows of tiny teeth on the outer surface, separated by two to four ridges (Fig. 3). The grooves in which these tooth remnants are located are wider than the other grooves. The central lumen is divided into two sides, presumably left and right, and the two tooth remnant tracts seem to be associated in the same left and right portions, one tooth tract on each of the two sides.

It would appear that the type material of *Cylindracanthus ornatus* comes from a larger individual (or individuals) than does SDSM 30638. Because the range of variation in this taxon is uncertain and because SDSM 30638 seems to match ANSP 5186-5188 in all major features (Fowler's diagnosis notwithstanding) we refer SDSM 30638 to the species. It is probable that they differ substantially in age, however, SDSM 30638 being Campanian and ANSP 5186-5188 being almost certainly Maastrichtian. Although Fowler (1911) gave a range of potential formation proveniences for the type material, its preservation is highly indicative of the Navesink Formation.

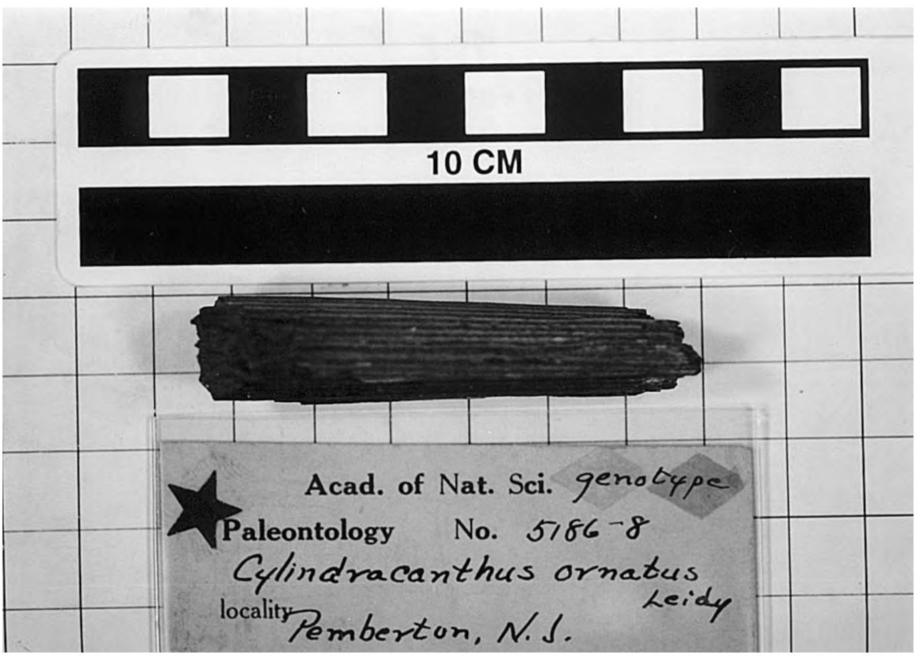

Figure 3. *Cylindracanthus ornatus* Leidy. ANSP 5186-5188, from Pemberton, Burlington County, NJ. TYPE. Believed to be from the Navesink Formation.

Specimens of Eocene age have also been referred to *Cylindracanthus ornatus* (and more often to the species *Cylindracanthus rectus* Agassiz, which was originally described as a species of *Coelorhynchus* and which is sometimes considered a senior synonym of *Cylindracanthus ornatus* Leidy). This is especially true of Gulf Coast area specimens (Woodward, 1891; Thurmond and Jones,1981).

We have had the opportunity to make detailed comparisons with three specimens described by Fallow (1964) through the courtesy of the University of North Carolina (UNC), and another which was loaned from the personal collection of Donald Clements of North Carolina. These specimens were not referred to any described species, but seem to be typical of Eocene specimens generally, except for those historically referred to the species *Cylindracanthus acus* Cope. Our comparisons, given as follows, offer some basis for distinction from Cretaceous specimens. Fallow's specimens are from the Castle Hayne Formation of North Carolina and the Santee Formation of South Carolina UNC 3595, 3596, 3597). Details of the ossification are more observable in these specimens, at least in binocular magnification, than in the Cretaceous specimens seen by us (Fig.4).

Grooves in these specimens seem to represent areas which are intensely vascularized and/or innervated relative to the ridges. Small pores are visible on the surfaces at the bottoms of the grooves. Where breaks have occurred, usually along the grooves (which apparently are weak positions), a network of fine interior grooves may be seen, suggestive of a capillary bed. Calcified tis-

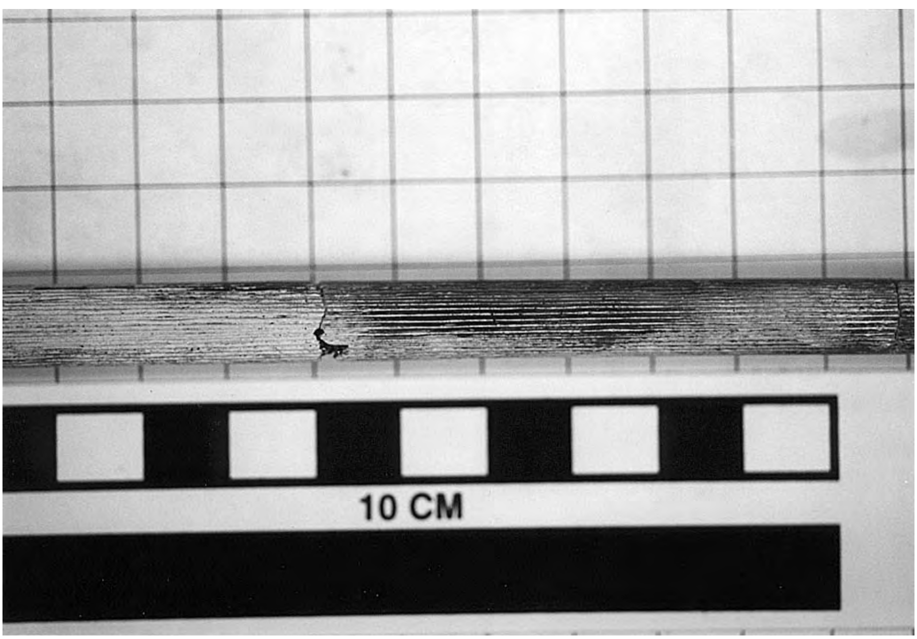

Figure 4. *Cylindracanthus rectus* Agassiz. ASM-PV 989.4.200, from the White Hills Locality, Lisbon Formation(Late Eocene) near Melvin, Choctaw County, AL.

sue of the ridges, when broken, generally appears granular, unlaminated, and in no way trabecular in contrast to the broken grooves.

The inner wall of the lumen of the specimens shows pores on the surface, appearing like vascular foraminae, which presumably are vessel passages to the central tissue mass. In some of the specimens the lumen is partially occluded by mounds of what appear to be secondary calcified tissue, developed inside the radially structured bone of the major portion of the specimen. Although lacking the radial structure, this secondary calcified tissue (which may be dentine or calcified cartilage) does have some vascular channels which run parallel to the long axis.

One specimen (UNC 3597) shows evidence on a broken end surface of organized calcification of the ridges. In each ridge there are patterns of organization of calcified tissue radiating outward (on a curving diagonal) from the center line of the ridge toward the outer surface of the cylinder and the outer surface of the ridge, presenting a feather-like pattern in end view. The vascular traces in the specimen are not absolutely straight, and it appears that there may be secondary osteons in the area of the internal midline ridge. The feather-like pattern suggests a pattern of calcification perhaps similar to teeth. The bone lining the lumen has a longitudinal (almost fibrous) structure.

The South Carolina specimen (UNC 3595) has the tip preserved and has a large foramen opening by the tip (possibly a sensory nerve passage) and the tip also appears worn rather evenly all around. The specimen loaned by Mr. Clements is from the Castle Hayne Formation at the Lanier Pit, Maple Hill, Pender County, North Carolina. It has a large groove, an indentation of the entire structure, possibly homologous to the grooves which bear dentition or dentition remnants, but it is sufficiently worn to have obliterated any actual remnants. A Cretaceous specimen loaned by Eugene Hartstein of Delaware came from the Mt.Laurel Formation spoil piles of the Chesapeake and Delaware Canal in New Castle County, Delaware. It has relatively large tooth bases, measuring approximately 1.58 millimeter diameter, with spacing at 28 per centimeter. There are four ridges between the tooth rows and a total of twenty in the entire circumference, none of them anastomosed within the short length of the specimen as preserved (less than 2 centimeters). The specimen is of particular interest in that the central lumen is not of normal orientation, but instead has an axis oblique to the tooth rows, despite the overall persistence of bilateral symmetry.

No teeth were mentioned by Fallow (1964) in his specimens, but in fact they are present as tiny remnants, readily seen if magnification is sufficient. Two rows of tooth bases are observable in UNC 3595 and a few remnants are visible in UNC 3596. Grooves are narrower on the Eocene specimens, and the tooth remnants consequently are much smaller than in the Cretaceous specimens.

Less detailed comparisons to other specimens, none of them published, confirmed the general observations listed above. We have examined approximately 200 such specimens of the genus ranging in age from Cretaceous to Eocene, and geographically from New Jersey to Texas. In addition to those institutions previously listed, we have viewed and borrowed specimens from

Louisiana State University (LSU) and the Mississippi Museum of Natural Science (MMNS). (There are reportedly some specimens from younger horizons, but we have not reviewed the validity of such records.) With regard to the species *Cylindracanthus ornatus,* there seems to be consistency in the lesser development of tooth base remnants in the younger horizons. While various authorities have placed *Cylindracanthus ornatus* Leidy and *Cylindracanthus acus* (Cope) in synonomy with *Cylindracanthus rectus* Agassiz, it seems clear to us that the latter species is perceived as having virtually no bilateral symmetry nor tooth base development, and is characteristically found in strata of Eocene age, as was the Agassiz type material (Arambourg,1952;Thurmond and Jones,1981; Weems,1999). *Cylindracanthus ornatus,* which exhibits tooth development, is Cretaceous through Eocene, but with diminished tooth development in specimens from younger strata. Because a rigorous taxonomic revision would require examination of the type material of Agassiz, we provisionally suggest that the three species should be retained as distinct, and restrict our primary comments on the teeth to the species *Cylindracanthus ornatus* Leidy.

DISCUSSION

Cylindracanthus has a lengthy history of recorded specimens and discussion of its affinities (Fierstine, 1974,1990; Schultz, 1987). We concede that only better specimens will ever reveal a definite taxonomic position for the genus. We at least have a better specimen than any found previously, and thus have some basis to form our own hypothesis. A complete historical review of the supposed relationships of the genus is beyond the scope of this present work, but it will suffice to note that many authorities have proposed that *Cylindracanthus* is related to the extant billfishes (Schultz, 1987). While we ourselves have discussed the genus as a possible xiphioid relative, the biostratigraphic record shows this to be a very awkward arrangement.

The extant xiphioids are very derived members of the order Perciformes, an order that is virtually confined to the Cenozoic. As some authors have noted (Weems, 1999), to place the genus *Cylindracanthus* in that group would make it one of the earliest taxa of the order, because of its appearance in the Cretaceous. However, it would appear that *Cylindracanthus*, if considered to be a perciform, is even more derived than the extant xiphioids, because in all probability the skeleton was cartilaginous except for the acellular bones of the bill. Extant xiphioids are bony, not cartilaginous, and it is highly unlikely that *Cylindracanthus* would have appeared so much earlier than other, supposedly related forms, which are less derived.

Based on our new anatomical evidence from the teeth and posterior insertions of the rostrum, we suggest another possible relationship which seems consistent with all available evidence. The Acipenseriformes, sturgeons and related forms, have a substantial fossil record in the Cretaceous, appearing at about the same time as *Cylindracanthus*. As noted in the monographic reviews of Grande and Bemis, 1991,1996), the acipenseriforms have tendencies toward cartilaginous skeletons and substantial rostral development. Of known actinopterygians, they are the only group known to have a projecting rostrum entirely anterior to the mouth, which was probably the case in *Cylindracanthus* as well, there being no evidence of an occlusion to a lower jaw on even the best of specimens. The acipenseriforms fared well during the Cretaceous, and also survived the Cretaceous/Tertiary extinction event (as did *Cylindracanthus*). They are extant in relatively small numbers and diversity, being somewhat at a competitive disadvantage with more derived forms (such as the Perciformes).

As many taxonomic groups of fishes have produced forms with bill-like projections of the rostrum, it is reasonable to speculate that *Cylindracanthus* was such a form among the Acipenseriformes, with which all known anatomical features are consistent. Among these features we can now cite the teeth, which greatly resemble those of juvenile paddlefish (*Polyodon*) and those of toothed species and growth stages of sturgeons *(Acipenser).* The South Dakota specimen also exhibits insertion grooves which resemble those on the rostrum of *Acipenser.* Furthermore, the ventral rostral bones,cylindrical in Polyodontidae (Grande and Bemis,1991) may be homologous to the vomer (Jollie,1980), commonly a tooth-bearing element in fishes.

Weems (1999) suggested that *Cylindracanthus* could be related to the Dercetidae. While based on the definite resemblance of the rostrum to that of *Rhynchodercetis* (Chalifa, 1989), the fully ossified skeleton, modest size, and fully functional dentition of dercetids lend little support for such a relationship. Furthermore, the resemblance of *Rhynchodercetis* is to *Cylindracanthus rectus* rather than to the Cretaceous specimens of *Cylindracanthus*, while *Rhynchodercetis* is early Cenomanian, considerably older than any taxa discussed here.

The trend in the dentition of *Cylindracanthus* is toward tooth reduction. The teeth were vestigial in the oldest specimens (Cretaceous) and became even more so, as noted within the species *Cylindracanthus ornatus.* This aspect may have biostratigraphic value when more fully studied. Presumably *Cylindracanthus* declined toward extinction when Eocene billed fishes of more modern aspect became too competitive for the survival of similar, but archaic forms. As a relatively common and widespread marine fossil that spans the Cretaceous/Tertiary boundary, the potential value of *Cylindracanthus* in biostratigraphy commands special interest, and it is to be hoped that yet more discoveries of better specimens will continue to improve our knowledge of it.

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William N. Parris, a student at the Princeton Child Development Institute, assisted with the collecting of SDSM 30638. In grateful appreciation to this respected institute for autism research, the site is now designated as the PCDI Site.

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OPTIMAL MACROINVERTEBRATE METRICS FOR THE ASSESSMENT OF A NORTHERN PRAIRIE STREAM

A.M. Larson and N.H. Troelstrup, Jr.
Department of Biology and Microbiology
South Dakota State University
Brookings, SD 57007

ABSTRACT

This research was conducted to (1) determine an optimal suite of macroinvertebrate metrics and (2) test the effectiveness of standard EPA biological assessment methods for identification of stream degradation. Invertebrate samples were taken from 18 sites on Bachelor and Brookfield Creeks in Moody County, South Dakota once per month from April through September 1998 and 1999. Data were applied to 51 invertebrate metrics which were (1) randomly selected in sets of 10, (2) grouped as per Plafkin et al. (1989) (3) optimized by minimizing reference site variability and maximizing site discriminatory power (Barbour et al., 1999), and (4) optimized using principal components analysis (PCA). Plafkin and randomly selected metric sets resulted in 60% of stream sites classified as slightly impaired and 40% of sites as moderately impaired. Optimized metrics resulted in 20% of stream sites classified as unimpaired, 47% of sites as slightly impaired, and 33% of sites as moderately impaired. PCA metrics resulted in 47% of sites classified as unimpaired and 53% of sites as slightly impaired. Three sites categorized as slightly impaired using the Plafkin set were considered non-impaired using the optimized set. All sites categorized as slightly impaired using the Plafkin set were considered non-impaired using the PCA set. These results suggest that objective selection of core metrics is necessary to prevent type I errors from biomonitoring investigations.

INTRODUCTION

The use of multimetric community indices to evaluate impairment of aquatic biota is now used widely within the United States. Karr et al. (1986) first demonstrated the multimetric approach with the Index of Biotic Integrity (IBI) for fish communities in Illinois. This approach combines information on fish abundance, species composition, guild composition and condition to provide a single integrated index of biological integrity in surface waters. His protocol has served as a model for development of other multimetric approaches including the Benthic Index of Biotic Integrity (B-IBI) developed for rivers of the Tennessee Valley (Kerans and Karr, 1994), the Invertebrate Community Index (ICI) developed by the Ohio EPA (DeShon, 1995), and the USEPA Rapid Bioassessment Protocols (RBPs) (Plafkin et al., 1989). While originally developed for fish communities, this approach has now been applied to algal and invertebrate assemblages (Barbour and Yoder, 2000).

Numerous measures (metrics) of invertebrate community characteristics have been tested for use in water resource management. Although some require regional modifications, metrics are used over wide geographic areas (Barbour et al., 1999). From a large list of metrics, a suite of candidate metrics is chosen that is appropriate for regional settings. Candidate metrics are chosen based on knowledge of aquatic systems, flora and fauna, historical data, and literature reviews (Barbour et al., 1995).

From the candidate metrics, a set of core metrics is selected to be included within an index of biotic integrity. Most multimetric indices are comprised of eight to ten core metrics, which are selected because they reflect an aspect of the biological system (Karr and Chu, 1999). These core metrics are incorporated into an index that should provide an integrated picture of abundance, community composition, habitat utilization, functional organization, and tolerance to pollution (Barbour, 1999; Karr and Chu, 1999). This approach, using several types of measures, provides a more holistic assessment of community structure and function (Plafkin et al., 1989).

Application of the invertebrate multimetric approach requires knowledge of local and regional fauna and likely sources of degradation to surface waters. For example, invertebrate metrics developed for high gradient streams in the Black Hills of South Dakota are unlikely suitable for low-gradient ephemeral streams of eastern South Dakota. Thus, research efforts are needed to document the composition of regional invertebrate assemblages and select invertebrate community metrics suitable for different ecoregions.

This effort was conducted to determine an optimal suite of core macroinvertebrate metrics suited for detecting biological impairment in eastern South Dakota streams and test the usefulness of standard EPA biological assessment methods for identifying areas of impairment.

STUDY AREA AND METHODS

The Bachelor Creek watershed (Fig. 1) is located in the Northern Glaciated Plains Ecoregion of Eastern South Dakota (Omernik, 1987), extending across Moody and Lake counties within South Dakota. The watershed drains an area of 24,022 hectares, of which 633 hectares are considered highly erodible land. The landscape is characterized with low slopes and large numbers of prairie pothole wetlands. Land-use in the watershed area is primarily agricultural with approximately 83 percent cropland, 5 percent grassland, and 7 percent farms and shelterbelts (Moody County Conservation District, 1991).

To facilitate an adequate assessment and to comply with standard methods, a reference drainage was defined for comparison. Hughes (1995) defines reference conditions as those approximating presettlement physical, chemical, and biological conditions, or those areas believed to have high ecological integrity. However, due to the difficulty of determining what conditions would be like prior to European settlement, minimal disturbance is often used as a reference condition. In this study, Brookfield Creek, a nearby tributary of the

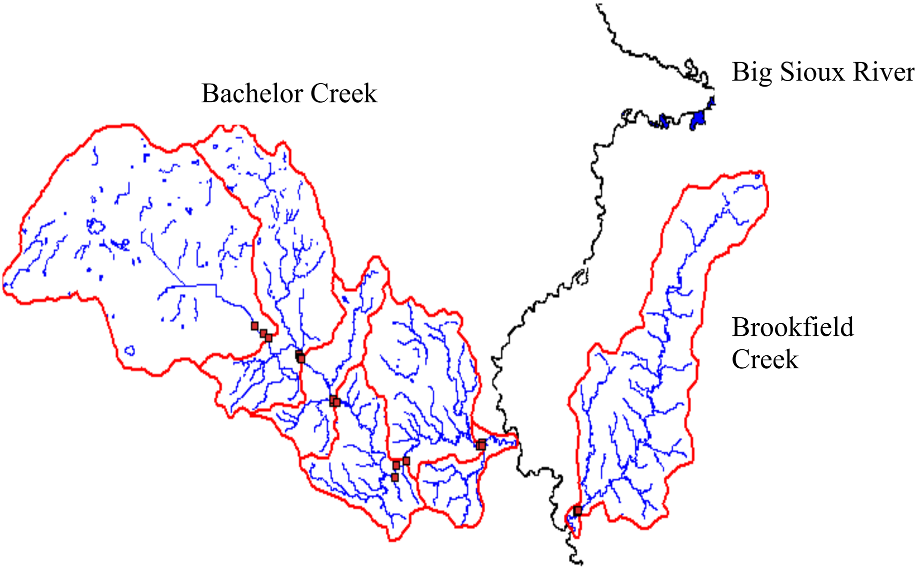

Figure 1. Location of sampling sites and reaches within Bachelor and Brookfield Creeks, Moody County, SD. Numbers indicate Bachelor Creek reaches (sub-watersheds). Dots represent sampling sites (Note: three sites per reach).

Big Sioux River, was selected as a reference stream for comparison to Bachelor Creek biological and habitat data.

Benthic macroinvertebrate samples were collected monthly from April through September in 1998 and 1999 from 5 reaches along the mainstem of Bachelor Creek (Fig. 1). Three riffle sites were sampled on each reach of Bachelor Creek (15 sites) and along the mainstem of Brookfield Creek (3 sites). Three standard one-minute kicknet samples were collected from each riffle site and combined to make one composite sample.

Invertebrate samples were subsampled and sorted within the laboratory. A fixed count (100-organism minimum subsample) was sorted from the matrix of detritus, sand, and mud (Newman, 1987). Major taxa were placed in separate vials and were identified to the genus/species level, excluding the phylum Annelida (Merritt and Cummins, 1996; Thorp and Covich, 1991).

Resulting invertebrate counts were applied to 51 candidate metrics (Table 1). These metrics were divided into five categories reflecting abundance, community composition, habitat utilization, functional organization, and tolerance to pollution (Barbour et al., 1999).

Four different core metric selection procedures were evaluated after metric scoring. Random sets of 10 candidate metrics were selected from the larger candidate set. These random sets become our null core set. The eight metric EPA Rapid Bioassessment core set was selected as our second core set. The third core set was selected following the metric optimization procedure of Barbour et al. (1999), producing a core metric set with high discriminatory power and low reference site variability. The final core set was derived using principal components analysis (PCA) applied to metric data.

Table 1. Metrics used to categorize invertebrate communities in Brookfield and Bachelor Creeks, Moody County, SD (sorted by metric category).

Metric Category	Metric	Change Due to Impairment Relative to Reference
Abundance	Estimated Total Abundance	Increase or Decrease
	Taxonomic Richness	Decrease
Community Composition	Coefficient of Community Loss Index	Increase
	% Contribution of Dominant Taxon	Increase
	% Ephemeroptera (E)	Decrease
	% Plecoptera (P)	Decrease
	% Trichoptera (T)	Decrease
	% EPT (together)	Decrease
	% Elmidae	Decrease
	% Diptera	Increase
	% Chironomidae	Increase
	% Other Diptera and Non-Insect Taxa	Increase
	% Oligochaeta	Increase
	% Tanytarsini	Decrease
	% Rheotanytarsus	Decrease
	% Glyptotendipes	Increase
	% Hyallela azteca	Increase
	Tanytarsini:Chironomidae Ratio	Decrease
	EPT:Chironomidae Ratio	Decrease
	EPT Richness	Decrease
	Ephemeroptera Richness	Decrease
	Plecoptera Richness	Decrease
	Trichoptera Richness	Decrease
	Diptera Richness	Decrease
	Chironomidae Richness	Decrease
	Tanytarsini Richness	Decrease
	Tanytarsini Richness:Total Richness	Decrease
	Tanytarsini Richness:Chironomidae Richness	Decrease
	Rheotanytarsus Richness	Decrease
	Glyptotendipes Richness	Increase
	Hyallela azteca Richness	Increase
Habitat Utilization	% Burrowers	Increase
	% Climbers	Decrease
	% Clingers	Decrease
	% Gliders	Increase
	% Skaters	Increase
	% Sprawlers	Decrease
	% Swimmers	Increase
	% Preferring Depositional Habitat	Increase
	% Preferring Erosional Habitat	Decrease
Functional Organization	% Filtering Collectors	Decrease
	% Gathering Collectors	Increase
	% Piercers	Decrease
	% Predator Engulfers	Increase
	% Scrapers	Increase
	% Shredders	Decrease
	% Filtering + Gathering Collectors	Decrease
	Scraper:Filtering Collector Ratio	Increase
Tolerance to Pollution	% Intolerant Invertebrates (HTV < 3.0)	Decrease
	% Tolerant Invertebrates (HTV > 7.0)	Increase
	Modified Hilsenhoff Biotic Index	Increase

Each of the core metric sets was scored relative to reference Brookfield Creek data using a modification of the EPA Rapid Bioassessment protocol (Plafkin et al., 1989). Metrics of each Bachelor site were assigned a score of 0, 2, 4 or 6 based upon comparisons with reference stream conditions. Low scores indicate large deviation while high scores indicate similarity with reference conditions (Table 2). The sum of metric scores was divided by the maximum possible score to derive a percent comparability (IBI score) for each Bachelor site. Impairment classes (unimpaired, slightly impaired, moderately impaired and severely impaired) were assigned based upon quartile deviations from average reference stream conditions (Table 3).

RESULTS

Of the 51 candidate metrics examined, ten metrics were included in the optimized IBI based upon two conditions: 1) large differences in metric values between paired reference and test samples (discriminatory power) and 2) low reference site variability (Table 4). All candidate metrics were ranked based on

Table 2. Optimized set of metrics and scoring criteria selected for the Bachelor Creek study, Moody County, SD.

Metric	OPTIMIZED INVERTEBRATE METRIC SCORES AND CRITERIA 6	4	2	0
% Burrowers [b]	>75%	50-75%	25-50%	<25%
Community Loss Index [a]	<0.5	0.5-1.5	1.5-4.0	>4.0
% EPT [b]	>75%	50-75%	25-50%	<25%
% Filtering Collectors [c]	>75%	50-75%	25-50%	<25%
% Gathering Collectors [b]	>75%	50-75%	25-50%	<25%
% Preferring Erosional Habitat [c]	>75%	50-75%	25-50%	<25%
% Clingers [c]	>75%	50-75%	25-50%	<25%
EPT Taxa Richness [a, c]	>90%	80-90%	70-80%	<70%
Modified Hilsenhoff Biotic Index [a, b]	>85%	70-85%	50-75%	<50%
% Tolerant Invertebrates [b]	>75%	50-75%	25-50%	<25%

[a] Scores calculated based upon original RBP III criteria (Plafkin et al. 1989)
[b] Scores calculated based upon ratio of reference site to study site x 100
[c] Scores calculated based upon ratio of study site to reference site x 100

Table 3. Stream condition categories based upon percent accumulated point totals derived from invertebrate metric scores (modified from Plafkin et al. 1989).

% of Possible Point Total	Stream Condition Category
>75% (>45 points)	Non-impaired
51-75% (31-45 points)	Slightly Impaired
25-50% (15-30 points)	Moderately Impaired
<25% (<15 points)	Severely Impaired

Table 4. Optimized set of invertebrate metrics and optimization rank for Bachelor Creek study, Moody County, SD.

Metric	Discriminatory Power	Rank	Reference C.V. (%)	Rank	Total Rank	Class
Modified Hilsenhoff Biotic Index	1.24	7	10.7	1	1	Tolerance
% Filtering Collectors	1.77	2	36.6	7	2	Feeding
% Preferring Erosional Habitat	1.10	9	27.4	3	3	Habit
% Clingers	0.91	12	30.7	5	4	Habit
Community Loss Index	1.37	4	60.7	16	5	Composition
% Tolerant Invertebrates (HTV>7)	1.25	6	58.7	15	6	Tolerance
EPT Taxa Richness	0.77	14	46.2	10	7	Richness
% Gathering Collectors	1.34	5	62.1	19	8	Feeding
% Burrowers	1.57	3	79.4	24	9	Habit
% EPT	1.00	12	70.6	22	10	Composition

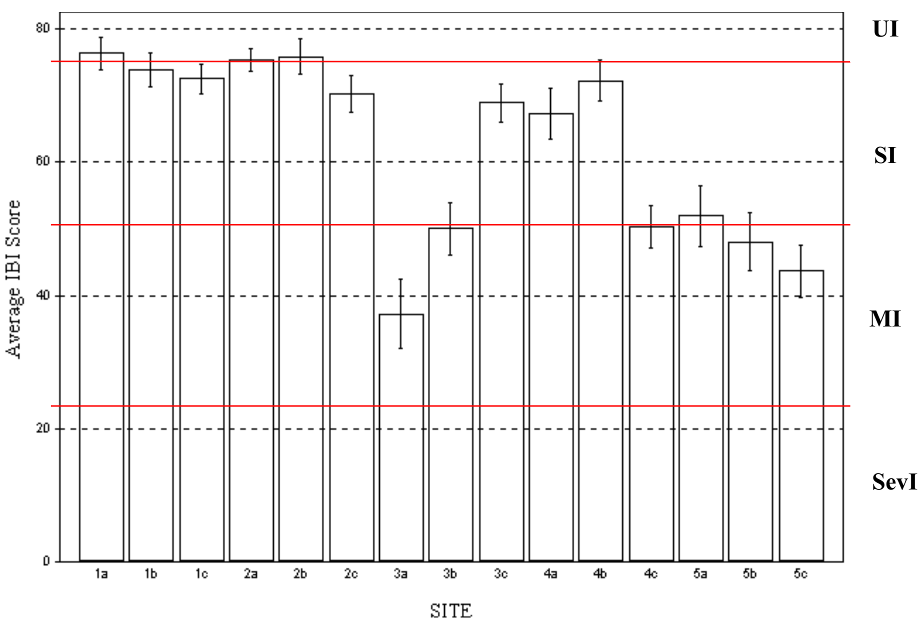

Figure 2. Average IBI scores for all sites using the optimized metric set. Solid horizontal lines indicate impairment category thresholds (UI=unimpaired, SI=slightly impaired, MI=moderately impaired, and SevI=severely impaired).

the above criteria and those that ranked in the top ten were retained (Fig.2). These qualities make this set most optimal for use in the Bachelor Creek assessment and applicable across the ecoregion.

Analysis of Bachelor Creek metric values resulted in 10 principle components explaining 83% of the variability in invertebrate community characteristics. The metric weighing most heavily on each principle component was selected to represent that component of ordinate space within the data set. This method resulted in ten metrics, which were collectively referred to as the PCA metric set (Table 5).

Table 5. Metrics included in the optimized, PCA and USEPA core metric sets for the Bachelor Creek study, Moody County, SD.

Optimized	PCA	USEPA
Hilsenhoff Biotic Index	% Preferring Depositional Habitat	Taxonomic Richness
% Filtering Collectors	% Chironomidae	Hilsenhoff Biotic Index
% Preferring Erosional Habitat	% Diptera	Scrapers:Filtering Collectors
% Clingers	% Burrower	EPT:Chironomidae
Community Loss Index	% Oligochaeta	% Dominant Taxon
% Tolerant Invertebrates	% Elmidae	EPT richness
% Gathering Collectors	Taxonomic Richness	Community Loss Index
EPT richness	Hilsenhoff Biotic Index	% Shredders
% Burrowers	Chironomidae richness	
% EPT	EPT richness	

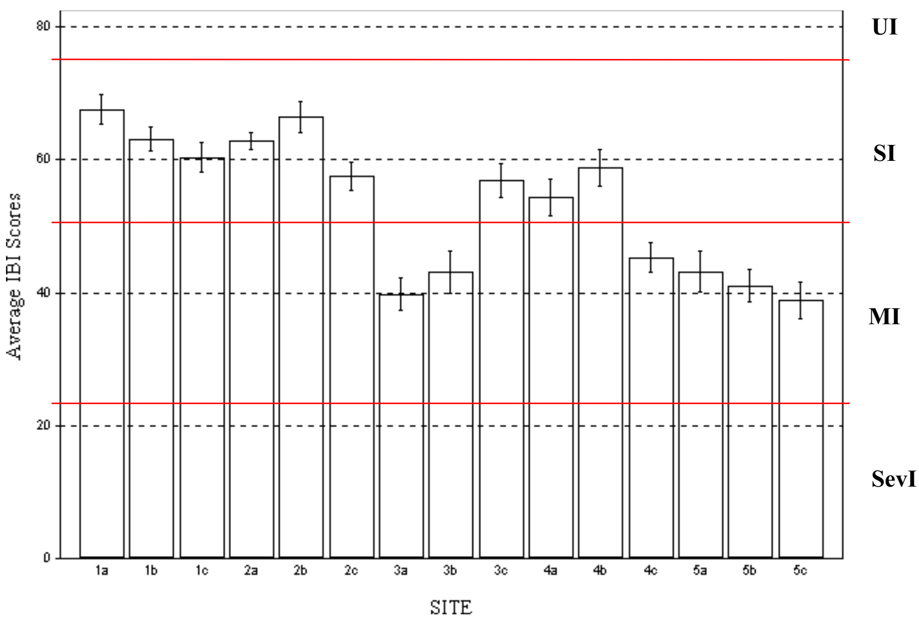

Figure 3. Average IBI scores for all sites using random (null) metric sets. Solid horizontal lines indicate impairment category thresholds (UI=unimpaired, SI=slightly impaired, MI=moderately impaired, and SevI=severely impaired).

Stream site impairment assignments varied among core metric sets. Random and Plafkin sets provided similar scorings with 60% of sites classified as slightly impaired and 40% as moderately impaired relative to reference Brookfield Creek communities (Figs. 3 and 4). In contrast, optimized core scorings suggest that 20% of Bachelor sites were unimpaired, 47% were slightly impaired and 33% were moderately impaired (Fig. 2). PCA metric set analysis deemed all sites either unimpaired (47%) or slightly impaired (53%) (Fig. 5).

We also examined the appropriate number of metrics to include in our optimal core set. Using one of the more degraded sites (site 5B) and the top ten optimized metrics, we evaluated the response of site IBI score upon adding one

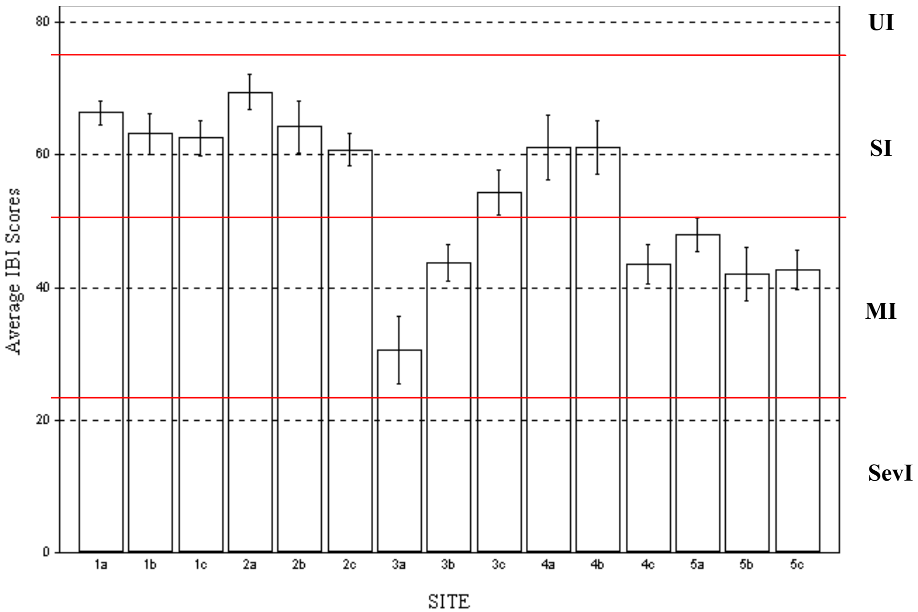

Figure 4. Average IBI scores for all sites using the Plafkin et al (1989) metric set. Solid horizontal lines indicate impairment category thresholds (UI=unimpaired, SI=slightly impaired, MI=moderately impaired, and SevI=severely impaired).

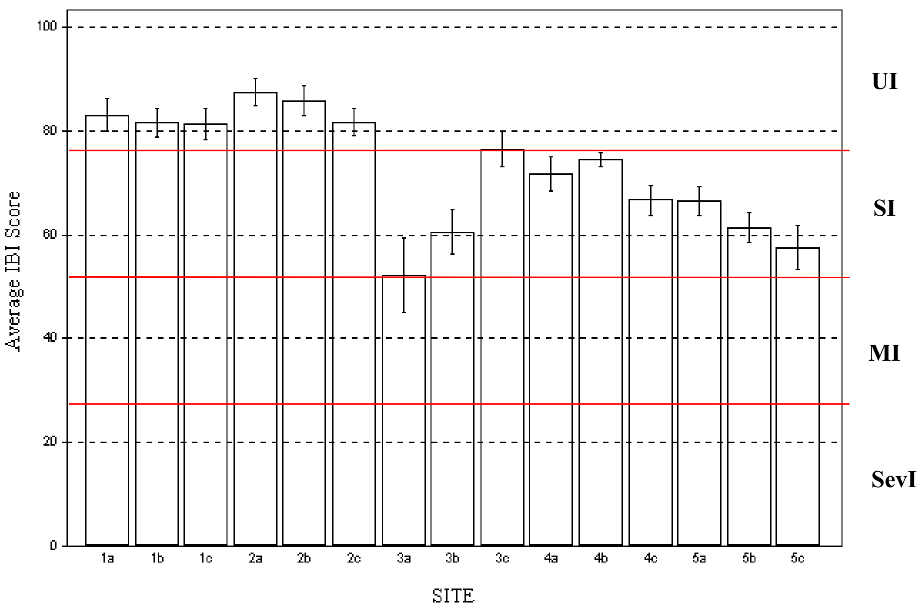

Figure 5. Average IBI scores for all sites using the PCA metric set. Solid horizontal lines indicate impairment category thresholds (UI=unimpaired, SI=slightly impaired, MI=moderately impaired, and SevI=severely impaired).

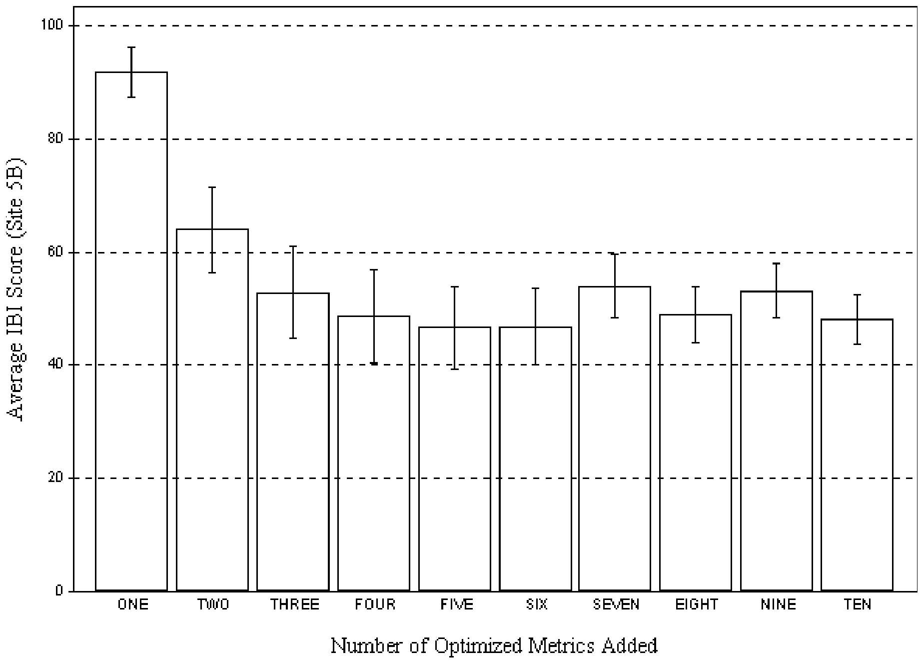

Figure 6. Average IBI score for site 5B adding one optimized metric in optimized order. Significant differences in scores result up through the addition of the thirdmetric.

metric at a time in optimized order. The IBI score using ten optimized metrics for site 5B was 48% (moderately impaired). With only one metric included in the index, site 5B IBI score was 92% (unimpaired). With two metrics included, the site score dropped to 64% (slightly impaired). The scores continue to significantly decrease ($p<0.017$; alpha level corrected using Bonferroni procedure) until after the addition of the third metric. An index incorporating the top three optimized metrics yielded an IBI score of 53% (slightly impaired). After the addition of the third metric, the IBI scores became stable (Fig. 6).

DISCUSSION

To account for the broad range of human impacts on aquatic systems, a multimetric approach has been found to be a successful assessment tool. Multimetric indices are now utilized by state agencies across the nation (Barbour and Yoder, 2000). More than 90% of state water agencies use a multimetric approach (Karr and Chu, 1999).

Core metrics are those that indicate various aspects of structure, composition, individual health or processes of the aquatic biota. When selecting a core set, representative metrics should be chosen from each of five primary categories: composition, richness, tolerance, feeding, and habit (Barbour et al., 1999). Accurate assessment of biological integrity requires a method that incorporates a biotic inspection of patterns and processes from individual to ecosystem levels (Barbour and Yoder, 2000).

Using an objective selection procedure, multimetric indices can be universally applied to a variety of waterbody and assemblage types. The multimetric approach has been applied to rivers, lakes, and wetlands and has been used to examine the health of fish, invertebrate and algal assemblages. Objectively chosen core metrics are also inherently adjusted for regional settings.

Traditionally, eight to ten metrics are used to form an integrated index (Karr and Chu, 1999). Based on our results, the IBI score stabilizes after the addition of three metrics, suggesting a need of only three metrics in an index. However, three metrics would not sufficiently represent all metric categories and may not accurately detect all disturbance types.

Accuracy, the ability of a measure to reflect actual conditions, can be weakened in two different ways. The measure could indicate that impairment has occurred when, in fact, it has not occurred (type I error). Conversely, the measure could indicate that impairment has not occurred when, in fact, it has (type II error) (Resh and Jackson, 1995). Our results indicate that objective selection of core metrics is necessary to prevent type I errors from biomonitoring investigations.

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A BIODIVERSITY ASSESSMENT OF COMPENSATORY MITIGATION WETLANDS IN EASTERN SOUTH DAKOTA

Sara Juni
Department of Wildlife and Fisheries Sciences
and
Charles R. Berry
South Dakota Cooperative Fish and
Wildlife Research Unit, USGS-BRD
South Dakota State University
Brookings, SD 57007

ABSTRACT

Wetland mitigation is the practice of avoiding, reducing, or compensating for human-caused impacts to wetlands. Compensatory mitigation in South Dakota usually consists of creating, restoring, or enhancing wetlands. Wetland restoration and creation can be successful in the Prairie Pothole Region, but few studies have assessed wetlands that were used for compensatory mitigation. Our objective was to compare biodiversity among restored, created, enhanced, and natural wetlands in eastern South Dakota. We used a rapid biodiversity assessment technique to determine bird, fish, amphibian and reptile, mammal, and aquatic invertebrate species richness and bird and aquatic invertebrate species diversity in 17 compensatory and natural wetlands. The wetlands were sampled twice each summer in 1999 and 2000. There were few statistically or biologically significant differences in biodiversity among wetland types or sample times. Aquatic invertebrate taxa richness was significantly different among some wetland types ($F=3.54$, $df=3$, $P=0.0268$); there were more invertebrate taxa in restored than in created or enhanced wetlands and more in natural wetlands than in created wetlands. Though not statistically significant, there appeared to be more bird species in restored than in other wetland types and more fish species in created than in natural wetlands. The similarities among wetland types for several animal groups indicate that compensation wetlands have biodiversity comparable to one another and to natural wetlands. These findings disagree with studies in other regions that showed limited success of compensatory mitigation wetlands. However, compared to studies of restored and created prairie wetlands not used for mitigation, it is clear that the wetlands we evaluated support the normal faunal assemblages in this region.

Keywords

Wetland mitigation, Prairie Pothole Region, creation, restoration, enhancement

INTRODUCTION

In the three decades that wetland mitigation has been practiced, wetland scientists, resource managers, and mitigation practitioners have studied how to restore and create wetland functions that replace those lost through permitted wetland impacts. Wetland restoration and creation may be less successful than assumed by wetland mitigation policy and there are few studies published in scholarly journals assessing mitigation projects (see reviews in Race and Christie 1982, Mitsch and Wilson 1996, Race and Fonseca 1996). Additionally, few mitigation projects are monitored for long-term success (Kentula et al. 1993, Mitch and Wilson 1996, Zedler and Callaway 1999).

Most studies that have assessed compensatory wetland mitigation reported partial success. For example, mitigation and natural wetlands were not functionally equivalent, but were similar in total floral species richness (Fennesy and Roehrs 1997). Eighty percent of mitigation wetlands in an Ohio study fulfilled permit requirements and had medium to high ecosystem success (Wilson and Mitsch 1996). In a study of 17 mitigation projects undertaken by 14 state departments of transportation, practical issues like planning and design elements prevented most efforts from meeting project goals or providing full functional replacement (Crabtree et al. 1992).

Wetland impacts in South Dakota are usually compensated by using restoration, creation, or enhancement (Jim Oehlerking, South Dakota Corps Regulatory Office, personal communication). There is a lack of research on mitigation that is specific to the Prairie Pothole Region (PPR). However, resource agencies have used wetland restoration, creation, and enhancement in this region to improve wildlife habitat, so there are studies assessing these techniques outside the realm of compensatory mitigation.

Wetland restoration in the PPR usually involves restoring the hydrology in a drained wetland by plugging a drainage ditch or breaking a subsurface drainage tile. Restoring the former hydrology is often sufficient to bring back plant communities because wetland ecosystems in this region evolved under extreme climate variation, including extended periods of drought. Several studies in the PPR have demonstrated that drained wetlands can be restored with relative ease and effectiveness to provide breeding bird habitat, although the vegetative structure typical of prairie wetlands is sometimes lacking (LaGrange and Dinsmore 1989, Sewell and Higgins 1991, Delphy and Dinsmore 1993, Galatowitsch and van der Valk 1996a,b).

Common wetland creation methods in the PPR include impounding a small stream or excavating a basin. Roush (1998) found that created wetlands and natural wetlands had similar biodiversity. Several studies have concluded that highway borrow pits provide some wildlife habitat (Kreil and Crawford 1986, Hop et al. 1989, Larson 1997). Wetland creation has been less common in this region than restoration because it is more time consuming, costly, complex, and often requires more maintenance.

Wetland enhancement means enhancing a particular function or set of functions in an existing wetland. Two common approaches to enhance a prairie wetland are meant to augment waterfowl production: manipulating water levels to make a wetland larger or change its vegetation structure, and adding nesting islands, nesting structures, or predator exclusion fences (see Ratti et al. 1982 for further information about these waterfowl management techniques). When used for mitigation, enhancement frequently involves increasing the size of a wetland by creating a new area connected to the existing wetland.

In FY 1994, Section 404 permits authorized impacts to at least 17,200 wetland acres in the United States (Corps 1995). The Corps of Engineers in South Dakota processed some 487 wetland impact permit applications from 1996 to 1999; all eligible permits were approved and 43.9% of approved permits involved compensation (Juni, unpublished data). Although state and regional reviews of Section 404 permit records show variability in the estimated wetland area change, South Dakota had a net gain over four years under that program. However, the estimated change in wetland area for a state or region could be misleading if based solely on a permit review, without information about permit compliance and functional success of compensation wetlands. The goal of this study was to address the latter need, with the specific objective of comparing biodiversity among three types of compensatory mitigation wetlands and natural wetlands in eastern South Dakota.

STUDY AREA

The 17 study sites were palustrine wetlands located in six eastern South Dakota counties and two physiographic regions (Table 1, Fig. 1). Twelve wetlands were part of compensatory mitigation projects (four each of restored, created, and enhanced wetlands). All were constructed within the last 10 years. Five natural wetlands were located on Waterfowl Production Areas managed by the US Fish and Wildlife Service. Study wetlands varied in area, water permanence, surrounding land use, and vegetation cover type.

The PPR includes parts of Manitoba, Saskatchewan, and Alberta in Canada, and northern Montana, North Dakota, eastern South Dakota, western Minnesota, and northern Iowa in the United States. Most palustrine wetlands in the PPR of South Dakota are dynamic systems, with both short- and long-term hydrologic fluctuations that influence water quality and vegetative communities (see Hubbard 1988, Kantrud et al. 1989, and van der Valk 1989 for more on characteristics of prairie wetlands).

STUDY METHODS

Biotic Assemblages

We used a rapid biodiversity assessment method to determine species richness and abundance of several taxa at each study wetland. This method has been used to assess mitigation projects for the South Dakota Department of Transportation and the City of Sioux Falls (Juni and Berry 2001). We sampled

Table 1. Descriptive physical characteristics for the study wetlands used in biodiversity assessment of eastern South Dakota compensatory mitigation wetlands, 1999-2000 (for Cover Type: 1= < 95% plant cover, 2=nearly even mix of plants and open water or mudflat, 3=narrow perimeter of plants around open water or mudflat, 4= >95% open water or mudflat, after Stewart and Kantrud 1971).

Wetland	Area (ha)	Water Permanence[2]	Surrounding Land Use[3]	Cover Type	Legal Description
Natural (N)					
N1	1.21	S	G	2	NE_ Sec 16 T111N R52W, Brookings County
N2	0.4	S	G	3	NW_ Sec 30 T102N R52W, Minnehaha County
N3	0.81	S	G	2	NW_ Sec 30 T102N R52W, Minnehaha County
N4	0.61	S	G	2	NW_ Sec 30 T102N R52W, Minnehaha County
N5	2.02	S	G	2	SW_ Sec 31 T104N R51W, Minnehaha County
Restored (R)					
R1	10.12	SP	G	3	NW_ Sec 31 T111N R52W, Brookings County
R2	0.61	T	G	1	NW_ Sec 4 T104N R55W, McCook County
R3	0.61	T	G	1	NW_ Sec 4 T104N R55W, McCook County
R4	4.86	SP	G/U	3	NW_ Sec19 T110N R51W, Brookings County
Created (C)					
C1	2.02	T, SP[1]	G	1	SE_ Sec 7 T103N R50W, Minnehaha County
C2	0.40	T	G	4	SE_ Sec 7 T103N R50W, Minnehaha County
C3	1.01	SP	C/G	3	NW_ Sec 20 T103N R60W, Davison County
C4	2.02	SP	C/G	3	NW_ Sec 20 T103N R60W, Davison County
Enhanced (E)					
E1	0.2	S	G/U	3, 4[1]	SE_ Sec 19 T110N R49W, Brookings County
E2	2.23	SP	Mowed	3	SW_ Sec 28 T117N R53W, Codington County
E3	1.82, 2.02[1]	SP	C/U	3	NW_ Sec 1 T99N R51W, Lincoln County
E4	0.40	S	G	3	NE_ Sec 9 T110N R52W, Brookings County

[1] These variables changed during the study, either intentionally through management activities, as side effects of compensation wetland manipulation, or because of natural development of new wetlands.
[2] S=Seasonal, SP=Semi-Permanent, T=Temporary
[3] G=Grassland, G/U=Grassland & Urban, C/G=Cropland & Grassland, C/U=Cropland & Urban

during four periods: spring 1999, fall 1999, spring 2000, and fall 2000. Two restored wetlands (R2 and R3) were not used during the first period. All traps described below were set overnight (16-20 hours).

Birds. We used two methods to census birds. First, we conducted a ten-minute point count at a location from which all or most of the wetland could be seen (Bibby et al. 1992). We then walked around the perimeter of the wetland to observe secretive or otherwise less visible birds. Bird counts were done in the late afternoon and again the following morning.

Fish. We collected fish where sufficient water was >50-cm deep. We set three modified fyke nets (1-m^3 PVC pipe frame with a 6.3-mm mesh nylon netting) with the lead running perpendicularly from shore. Trap openings were about 20-cm in diameter with the funnel in the center of the frame. We set the traps with the funnel opening submerged and some of the trap above water, so that captured semi-aquatic animals could survive.

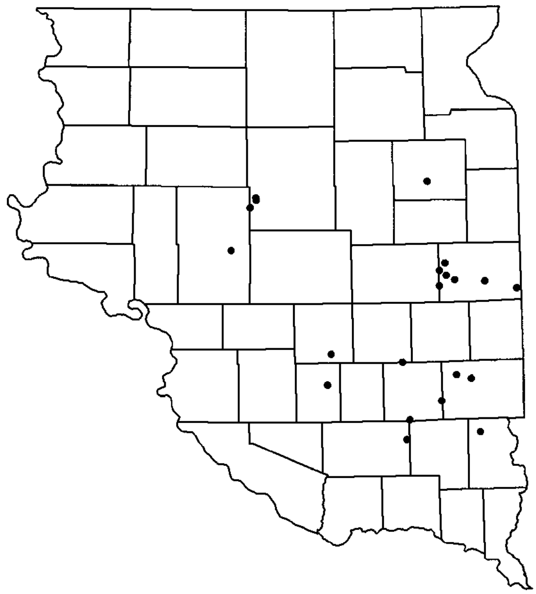

Figure 1. Map of eastern South Dakota with relative locations of study wetlands used in biodiversity assessment of compensatory mitigation, 1999-2000 (each dot represents one or more study wetlands).

Amphibians and Reptiles. We used three methods to sample amphibians and reptiles. First was a combination of pitfall traps and drift fences (Campbell and Christman 1982). We set two 8-m long drift fences in an "L" shape, with a pitfall trap (10-L plastic bucket, 25-cm deep) at each end and where the fences met. We also counted amphibians and reptiles observed during the perimeter walk or caught in the fish nets.

Mammals. We sampled small mammals by setting live-traps baited with rolled oats and peanut butter (Call 1986). We set 20 live traps along four transects, each with five traps spaced 5-m apart. Mammals captured in pitfall traps were also recorded. We recorded the presence of larger mammals from sign (e.g., tracks or scat) observed during the perimeter walk.

Aquatic Invertebrates. We collected aquatic invertebrate samples from each wetland using activity traps made from 2-L plastic bottles with a funnel opening as described by Swanson (1978). We set three horizontal traps in shallow water, with the funnel mouth at the water surface. We set three vertical traps in deeper water with the funnel mouth oriented down and the top of the trap level with the water surface. We sieved the organisms through a 149-µm screen, preserved them in 80% ethanol, then identified and counted them in the laboratory.

Statistical Analysis

We used two diversity measures to represent biodiversity in the wetlands. Species richness was defined as the number of species (or lowest practical taxon) in a group of animals. For birds and aquatic invertebrates we calculated Shannon's Diversity Index (H') values. We used the following equation to determine diversity index values:

$$H' = -\sum (n_i / n)\ln(n_i / n)$$

Where: n_i=number of individuals in the taxon
n=number of individuals in the sample

We used a two-way analysis of variance (ANOVA) to compare bird and aquatic invertebrate species richness and diversity among the four wetland types and the four sample periods. When two or more main effects in the model appeared significantly different, we utilized Fisher's LSD to determine which wetlands or sample periods differed. The range of values for fish, amphibian and reptile, and mammal richness was too small for ANOVA to be an appropriate statistical method (T. Wittig, SDSU Department of Mathematics and Statistics, personal communication), so we used a chi-square test of independence to determine associations due to wetland type or sample period. Some data were problematic in meeting the homogeneity of variance assumption for ANOVA, and we took that into consideration during analysis. We assumed that wetlands and sample periods were independent. We used a significance level of 0.1.

RESULTS

Birds

We observed 76 bird species during the study. Barn swallow *(Hirundo rustica),* common grackle *(Quiscalus quiscula),* common yellowthroat *(Geothlypis trichas),* red-winged blackbird *(Agelaius phoeniceus),* and song sparrow *(Melospiza melodia)* were the most common (i.e., these species were observed at most wetlands). The most abundant (i.e., the greatest number of individuals) bird species were barn swallow, blue-winged teal *(Anas discors),* mallard *(Anas platyrhynchos),* and red-winged blackbird.

There were no statistically significant differences for bird richness or diversity. The ANOVA model using wetland type and sample period as main effects did not explain the variance observed in bird richness values ($F=0.90$, $df=15$, $P=0.5715$). However, certain trends were evident. Mean bird species richness was highest in restored wetlands, followed by created, enhanced, and natural wetlands (Fig. 2A). Mean bird species richness was fairly constant over the four sample periods (Fig. 2B).

The ANOVA model for bird diversity was not significant ($F=0.76$, $df=15$, $P=0.7150$). Mean bird species diversity was similar among wetland types, with slightly higher values at created and restored wetlands than at enhanced or natural wetlands (Fig. 2C). Mean bird species diversity was relatively constant over the four sample periods (Fig. 2D).

Fish

We sampled nine fish species in the study wetlands; the most commonly observed species were black bullhead *(Ameiurus melas)* and fathead minnow *(Pimephales promelas).* Fish richness was not associated with sample period or wetland type ($X^2=3.973$, $df=9$, $P=0.913$). However, created wetlands appeared to have more species of fish than restored wetlands, which had more than enhanced or natural wetlands (Fig. 3A). The mean number of fish species was consistent among sample periods, except fewer fish species were observed during spring 1999 (Fig. 3B).

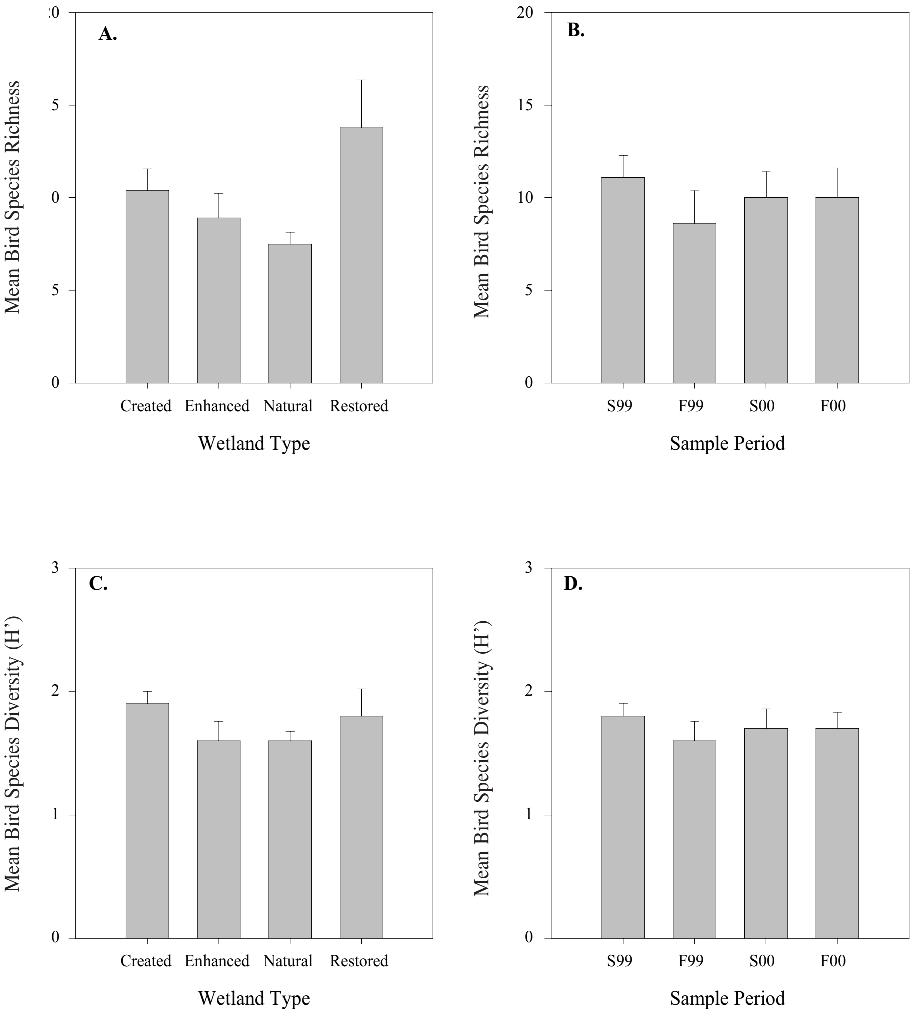

Figure 2. Mean bird species richness at (A) three kinds of compensatory mitigation wetlands and natural wetlands in eastern South Dakota and (B) during four sample periods (S=Spring, F=Fall). Mean bird species diversity at (C) three kinds of compensatory mitigation wetlands and natural wetlands in eastern South Dakota and (D) during four sample periods (S=Spring, F=Fall). Error bars are one SE.

Amphibians and Reptiles

Of 11 amphibian and reptile species observed during the study, American toad *(Bufo americanus),* garter snake *(Thamnophis sirtalis),* northern leopard frog *(Rana pipiens),* painted turtle *(Chrysemys picta),* and tadpoles (species unknown) were common. Neither sample period nor wetland type was associated with amphibian and reptile species richness (X^2=5.305, df=9, P=0.807). Although not significant, there appeared to be more amphibian and reptile species at enhanced and restored wetlands than created or natural wetlands

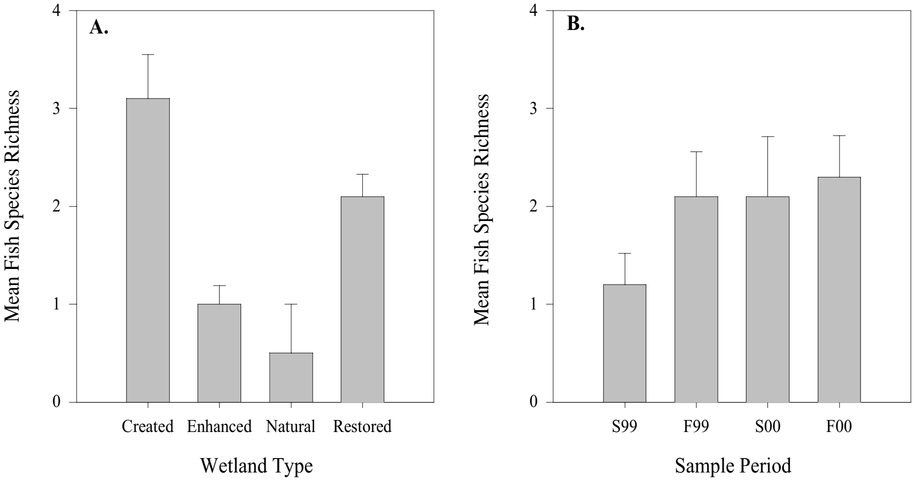

Figure 3. Mean fish species richness at (A) three kinds of compensatory mitigation wetlands and natural wetlands in eastern South Dakota and (B) during four sample periods (S=Spring, F=Fall). Error bars are one SE.

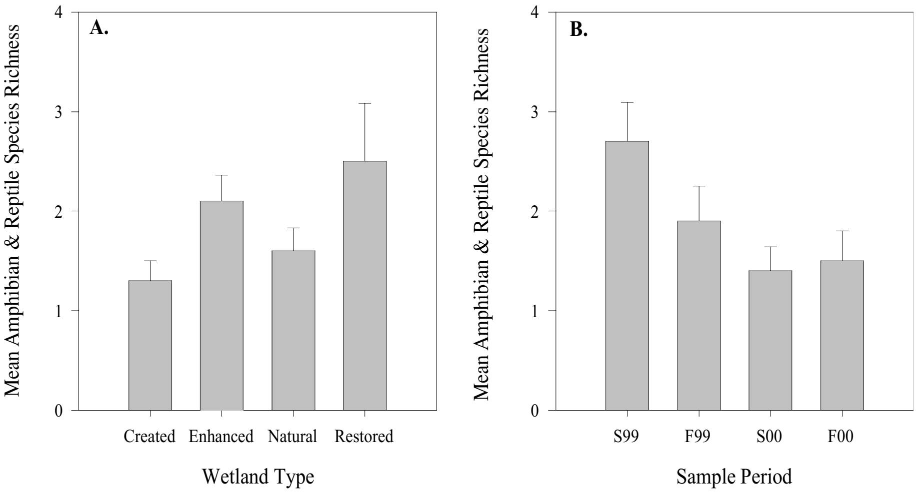

Figure 4. Mean amphibian and reptile species richness (A) at three kinds of compensatory mitigation wetlands and natural wetlands in eastern South Dakota and (B) during four sample periods (S=Spring, F=Fall). Error bars are one SE.

(Fig. 4A). There also seemed to be a greater mean amphibian and reptile species richness during the spring 1999 sample period than other sample periods (Fig. 4B).

Mammals

Sixteen mammal species were observed during the study. The most common mammals were raccoon *(Procyon lotor)* and whitetail deer *(Odocoileus virginianus).* Deer mouse *(Peromyscus maniculatus),* masked shrew *(Sorex cinereus),* and meadow vole *(Microtus pennsylvanicus)* were common small mammal species. Mammal species richness was not associated with sample period or wetland type (X^2=4.123, df=9, *P*=0.903). Restored and created wetlands appeared to have the highest mean mammal species richness, followed by enhanced and natural wetlands (Fig. 5A). The mean number of mammal species was similar among the four sample periods (Fig. 5B).

Aquatic Invertebrates

We found 52 aquatic invertebrate taxa during the study. Several groups of aquatic invertebrates were common, including Corixidae, Dytiscidae, Chironomidae, Hydracarina, and snails (Limnophila, Lymnaeidae and Physidae). Talitridae, Chironomidae, and Corixidae were invertebrate families with the most abundant number of individuals collected.

The two-way ANOVA model using wetland type and sample period as main effects was significant for invertebrate taxa richness (F=1.83, df=14, *P*=0.0817). Invertebrate taxa richness varied among wetland types (F=3.54,

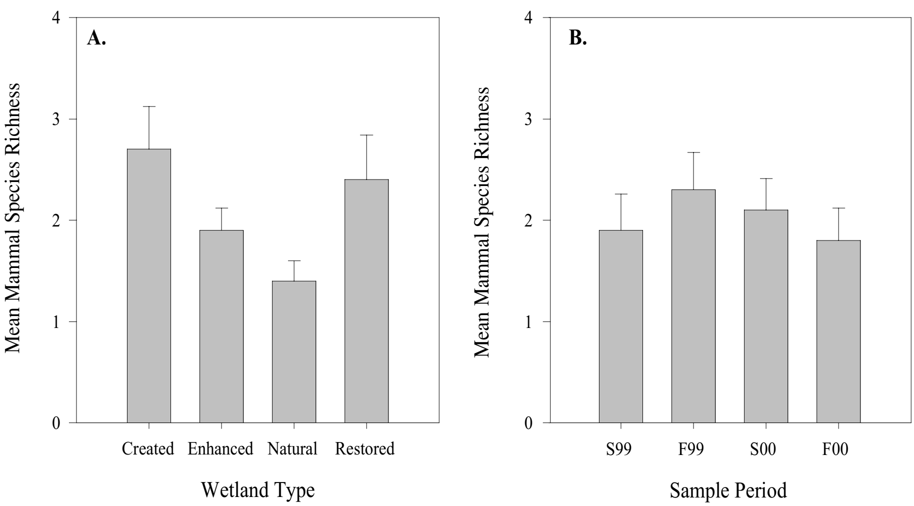

Figure 5. Mean mammal species richness (A) at three kinds of compensatory mitigation wetlands and natural wetlands in eastern South Dakota and (B) during four sample periods (S=Spring, F=Fall). Error bars are one SE.

df=3, *P*=0.0268). Restored wetlands had more aquatic invertebrate taxa than created or enhanced wetlands. There were also more invertebrate taxa at natural than created wetlands (Fig. 6A). Sample period did not explain variation in aquatic invertebrate richness (F=2.00, df=3, *P*=0.1868), though there appeared to be fewer invertebrate taxa during the Spring 2000 sample period (Fig. 6B).

The ANOVA model did not explain aquatic invertebrate diversity variability (F=0.34, df=14, *P*=0.9822). Mean invertebrate diversity seemed consistent for both wetland type and sample period (Figs. 6C and 6D, respectively).

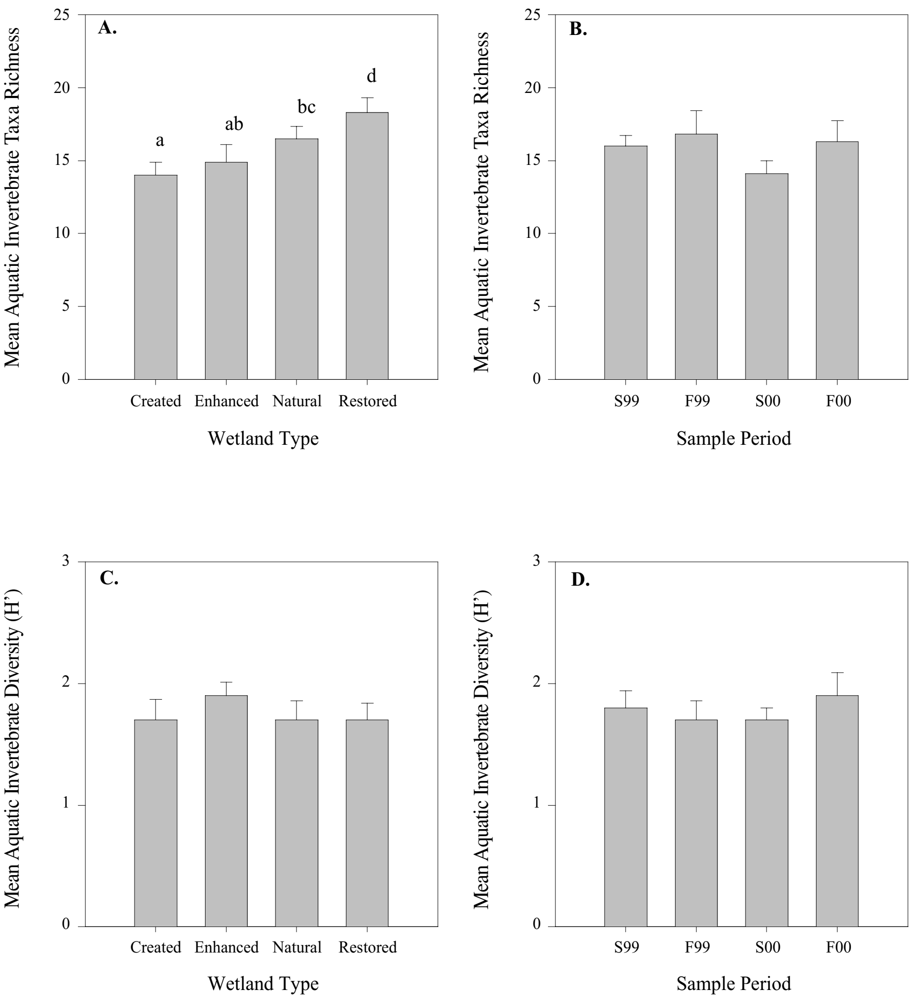

Figure 6. Mean aquatic invertebrate taxa richness (A) at three kinds of compensatory mitigation wetlands and natural wetlands in eastern South Dakota and (B) during four sample periods (S=Spring, F=Fall). Mean Aquatic invertebrate taxa diversity values (C) at three kinds of compensatory mitigation wetlands and natural wetlands in eastern South Dakota and (D) during four sample periods (S=Spring, F=Fall). Error bars are one SE. Bars with different letters are significantly different.

DISCUSSION

Birds

Although not statistically significant, it appeared that more bird species used restored wetlands than the other wetland types and that natural wetlands had the lowest bird species richness. Bird richness is commonly used to compare restored, created, and natural wetlands in the PPR but the results from these studies vary. Studies of restored wetlands have found that breeding waterfowl and other bird species rapidly colonized restored wetlands in South Dakota, Minnesota and Iowa (Sewell and Higgins 1991 and VanRees-Siewert and Dinsmore 1996). A study in South Dakota showed similar bird richness between restored and natural wetlands (Larson 1997), whereas another found that bird species richness was higher in natural wetlands than restored (Delphy and Dinsmore 1993). Roush (1998) found fewer bird species in created wetlands than natural wetlands during some sample periods.

Initial species richness may be higher in a newly available habitat like a restored or created wetland than in an existing system because there is minimal competition and more available space in the newer system (Bradshaw 1983, Noss 1983, Kentula et al. 1993). This concept may explain why we observed more bird species in mitigation than natural wetlands, since the mitigation wetlands in this study were constructed within the last decade.

The variation in physical characteristics of the study wetlands may have influenced bird richness. For example, wetland area may explain the high bird species richness observed in restored wetlands. The two restored wetlands (R1 and R4) that were used for the entire study were larger than other wetlands. The survey methods used in this study did not account for wetland size, but wetland area is known to influence bird species richness and composition (Brown and Dinsmore 1986, Naugle et al. 1999).

Fish, Amphibians and Reptiles, and Mammals

There was little variation in mean species richness values for fish, amphibians and reptiles, or mammals. Larson (1997) also found no differences in amphibian and turtle, fish, or mammal richness among wetland types. These results suggest that mitigation wetlands in the PPR can support these groups of animals as well as natural wetlands.

The higher fish species richness we observed in created wetlands than in natural wetlands may have been a biologically significant difference. Historically there were few fish species in natural prairie wetlands because they are typically shallow, have low dissolved oxygen contents, and infrequently or never have surface water connections to other water bodies (Kantrud et al. 1989). The created wetlands in this study depended on a surface water connection to a nearby stream at some point each year as the main water source, which also provided a means for fish dispersal. Because fish affect prairie wetland ecology, different fish populations in created wetlands may be one distinction between otherwise similar biotic communities. Fathead minnows, one of the most commonly observed fish species in this study, may compete with waterfowl for invertebrate food sources (Hanson and Riggs 1995).

Aquatic Invertebrates

We collected significantly more aquatic invertebrate taxa in restored than in other wetland types. Sewell and Higgins (1991) found that invertebrate colonization was rapid in restored wetlands. We also found that natural wetlands had higher invertebrate richness than did created wetlands. This is corroborated by a study in North Dakota in which invertebrate diversity and density were higher in natural wetlands than borrow pit wetlands (Kreil and Crawford 1986).

Differences in aquatic invertebrate richness may reflect varying methods of invertebrate colonization among mitigation wetland types. As an adaptation to dynamic water cycles in the PPR, several invertebrate taxa in this region can tolerate extended periods of drought (Kantrud et al. 1989, Gleason 2001). Like the persistent seed banks found in drained prairie wetlands, aquatic invertebrate egg banks can persist over a long period. In contrast, invertebrate colonization in created wetlands requires sources from outside the basin. The enhanced wetlands in this study were either connected to or near an existing wetland and aquatic invertebrate richness was similar to created and natural wetlands. The success of the invertebrate egg bank in restored wetlands may be restricted by a high sediment load, so surrounding land use factors could influence invertebrate colonization in restored wetlands (Gleason 2001).

Judging Mitigation Wetland Success

Wetlands in the PPR are temporally dynamic in terms of water permanence, hydrology, water chemistry, and floral species composition and structure. As Zedler and Callaway (1999) explained, mitigation policy assumes that "a restored or created ecosystem will, in relatively short order, replace losses in structure and function." They point out, however, that short-term observations are not sufficient to determine functional success for a system that is subject to high annual variability. In addition to factors like the initial site conditions and surrounding land use practices, a disturbance event could alter the rate or direction of ecosystem development.

Although many authors are skeptical of our ability to replace wetland ecosystems, it is inappropriate to "lump all [mitigation] projects into one basket" (Munro 1991). Despite the long-term failure of created wetlands in California to provide habitat for an endangered marsh bird, Zedler and Callaway (1999) acknowledged that some mitigation project goals should be easier to accomplish. Prairie wetlands are one wetland ecosystem that can be restored with relative ease and effectiveness. They evolved under a regular disturbance regime, do not undergo traditional vegetative or soil succession, and have adaptations like persistent seed and egg banks that can survive through natural drought periods or human-induced drainage.

Although the diverse faunal communities in wetlands have been a key impetus for wetland protection policies, Kentula et al. (1993) stated that "relatively few studies have monitored [these communities], so sampling protocols and comparative data are relatively scarce as compared to the literature and data on plants." The rapid bioassessment method used in this study is a practical monitoring technique; compared to methods used in more comprehensive research, it has high variability and low statistical power. For instance, depressional prairie wetlands contain too few species of fish, amphibians and reptiles, or mammals for these groups to be valuable for statistical analysis. Most studies reported in scientific journals focus instead on bird, aquatic invertebrate, and plant surveys. However, we wanted to use a holistic assessment method that would provide a more robust understanding of mitigated prairie wetlands than using only a few taxa.

Future Research Directions

Despite the apparent effectiveness of restored, enhanced and created wetlands to support biotic communities, there are several areas of study that would improve our ability to replace natural wetland systems. First, a study of mitigation sites through an entire wet-dry cycle (five to ten years) would help us to understand their persistence and whether they perform like natural wetlands over a longer time scale. Zedler and Callaway (1999) suggested that mitigation wetland development does not always follow a straight trajectory, but how does this theory apply to relatively easily restored prairie wetlands? Simple factors like the need for long-term maintenance (e.g., water pump operation, spillway cleanouts) may also influence mitigation wetland success over time.

Landscape scale studies are needed to determine how compensatory mitigation and other wetland protection efforts are influencing landscape patterns and processes in eastern South Dakota. For example, there is concern about a shift from historic wetland complexes to larger, isolated wetlands (Gibbs 1993, Galatowitsch et al. 1998). Similarly, it would be interesting to compare success of mitigation techniques in different landscape settings – how do the different mitigation wetland types perform within urban, agricultural, or natural prairie surroundings? Amphibian species richness was lower in Minnesota wetlands when the wetlands were more isolated or located in areas with high road densities (Lehtinen et al. 1999). An Oregon study showed degraded floristic quality in natural and mitigation wetlands in urbanizing landscapes. Wetlands surrounded by agricultural or urban land uses had more introduced species than wetlands surrounded by undeveloped land (Magee et al. 2000).

CONCLUSIONS

We determined few statistically or biologically significant differences in biodiversity among wetland types or sample periods in eastern South Dakota wetlands. There were significantly more aquatic invertebrate taxa in restored than in created or enhanced wetlands and in natural wetlands than in created wetlands. This may indicate differences among wetland types in invertebrate colonization rates. Though not statistically significant, there appeared to be more bird species in restored than other wetland types and more fish species in created than natural wetlands. The similarities among wetland types for several animal groups indicate that each type of compensatory wetland used in this study will provide biodiversity comparable to one another and natural wetlands. These findings disagree with several studies that found limited functional success of mitigation wetlands, but agree with studies that demonstrated the ecological success of restored and created prairie wetlands not used for mitigation.

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USE OF THE USDA FOREST SERVICE GEOGRAPHIC INFORMATION SYSTEM FOR DETERMINING COVER TYPE USE BY WHITE-TAILED DEER

Christopher S. DePerno
Minnesota Department of Natural Resources
Farmland Wildlife Populations and Research Group
Madelia, MN 56062

Jonathan A. Jenks
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

Steven L. Griffin
South Dakota Department of Game, Fish and Parks
Rapid City, SD 57702

Robert W. Klaver
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007
USGS EROS Data Center
Sioux Falls, SD 57198

ABSTRACT

Cover type use by white-tailed deer *(Odocoileus virginianus dacotensis)* in the central Black Hills of South Dakota was compared to the United States Department of Agriculture (USDA) Forest Service digital data using a Geographic Information System (GIS). Cover types were determined from observations of radiocollared deer and random locations and from corresponding point locations in the Forest Service digital data. Cover type information was collected at 3,145 white-tailed deer locations and 1,044 random locations. On winter range, cover types determined from observations of radiocollared deer included pine *(Pinus ponderosa),* pine-deciduous, aspen *(Populus tremuloides),* aspen-coniferous, burned pine, and meadows; cover types determined from Forest Service data included pine, aspen, grasslands, and private land. On summer range, cover types determined from observations of radiocollared deer included pine, pine-deciduous, aspen, aspen-coniferous, white spruce *(Picea glauca),* white spruce-deciduous, and meadows; cover types determined from Forest Service digital map data included pine, aspen, grasslands, and private land. Cover types used by white-tailed deer compared to the Forest Service data resulted in 42% agreement on summer range and 62% agreement on winter range. On winter and summer range, Forest Service data tended to overestimate ponderosa pine and aspen habitats used by white-tailed deer, while

failing to account for mixed (secondary) cover types. To improve the accuracy of habitat management decisions relative to white-tailed deer, the Forest Service GIS would be strengthened if mixed (secondary) cover type classifications were included in the database.

Keywords

Black Hills, cover type, GIS, habitat, Odocoileus virginianus, USDA Forest Service, white-tailed deer

INTRODUCTION

Geographic Information Systems (GIS) are a powerful set of tools for collecting, storing, retrieving, transforming, and displaying spatial data for a particular set of purposes (Burrough 1986). A GIS has many benefits and is particularly helpful in the analysis of spatial relationships within habitat selection analyses (Tomlin et al. 1988). A GIS automates the process of integrating maps and databases of diverse geographic features (Johnson 1995) and is an excellent tool for producing maps of different scales and colors (McLaren and Braun 1993).

The United States Department of Agriculture (USDA) Forest Service uses an overstory based GIS in forest management decisions. Because the white-tailed deer *(Odocoileus virginianus dacotensis)* herd has declined (DePerno 1998, DePerno et al. 2000) in the central Black Hills and because habitat selection is known (DePerno et al. In press) it is important to understand how cover type information contained in the Forest Service GIS compares to cover types used by white-tailed deer. This information will aid our understanding of the relationship between deer habitat use and the GIS presently used to make forest management decisions in the central Black Hills of South Dakota and Wyoming.

Effective management of wildlife populations largely depends on understanding and predicting habitat needs (Clark et al. 1993). In the northern Black Hills, it was determined that comparisons of habitat proportions within white-tailed deer home ranges and core areas did not differ from randomly derived home ranges (Nelson 1995, Nelson and Jenks 1995). Furthermore, these authors indicated the USDA Forest Service stand maps and site data lacked the detail necessary for defining habitat availability in the northern Black Hills. Data provided by the Forest Service consisted of a single cover type layer, whereas variables such as understory and cover-type mixes were absent (Nelson 1995, Nelson and Jenks 1995). Therefore, our objective was to compare cover types used by white-tailed deer (DePerno 1998, DePerno et al. In press) with the GIS presently used by the Forest Service to make critical management decisions within the central Black Hills.

STUDY AREA

The Black Hills is an isolated mountainous area in western South Dakota and northeast Wyoming that extends approximately 190 km north to south and 95 km east to west (Petersen 1984). Elevation of the Black Hills ranges from

973 - 2,202 m above mean sea level (Orr 1959, Turner 1974). Annual mean temperatures are typical of a continental climate and range from 5–9°C with extremes of -40–44°C (Thilenius 1972). Mean annual precipitation ranges from 45–66 cm (Orr 1959) and yearly snowfall may exceed 254 cm at higher elevations (Thilenius 1972).

The central Black Hills study area (43° 52' N to 44° 15' N – 104° 07' W to 103° 22' W) includes Pennington and Lawrence counties of South Dakota and Crook and Weston counties of Wyoming. The study area is composed of separate winter and summer ranges used by migratory white-tailed deer (DePerno 1998, DePerno et al. 2000, Griffin 1994, Griffin et al. 1995, 1999). Public land within the study area is managed by the United States Forest Service, within the Pactola, Harney, and Elk Mountain Ranger Districts, primarily for timber production and livestock grazing (1 June - 31 October).

Cover type on winter range consists primarily of monotypic stands of ponderosa pine *(Pinus ponderosa)* interspersed with stands of burned pine, quaking aspen *(Populus tremuloides),* and paper birch *(Betula papyrifera)* (McIntosh 1949, Orr 1959, Thilenius 1972, Richardson and Petersen 1974, Hoffman and Alexander 1987). Cover type on summer range consists primarily of ponderosa pine and white spruce *(Picea glauca)* interspersed with small stands of quaking aspen (McIntosh 1949, Orr 1959, Thilenius 1972, Richardson and Petersen 1974, Hoffman and Alexander 1987).

METHODS

White-tailed deer were captured during February and March 1993 - 1996 using modified, single-gate Clover traps (Clover 1956) baited with fresh alfalfa *(Medicago sativa)* hay. Deer were captured on four trap sites located northeast, northwest, and west of Hill City, South Dakota, on the McVey Burn deer winter range (Griffin et al. 1995, 1999, DePerno 1998). Adult and yearling female (n = 73) and male (n = 12) white-tailed deer were fitted with radiocollars (Telonics Inc., Mesa, Arizona; Lotek Engineering, Inc. Ontario, Canada), ear-tagged, aged by lower incisor wear, and released. Captured fawn white-tailed deer were ear-tagged and released (Griffin et al. 1995, DePerno 1998).

From July 1993 - July 1996, individual radiocollared deer were visually located from the ground 1 - 3 times per week. Deer were radiotracked at different time periods to maximize observations of diurnal activities (Hayes and Krausman 1993, Kernohan et al. 1996) and to obtain adequate sample sizes without violating the assumption of independent observations (White and Garrott 1990). Kernohan et al. (1996) and Hayes and Krausman (1993) demonstrated no differences between diurnal and 24-hour habitat use for white-tailed deer and mule deer, respectively. Within the central Black Hills, steep hills, deep draws, and long migration distances limited data collection activities to diurnal visual observations of deer and prevented the use of other techniques (e.g., triangulation) for obtaining radiolocations. Furthermore, because of the terrain and inaccessibility of many areas, attempts at spotlighting radiocollared deer to obtain nocturnal data were inefficient and represented a bias toward deer that were more accessible. Deer locations were plotted on 7.5-minute US-

GS topographical maps (scale, 1:24,000) and assigned Universal Transverse Mercator (UTM) coordinates (Edwards 1969, Grubb and Eakle 1988).

Because separate winter and summer ranges are used by migratory white-tailed deer (DePerno 1998, DePerno et al. 2000, Griffin 1994, Griffin et al. 1995, 1999), for analyses we stratified data according to seasonal elevation shifts made by each individual each year (Apps et al. 2001) and assigned each deer location and the corresponding habitat information to either winter or summer range. Habitat information was collected from 400-m^2, circular plots centered on each deer observation site (providing the location of the radiocollared deer was visually determined without disturbing the animal) and, to obtain a measure of relative habitat availability, at computer generated random locations sampled throughout the study area (Marcum and Loftsgaarden 1980, Kennedy 1992). Information recorded at each deer and random location included: UTM location (north and east), and dominant overstory tree species. If $\geq$2 tree species provided canopy cover, the species that provided the largest amount of cover was recorded as the primary forest species; remaining species were recorded as secondary species.

The GIS software PC ARC/INFO (Environmental Systems Research Institute, Inc., Redlands, CA) was used to compare cover types used by radiocollared white-tailed deer and random locations with cover types corresponding to the 1995 Black Hills GIS digital map data obtained from the USDA Forest Service. Basic map information for site polygons included area and cover type. Cover type information within the Forest Service GIS was primarily determined by aerial photograph delineation. The majority of land within the Forest Service data was owned by the USDA Forest Service with lesser amounts in private holdings.

Deer winter and summer ranges were derived by extracting regions above and below the 1829 m (6000 ft) contour from the National Elevation Dataset. The elevation coverage was then used to clip corresponding winter and summer range areas from the Forest Service digital data. Deer and random point locations were generated into separate coverages, overlaid, and intersected with the clipped winter and summer range coverages; thereby containing cover type information specific to each point location.

Cover types for deer and random point locations were pooled for all years of the study because of high fidelity to seasonal sites (Progulske and Baskett 1958, Ozoga et al. 1982, Tierson et al. 1985, Kennedy 1992, Nelson 1995). Cover types associated with deer and random locations were compared to the corresponding cover types described by the Forest Service data. A Chi-square test of homogeneity was used to determine differences between expected and observed distributions of habitats (Jelinski 1991, Kennedy 1992). Habitat use (i.e., deer) and availability (i.e., randoms) were compared to habitats in the Forest Service data (Neu et al. 1974, Byers et al. 1984, Kennedy 1992). Significance levels for 90% confidence intervals were determined using the Bonferroni method (Neu et al. 1974, Byers et al. 1984). All analyses were performed using SYSTAT (Wilkinson 1990).

RESULTS

In the central Black Hills, typical autumn migration for white-tailed deer is in a southeast direction from high elevation summer ranges to low elevation winter ranges and generally occurs between August and February (DePerno 1998, Griffin et al. 1999). Typical spring migration is in a northwest direction from low elevation winter ranges to high elevation summer ranges and generally occurs between 17 and 23 May (DePerno 1998, Griffin et al. 1999).

Between July 1993 and July 1996, cover type information was collected at 3,145 deer locations and, to obtain a measure of relative habitat availability, at 1,044 computer generated random locations sampled throughout the study area. Excluded from analyses were data on one radiocollared male that remained on winter range throughout the year and one radiocollared female that demonstrated an abnormal migration pattern (DePerno et al. 1997).

On winter range, white-tailed deer used areas that were predominantly pine or pine-deciduous (Table 1). Meadows, burned pine stands, aspen, and aspen-coniferous habitats accounted for ~17% of 1,538 locations. When deer locations were overlaid, the corresponding data provided by the Forest Service indicated that white-tailed deer primarily used areas dominated by pine, aspen, and private land (Table 1). On winter range, cover types used by white-tailed deer compared to the Forest Service data resulted in 62% agreement. On summer range, white-tailed deer used areas that were predominantly pine or pine-deciduous (Table 2). Spruce, spruce-deciduous, aspen, and aspen-coniferous habitats were used at moderate levels. When deer locations were overlaid, the corresponding data provided by the Forest Service indicated that white-tailed deer primarily used areas dominated by pine, aspen, and spruce (Table 2). On summer range, cover types used by white-tailed deer compared to the Forest Service data resulted in 42% agreement.

Because the Forest Service database did not account for secondary cover types (Tables 1, 2), we combined mixed stands with primary cover types prior to conducting analyses. During winter, cover characteristics (Tables 3, 4) varied for deer (χ^2 = 189.42, df = 4, P < 0.001) and random locations (χ^2 = 91.00,

Table 1. Cross-tab comparison of white-tailed deer and USDA Forest Service cover types for winter range in the central Black Hills, South Dakota and Wyoming, 1993-1996.

	USDA FOREST SERVICE COVER TYPE				
White-tailed Deer Cover Type	**Pine**	**Aspen**	**Grassland**	**Private**	**Total**
Pine	939	40	14	67	1060
Pine-Deciduous	189	13	2	8	212
Aspen	18	10	1	2	31
Aspen-Coniferous	21	8	0	2	31
Spruce	0	0	1	2	3
Burned Pine	109	0	1	0	110
Meadows	41	6	6	38	91
Total	*1317*	*77*	*25*	*119*	*1538*

Table 2. Cross-tab comparison of white-tailed deer and USDA Forest Service cover types for summer range in the central Black Hills, South Dakota and Wyoming, 1993-1996.

	USDA FOREST SERVICE COVER TYPE						
White-tailed Deer Cover Type	Pine	Aspen	Spruce	Grass-land	Poa Grassland	Private	Total
Pine	586	20	16	2	2	86	712
Pine-Deciduous	213	28	2	6	1	83	333
Aspen	26	31	0	0	0	32	89
Aspen-Coniferous	67	33	2	3	1	36	142
Spruce	118	7	57	4	1	29	216
Spruce-Deciduous	43	10	19	1	1	16	90
Burned Pine	1	0	0	0	0	0	1
Meadows	11	1	0	1	1	10	24
Total	*1065*	*130*	*96*	*17*	*7*	*292*	*1607*

Table 3. Comparison of cover characteristics for white-tailed deer locations on winter range in the central Black Hills, South Dakota and Wyoming, 1993-1996, as determined by deer use data and USDA Forest Service Geographical Information System (GIS) stand data.

Cover Type	Deer Location Data ($\underline{n}$ = 1335)	Forest Service Data (90% CI) ($\underline{n}$ = 1335)
Pine/Pine-Deciduous	89.66 +	85.32 (82.89-87.47)
Aspen/Aspen-Coniferous	4.05	5.17 (3.84-6.74)
Spruce/Spruce-Deciduous	0.30	0.00 (0.00-0.33)
Meadows	5.99 +	1.65 (0.93-2.63)
Private Land	0.00 -	7.87 (6.22-9.73)

Table 4. Comparison of cover characteristics for random locations on winter range in the central Black Hills, South Dakota and Wyoming, 1993-1996, as determined by random habitat data and USDA Forest Service Geographical Information System (GIS) stand data.

Cover Type	Randoms ($\underline{n}$ = 483)	Forest Service Data (90% CI) ($\underline{n}$ = 483)
Pine/Pine-Deciduous	81.78	80.12 (75.31-84.21)
Aspen/Aspen-Coniferous	4.76	3.93 (2.07-6.53)
Spruce/Spruce-Deciduous	1.24	0.41 (0.00-1.72)
Meadows	12.22 +	4.76 (2.69-7.54)
Private Land	0.00 -	10.56 (7.40-14.30)
Not Identified[a]	0.00	0.21 (0.00-1.36)

[a] dominant cover type not identified but determined to be water (WAT) by the USDA Forest Service GIS database.

df = 5, $P < 0.001$). Similarly, during summer, cover characteristics (Tables 5, 6) varied for deer ($\chi^2 = 270.16$, df = 4, $P < 0.001$) and random locations ($\chi^2 = 93.99$, df = 5, $P < 0.001$).

On winter range, white-tailed deer were located in pine and meadow habitats in proportions greater than the corresponding Forest Service data (Table 3). Meadows were categorized for random locations at greater levels than the corresponding Forest Service data (Table 4). On summer range, white-tailed deer were located in aspen and spruce areas in proportions greater than those occurring in Forest Service data, while using pine habitats less than those occurring in Forest Service data (Table 5). Spruce and meadows were categorized for random locations at greater levels than the corresponding Forest Service data (Table 6).

Table 5. Comparison of cover characteristics for white-tailed deer locations on summer range in the central Black Hills, South Dakota and Wyoming, 1993-1996, as determined by deer use data and USDA Forest Service Geographical Information System (GIS) stand data.

Cover Type	Deer Location Data (n = 1231)	Forest Service Data (90% CI) (n = 1231)
Pine/Pine-Deciduous	64.58 -	73.84 (70.78-76.68)
Aspen/Aspen-Coniferous	13.08 +	8.53 (6.75-10.54)
Spruce/Spruce-Deciduous	20.80 +	6.74 (5.16-8.57)
Meadows	1.54	1.63 (0.89-2.65)
Private Land	0.00 -	9.26 (7.41-11.34)

Table 6. Comparison of cover characteristics for random locations on summer range in the central Black Hills, South Dakota and Wyoming, 1993-1996, as determined by random habitat data and USDA Forest Service Geographical Information System (GIS) stand data.

Cover Type	Randoms (n = 561)	Forest Service Data (90% CI) (n = 561)
Pine/Pine-Deciduous	71.84	75.58 (70.87-79.73)
Aspen/Aspen-Coniferous	5.88	3.74 (2.04-6.07)
Spruce/Spruce-Deciduous	9.80 +	5.88 (3.70-8.64)
Meadows	12.48 +	5.70 (3.56-8.43)
Private Land	0.00 -	8.56 (5.91-11.74)
Not Identified[a]	0.00	0.54 (0.04-1.77)

[a] dominant cover type not identified but determined to be water (WAT) and non-vegetated sites (NFL) by the USDA Forest Service GIS database.

DISCUSSION

Quality of GIS analyses depends as much on the accuracy of the digital maps as the habitat factors (Donovan et al. 1987, Lyon 1983, Stoms et al. 1992, Nelson 1995 Nelson and Jenks 1995). Different levels of map and data detail may be necessary to obtain satisfactory modeling results and the effectiveness of a GIS as a management tool depends largely on the quality of data used (Stoms et al. 1992, Nelson and Jenks 1995). However, erroneous models could result from inaccurate animal locations and misclassification of habitat types (Donovan et al. 1987, Lyon 1983, Stoms et al. 1992).

On winter and summer range, Forest Service data tended to overestimate ponderosa pine and aspen habitats used by white-tailed deer, while failing to account for mixed (secondary) cover types (Tables 1, 2). For instance, in the Forest Service database pine-deciduous and aspen-coniferous stands are not distinguishable from pine or aspen stands, respectively. Additionally, the Forest Service data failed to characterize burned pine habitats. Meadow habitats, although not specifically designated in the Forest Service data, were characterized as grass habitats (GRA) and bluegrass dominated habitats (GPO). Furthermore, habitats on private lands were not identified in the Forest Service database (Tables 1–6).

On winter range, when mixed (secondary) cover types were combined with primary cover types, pine habitats were more abundant at deer locations than in the corresponding Forest Service data (Table 3). On winter range, meadows were more abundant at deer and random locations than in corresponding Forest Service data (Tables 3, 4). On summer range, aspen, spruce, and meadow habitats were more abundant at deer and random sites than in the corresponding Forest Service data (Tables 5, 6). Many of the meadows and aspen stands occupied by white-tailed deer were small and may not have been evident in the aerial photographs used by the Forest Service or too large of a minimum mapping unit was used to develop their GIS data base. Moreover, it may be difficult to distinguish spruce and ponderosa pine from aerial photographs.

Cover types classified by the Forest Service lack the detail necessary for defining habitats used by white-tailed deer and available at random sites in the central Black Hills (Tables 1, 2). Deer and random data included mixed-cover characteristics that were absent in the Forest Service digital data. Such under representation of habitats could be related to a failure to recognize the finer scale habitat features that occur within a larger habitat type (Stoms et al. 1992). Poor quality of cover types classified in the Forest Service GIS should be recognized and accounted for in future analyses and management decisions. However, improvements have recently been made to the Forest Service database. Nevertheless, if mixed cover types are not considered in habitat classification, a stand with secondary cover layers could be labeled as one uniform stand (Nelson 1995, this study). To improve the accuracy of habitat management decisions relative to white-tailed deer, the Forest Service GIS would be strengthened if mixed (secondary) cover type classification were included in the database or if a smaller minimum mapping unit was used. In the spirit of cumulative effects analysis as required by the National Environmental Protection Act (NEPA) and ecosystem management (Boyce and Haney 1997), we recommend gathering data in the Black Hills without regard to landownership (i.e., the USDA Forest Service should gather information on public and private lands).

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EFFECTS OF GRAZING CONSERVATION RESERVE PROGRAM LANDS IN NORTH DAKOTA ON BIRDS, INSECTS, AND VEGETATION

Carmen L. Kennedy and Jonathan A. Jenks
Department of Wildlife and Fisheries Sciences
South Dakota State University, Brookings, SD 57007

Kenneth F. Higgins
USGS/BRD
South Dakota Cooperative Fish and Wildlife Research Unit
Brookings, SD 57007

ABSTRACT

Effects of two grazing systems on nongame birds, insect biomass, and vegetation structure in Conservation Reserve Program (CRP) grasslands were evaluated in North Dakota. Treatments included idle (controls), 3-pasture twice-over deferred rotation grazing, and season-long grazing systems. Twelve species of nongame passerine birds in 1992 and 10 species in 1993 used CRP fields. The lark bunting *(Calamospiza melanocorys),* grasshopper sparrow *(Ammodramus savannarum),* red-winged blackbird *(Agelaius phoeniceus)* and brown-headed cowbird *(Molothrus ater)* dominated species composition in 1992 and 1993. CRP pastures under rotational or season-long grazing treatments maintained equal or higher mean male bird densities compared to idle CRP control fields. Mean density of male birds, terrestrial insect biomass and, for the most part, vegetation height, were lower in 1993 than 1992. Results indicated that high insect biomass in pastures with dense cover does not necessarily equate to higher nongame bird use. At moderate stocking rates (~2.1 AUM/ha), our results indicated that grazing of CRP lands could be included in contract terms or in negotiations in any extensions or modifications of future CRP contracts without any significant losses to nongame birds.

INTRODUCTION

About 11 million hectares (28 million acres) of natural grasslands in North Dakota have been converted to crop production (Senechal, 1990). Over 4 million hectares (11 million acres) of cropland have been converted back to grassland through the Conservation Reserve Program (CRP) in the Northern Great Plains Region, of which over 1 million hectares (3 million acres) are located in North Dakota (Luttschwager and Higgins, 1991). Most of the CRP acreage in North Dakota has been planted to mixtures of tame grasses and legumes.

In 1992, the North Dakota CRP task force began a grazing and haying Demonstration Project on several tracts of CRP grasslands (Nyren *et al.,* 1993).

The Animal and Range Science Department at North Dakota State University coordinated the Demonstration Project through 1995. Demonstration Project objectives included collecting data on effects in floristic composition, vegetation production and utilization, hay production, quality beef production, erosion, economic returns, and wildlife use under different grazing (season-long and twice-over deferred rotation) regimes.

Although studies have addressed waterfowl (Kantrud, 1993; Luttschwager and Higgins, 1991; Luttschwager *et al.,* 1994), upland game (Luttschwager and Higgins, 1992; King and Savidge, 1995; Riley, 1995; Kimmel and Berner, 1998) and big game (Luttschwager and Higgins, 1992; Gould and Jenkins, 1993) utilization of CRP grasslands, little research attention has been given to nongame species (Johnson and Schwartz, 1993a and b; King and Savidge, 1995) in CRP grasslands in the Northern Great Plains or to the effects of grazing of CRP grasslands on nongame wildlife species.

This study evaluated effects of two grazing systems on nongame birds, insect biomass, and vegetation structure in CRP grasslands of the Demonstration Project in North Dakota. Specific objectives of this study were: 1) to compare density of male grassland nesting passerines in grazed and idle CRP treatments; 2) to compare summer-season above-ground terrestrial invertebrate biomass in grazed and idle CRP treatments; 3) to compare vegetation structure in grazed and idle CRP treatments; and 4) to determine relationships among bird density, insect biomass, and vegetation structure as a result of treatment *(i.e.,* grazed or idle tracts) in CRP grasslands.

METHODS

This study was conducted on three, large CRP grassland sites that were selected for the Demonstration Project. Because these sites were for demonstration, they were selected on the basis of representativeness to the whole region and willingness of landowner cooperation; thus, precluding selection by random chance. They were located in Bowman, Ward, and Stutsman counties, North Dakota. Treatments within each of the CRP tracts included: 3 pastures (A, B, and C) under a twice-over deferred rotation grazing system (TOR-A, TOR-B, and TOR-C), one pasture under a season-long (SL) grazing system, and an idle field (control). Grazing systems design and livestock specifics are described in detail for each study site by Kennedy (1994). Grazing intensity on all three sites averaged 2.1 AUM's/ha ± 0.12(SE).

The Bowman County study area (BCSA) was located in southwestern North Dakota, about 16 km (10 miles) south of Bowman, North Dakota. The BCSA was situated on the Missouri Plateau (Stewart, 1975); topography is characterized as a gently sloping plain with buttes and hills (USDA-SCS, 1975). Climate of Bowman County is characterized as a semiarid, continental type (Omodt *et al.,* 1968). In fall 1988, about 150 ha (370 acres) were planted with a CRP mixture of crested wheatgrass *(Agropyron cristatum L.),* intermediate wheatgrass *(A. intermedium* [Host] Beauv.), and alfalfa *(Medicago sativa* L.). Scientific names of all flora are according to The Great Plains Flora Association (1977).

The Stutsman County study area (SCSA) was located in west-central North Dakota, about 3.2 km (2 miles) west of Streeter, North Dakota. The SCSA was situated on the Missouri Coteau physiographic region within the Prairie Pothole Region (Stewart, 1975). Climate of this area is characterized as a cool and subhumid, continental type (Omodt *et al.,* 1968). In spring of 1987, 136 ha (337 acres) of the SCSA were planted with a CRP mixture of tall wheatgrass *(A. elongatum* [Host] Beauv.), intermediate wheatgrass, smooth bromegrass *(Bromus inermis* Leyss.), alfalfa, and yellow and white sweet clover *(Melilotus officinalis* [L.] Pall. and *M. alba* Medic.). About 13 ha (32 acres) of wetlands were interspersed throughout the SCSA experimental tract.

The Ward County study area (WCSA) was located in north-central North Dakota, about 48 km (30 miles) northwest of Max, North Dakota. The WCSA was within the Missouri Coteau Physiographic region of the Prairie Pothole Region (USDA-SCS, 1974). Area topography varies from level morainic plains in the northeastern portion of the county to morainic hills in the southwest (USDA-SCS, 1974). Ward County is characterized as a subhumid, continental type climate (Omodt *et al.,* 1968). In spring 1987, 99.2 ha (245 acres) were planted with a CRP mixture of western wheatgrass *(A. smithii* Rydb.), slender wheatgrass *(A. caninum* [L.] Beauv.) and alfalfa. About 13.4 ha (33 acres) of wetlands were interspersed throughout the WCSA experimental tract.

Birds were surveyed along a 400-m transect systematically positioned about 30 m from pasture borders and wetlands to minimize potential bias associated with edges (Arnold and Higgins, 1986; Reese and Ratti, 1988). Pastures were surveyed for birds 7 times from May - July 1992 and 6 times from May - July 1993. Bird surveys were conducted at about weekly intervals from 0.5 hour before sunrise until 1.5 hours after sunrise on mornings with mild winds *(i.e.,* <20 km/h) and no precipitation (Mikol, 1980). Each survey was conducted by walking the transect and recording all avian species heard or seen. Additional bird data recorded along each transect included: sex and behavioral or detectional cues (Arnold and Higgins, 1986; Burnham *et al.,* 1980; Mikol, 1980). An index of breeding bird density *(i.e.,* number of perched and/or singing male birds encountered divided by area) was calculated from transect data. Fixed width area (modified after Emlen, 1977) for density calculations was determined as the largest area not visually obstructed *(e.g.,* obstruction by terrain) and 30 m from fence borders or wetlands (Arnold and Higgins, 1986). As such, transect width varied among treatments, ranging from 100-150 m wide. Once established, transect width was fixed for all subsequent surveys in the treatments. All birds seen along a transect were recorded regardless of sex, location, and activity within the treatment; however, only data on perched and/or singing males occurring within the fixed width area were used for statistical analyses. Scientific names of all bird species are according to The American Ornithologists' Union (1983).

Terrestrial insect samples were collected along a 400-m transect, which ran parallel to each bird transect. Five sampling points, spaced about 80 m apart were established along this transect. A sampling point consisted of a 15-m sample line, which ran perpendicular to the main transect. Insects were collected along each sampling line (1 sweep/pace for 15 paces) with a Ward's

Company heavy-duty beating net *(i.e.,* sweep-net). In 1992, insects were sampled 6 times in each study area. In 1993, insects were sampled 6 times in the WCSA and 5 times in the BCSA and SCSA, rain precluded insect collections during the 6th sample period for the BCSA and SCSA. Sweep-net sampling was conducted one day after bird surveys, beginning at 1000 hrs, and only when there was no precipitation and little to no wind. Samples were collected at the same time of day in each county to standardize the variation that occurs due to time and weather influences (Southwood, 1978). Each sweep was taken swiftly in a straight line and as low to the ground as possible (Southwood, 1978). All sampled insects were placed in plastic containers in the pasture and later frozen. In the lab, insect samples were dried at 60°C (140°F) for 24 hours *(i.e.,* constant weight), and then weighed to the nearest mg dry weight.

Vegetation sampling points ($\underline{n}$=25) were equidistantly spaced at 16-m intervals along a linear transect within each pasture. Vegetation transects were placed parallel to bird and insect transects. Vegetation measurements were conducted during the same day as the bird surveys. In all study areas, vegetation transects within each treatment were surveyed 7 times during 1992 and 6 times during 1993. Vertical density measurements (visual obstruction) of vegetation were made with a modified visual obstruction pole (Robel *et al.,* 1970; Higgins and Barker, 1982). Obstruction occurred when vegetation limited visibility of the pole by 100% when visual obstruction readings (VORs) were taken from a sighting height of 1 m and a distance of 4 m (Robel *et al.,* 1970). One hundred VORs per transect were recorded to the nearest 0.25-dm height. Four readings (1 from each cardinal direction) were taken at each of the 25 sampling stations. Vegetation height (VH) was determined by lowering a 15-cm diameter plastic disc down the pole until the first part of any plant was touched (Higgins and Barker, 1982).

This study was treated as a randomized complete block design (counties as blocks) over years, with time as subsamples. To be consistent with Demonstration Project objectives, counties were classified as fixed variables. The following *a priori* statistical hypotheses were tested relative to the study objectives: 1) there was no difference in the index of male nongame bird density among treatments; 2) there was no difference in terrestrial invertebrate biomass among treatments; and 3) there was no difference in vegetation structure among treatments.

Confidence intervals (95%) were used to determine if differences in bird density, insect biomass, and vegetation structure occurred among grazing treatments and the idle tract.

Bird density data were slightly skewed, and thus, were transformed to square-root density. The SAS GLM (General Linear Model) procedure (SAS, 1985) was used to determine if there were any significant ($P < 0.05$) main effects or interactions among counties, years and treatments. Confidence intervals (95%) were computed for comparison tests according to the highest order interaction.

RESULTS

Bird Species Composition. Twelve species of passerine birds in 1992 and 10 species in 1993 used CRP pastures in North Dakota (Table 1). During 1992, the lark bunting *(Calamospiza melanocorys),* grasshopper sparrow *(Ammodramus savannarum),* red-winged blackbird *(Agelaius phoeniceus)* and brown-headed cowbird *(Molothrus ater)* composed 47.7, 24.6, 6.5, and 7.2%, respectively, of total male bird species. During 1993 surveys, lark buntings (37.6%), grasshopper sparrows (39.4%), bobolinks *(Dolichonyx oryzivorus)* (4.8%), and brown-headed cowbirds (6.1%) composed 87.9% of the total male bird species.

Differences in bird species composition occurred among counties and years (Table 2). Lark buntings were the most abundant bird species on the BCSA in 1992 and 1993, followed by grasshopper sparrows, red-winged blackbirds and brown-headed cowbirds. Grasshopper sparrows, bobolinks, and savannah sparrows *(Passerculus sandwichensis)* were the most common bird species encountered on the SCSA during 1992 and 1993. Lark buntings, grasshopper sparrows, brown-headed cowbirds, and clay-colored sparrows *(Spizella pallida)* were the most common bird species encountered on the WCSA during 1992 and 1993. The overall number of species encountered in SCSA and WCSA was lower in 1993 than in 1992.

Bird Densities. The treatment by county by year interaction for bird density comparisons approached significance ($\underline{F}$ = 1.93, df = 8, 161, P = 0.059) (Table 3). Therefore, confidence intervals (0.95%) were used to compare among treat-

Table 1. Number (No.) and percent (%) composition of perched and/or singing male passerine birds surveyed in CRP Demonstration Project grasslands in Bowman, Stutsman, and Ward County, North Dakota, during summer of 1992 and 1993.

	1992		1993	
Species	**No.**	**%**	**No.**	**%**
Grasshopper Sparrow	431	24.6	285	39.4
Lark Bunting	834	47.7	272	37.6
Red-winged Blackbird	114	6.5	17	2.3
Western Meadowlark	82	4.6	25	3.4
Savannah Sparrow	57	3.3	16	2.2
Brown-headed Cowbird	127	7.2	44	6.1
Bobolink	51	3.0	35	4.8
Clay-colored Sparrow	35	2.0	20	2.7
Common Yellowthroat	1	0.1	0	0.0
Eastern Kingbird	1	0.1	0	0.0
Sedge Wren	0	0.0	3	0.4
Yellow-headed Black Bird	2	0.1	0	0.0
Baird's Sparrow	12	0.6	6	0.8
Total number	*1,747*		*723*	
Total species	*12*		*10*	

Table 2. Number (No.) and percent (%) composition of perched and/or singing male passerine birds surveyed in Bowman, Stutsman, and Ward County CRP Demonstration Project grasslands in North Dakota during 1992 and 1993.

	BCSA				SCSA				WCSA			
	1992		1993		1992		1993		1992		1993	
Species	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Grasshopper Sparrow	133	16	131	40	147	43	117	63	151	27	37	18
Lark Bunting	586	69	166	50	9	3	0	0	239	43	106	52
Red-winged Blackbird	80	9	10	3	19	6	7	4	15	3	0	0
Western Meadowlark	15	2	7	2	35	10	10	5	32	6	8	4
Savannah Sparrow	9	1	0	0	40	12	14	8	8	1	2	1
Brown-headed Cowbird	32	4	7	2	37	11	7	4	58	11	30	15
Bobolink	0	0	8	2	49	14	27	15	2	0.4	0	0
Clay-colored Sparrow	0	0	1	0.3	1	0.3	1	0.5	34	6	18	9
Common Yellowthroat	0	0	0	0	1	0.3	0	0	0	0	0	0
Eastern Kingbird	0	0	0	0	0	0	0	0	1	0.2	0	0
Sedge Wren	0	0	0	0	0	0	3	2	0	0	0	0
Yellow-headed Blackbird	0	0	0	0	2	0.5	0	0	0	0	0	0
Baird's Sparrow	0	0	3	0.9	0	0	0	0	12	2	3	1
Total number	*855*		*333*		*340*		*186*		*552*		*204*	
Total species	*6*		*8*		*10*		*8*		*10*		*7*	

Table 3. Mean (SE) density of male birds per 100 ha by treatment in CRP Demonstration Project grasslands in the Bowman, Stutsman, and Ward County study areas (BCSA, SC-SA, and WCSA, respectively) in North Dakota during 1992 and 1993.

	TREATMENT[a]		
Study area	TOR	SL	I
BCSA			
1992	82.8 (22.7)a1[bc]	112.4 (14.9)a1	76.2 (7.9)a1
1993	109.9 (8.2)a1	40.0 (4.4)b2	34.7 (5.5)b2
SCSA			
1992	31.6 (3.3)ab1	48.6 (7.4)a1	18.6 (4.2)c1
1993	18.3 (3.7)a1	20.5 (2.6)a2	27.8 (4.9)a1
WCSA			
1992	62.2 (7.5)a1	55.3 (5.9)a1	58.9 (7.3)a1
1993	30.4 (6.1)a2	16.1 (2.5)a2	24.3 (1.9)a2

[a] Conservation Reserve Program Demonstration Project treatments include: a 3 pasture (A, B, and C) twice over deferred rotation grazing system (TOR) one pasture under a season-long grazing system (SL) and one idle field (I).
[b] Density of male birds (100 ha) in rows with shared letters are not significantly ($P < 0.05$) different.
[c] Density of male birds (100 ha) within a county and treatment with shared numbers are not significantly ($P < 0.05$) different.

ments within each county and year. Also, confidence intervals were used to compare bird densities by treatment and county across years and among counties by year.

Mean density of male birds was generally highest in the BCSA and lowest in the SCSA during 1992 and 1993 *(i.e.,* a county * year interaction). Furthermore, treatments within each county exhibited a downward trend in mean male bird density from 1992 to 1993 *(i.e.,* a treatment * year interaction). Mean values for density within all the BCSA treatments except for TOR were lower (P < 0.05) in 1993 compared to 1992 *(i.e.,* treatment * county * year interaction). In the SCSA, mean values for bird density differed (P < 0.05) in the SL treatment from 1992 to 1993. in WCSA, mean values for bird density in SL and Idle treatments were lower (P < 0.05) in 1993 compared to 1992.

Bowman County—In 1992, mean bird density did not differ (P > 0.05) among treatments. In 1993, the mean bird density in the TOR was higher (P < 0.5) than in SL and Idle treatments.

Stutsman County—In 1992, mean bird density in the SL treatment was higher (P < 0.05) than in the idle pasture. In 1993, no statistical differences in mean male bird densities occurred among treatments.

Ward County—In 1992 and 1993, mean bird densities did not differ among treatments.

Terrestrial Insect Biomass. Analysis of variance of insect biomass data (Table 4) revealed a significant treatment by county by year interaction ($\underline{F}$ = 1.94,

Table 4. Terrestrial insect dry-weight biomass (mean and SE) in grams per 15 meter transect (15 sweeps) in grazed and idle CRP Demonstration Project grasslands in Bowman, Stutsman, and Ward County study areas (BCSA, SCSA, and WCSA, respectively) in North Dakota during 1992 and 1993.

		TREATMENT[a]	
Study area	**TOR**	**SL**	**I**
BCSA			
1992	0.46 (0.09)a1	0.31 (0.05)a1	1.09 (0.34)a1
1993	0.06 (0.01)a2	0.06 (0.01)a2	0.03 (0.01)a2
SCSA			
1992	0.06 (0.02)a1	0.17 (0.02)b1	0.04 (0.01)b1
1993	0.04 (0.01)a1	0.05 (0.01)a2	0.02 (0.001)a1
WCSA			
1992	0.47 (0.06)a1	0.49 (0.07)a1	0.57 (0.10)a1
1993	0.06 (0.01)a2	0.06 (0.01)a2	0.03 (0.01)a2

[a] Conservation Reserve Program Demonstration Project treatments include: a 3 pasture (A, B, and C) twice over deferred rotation grazing system (TOR) one pasture under a season-long grazing system (SL) and one idle field (I).
[b] Insect biomass (g) among treatments within a county and year with shared letters are not significantly (P < 0.05) different.
[c] Insect biomass (g) between years within a county and treatment with shared numbers are not significantly (P < 0.05) different.

df = 8, 161, P = 0.059). Therefore, confidence intervals of insect biomass for treatments were calculated for each county and year. Also, confidence intervals of insect biomass for years were compared within each county and treatment.

Terrestrial insect biomass in all counties was generally lower in 1993 than in 1992 (Table 4). However, lsmean tests indicated significantly lower insect biomass in only 6 of 15 pastures in 1993 compared to 1992. In the BCSA, insect biomass in the TOR ($P < 0.05$), SL ($P < 0.05$) and idle ($P < 0.05$) fields were lower in 1993 than in 1992. In the SCSA, the mean values for insect biomass computed for the TOR and idle treatments did not differ ($P < 0.05$) in 1993 compared to 1992. The SL treatment was lower ($P < 0.05$) in 1993 than 1992. In the WCSA, the mean insect biomass was lower ($P < 0.05$) in all treatments in 1993 compared to 1992.

Bowman County—In the BCSA, mean insect biomass did not differ ($P > 0.05$) among treatments in 1992 or 1993.

Stutsman County—Within the SCSA, a significant difference in insect biomass occurred with the SL treatment higher ($P < 0.05$) than TOR and Idle treatments in 1992; no difference ($P > 0.05$) occurred among treatments in 1993.

Ward County—Within the WCSA, no difference ($P > 0.05$) in insect biomass occurred among treatment in 1992 or 1993.

Vegetation Structure. Analysis of variance of vegetation structure data revealed a significant treatment by county by year interaction for VH ($\underline{F}$ = 2.31, df = 8, 165, P = 0.023) (Table 5) and VORs ($\underline{F}$ = 4.32, df = 6, 165, P = 0.0001) (Table 6). Therefore, signifiance tests among treatments were conducted within each county and year. Also, signifiance tests between years were conducted within each county and treatment.

Bowman County—During 1992 and 1993, the mean value for VH in the idle tract was greater than in the SL ($P < 0.05$) and TOR ($P < 0.05$) treatments. Overall, VH was lower in 1993 compared to 1992 in the idle ($P < 0.05$) field; the opposite occurred in the SL and TOR treatments. During 1992, mean VOR's were higher in the idle and TOR than in the SL treatment. During 1993, TOR and SL treatments had higher VOR's than the idle treatment. Overall, VOR's were higher in 1992 than in 1993 in TOR and SL treatments but lower in 1993 than 1992 in the idle treatment.

Stutsman County—During 1992, the idle tract had a higher mean VH value than the SL ($P < 0.05$) and TOR ($P < 0.05$) treatments. During 1993, the idle tract had a higher mean VH value than the SL ($P < 0.05$) and TOR ($P < 0.05$) treatments. Mean value for VH in the TOR was higher ($P < 0.05$) than in the SL treatment. Overall, VH values in all treatments were lower ($P < 0.05$) in 1993 than in 1992.

During 1992, mean value for visual obstruction was higher in the idle ($P < 0.05$) compared to the SL and TOR treatments. During 1993, mean VOR was higher in the TOR ($P < 0.05$) and idle tract ($P < 0.05$) compared to the SL treatment. Similarly, mean VOR values for the TOR were higher ($P < 0.05$) than in the SL treatment. Visual obstruction readings in 1993 were lower ($P < 0.05$) in all treatments compared to 1992 VORs.

Ward County—During 1992, mean values for VH in the idle tract were higher than in SL ($P < 0.05$) and TOR ($P < 0.05$) treatments. During 1993, VH

Table 5. Mean (SE) vegetation height (VH) (dm) in grazed and idle CRP Demonstration Project grasslands in Bowman, Stutsman, and Ward County study areas (BCSA, SCSA, and WCSA, respectively) in North Dakota during 1992 and 1993.

		TREATMENT[a]	
Study area	**TOR**	**SL**	**I**
BCSA			
1992	6.3 (0.1)a1	6.0 (0.2)a1	7.9 (0.2)b1
1993	5.3 (0.06)a2	5.5 (0.1)b2	5.7 (0.1)c2
SCSA			
1992	5.8 (0.11)a1	5.2 (0.1)b1	8.4 (0.2)c1
1993	3.8 (0.08)a2	3.5 (0.2)b2	6.4 (0.2)c2
WCSA			
1992	4.3 (0.06)a1	4.3 (0.1)a1	5.7 (0.1)b1
1993	3.6 (0.06)a2	3.6 (0.1)a2	4.8 (0.2)b2

[a] Conservation Reserve Program Demonstration Project treatments include: a 3 pasture (A, B, and C) twice over deferred rotation grazing system (TOR) one pasture under a season-long grazing system (SL) and one idle field (I).
[b] VH (dm) within a county and year with shared letters among treatments are not significantly ($P < 0.05$) different.
[c] VH (dm) within a county and treatment with shared numbers between years are not significantly ($P < 0.05$) different.

Table 6. Mean (SE) visual obstruction (VOR) in grazed and idle CRP Demonstration Project grasslands in Bowman, Stutsman, and Ward County study areas (BCSA, SCSA, and WCSA, respectively) in North Dakota during 1992 and 1993.

		TREATMENT[a]	
Study area	**TOR**	**SL**	**I**
BCSA			
1992	2.4 (0.06)a1	1.7 (0.1)b1	3.1 (0.1)c1
1993	2.7 (0.06)a2	2.4 (0.1)a2	1.6 (0.1)b2
SCSA			
1992	1.9 (0.06)a1	1.8 (0.1)a1	2.3 (0.1)b1
1993	1.2 (0.03)a2	0.8 (0.03)b2	1.6 (0.1)c2
WCSA			
1992	1.7 (0.06)a1	1.7 (0.1)a1	1.3 (0.1)a1
1993	1.3 (0.03)a2	1.4 (0.1)a1	1.4 (0.1)a1

[a] Conservation Reserve Program Demonstration Project treatments include: a 3 pasture (A, B, and C) twice over deferred rotation grazing system (TOR) one pasture under a season-long grazing system (SL) and one idle field (I).
[b] VOR (dm) within a county and year with shared letters among treatments are not significantly ($P < 0.05$) different.
[c] VOR (dm) within a county and treatment with shared numbers between years are not significantly ($P < 0.05$) different.

in the idle tract was higher than in the TOR ($P < 0.05$), and SL ($P < 0.05$). Overall, 1993 mean values for VH were lower compared to 1992.

During 1992 and 1993, mean VORs did not differ ($P > 0.05$) among treatments. Overall, mean VORs in 1993 were lower ($P < 0.5$) than in 1992 for the TOR, while all other treatments was similar across years.

DISCUSSION

Livestock grazing is the most widespread economic use of grasslands in western North America, and it potentially affects a large number of grassland nesting passerines (Bock *et al.,* 1993). Study results and general field observations indicated that moderate intensity grazing (2.1 AUMs/ha) did not preclude the use of CRP grasslands in North Dakota by 12 passerine bird species. In several instances, higher passerine bird densities occurred in grazed CRP pastures than in idle tracts that served as controls or references areas. As expected, bird density, insect biomass, and vegetation structure values varied considerably among grazing treatments and controls (idled tracts) and by counties and years. However, patterns of variation in time or space were mostly lacking, and for the most part unexplainable, except perhaps for the effects of climatic or geographical location.

Overall, pastures subjected to systems of rotational grazing maintained equal or higher bird densities than idled tracts. Furthermore, in the BCSA, the SL grazing treatment supported the highest bird densities in 1992. Although some grazed treatments supported high bird densities, these pastures also tended to have lower insect biomass. Thus, these results indicate that high insect biomass in pastures with dense cover does not necessarily equate to higher nongame bird use. Perhaps, open or less densely vegetated areas within CRP pastures are important components of cover-forage complexes that birds use. However, the quality of cover in CRP grasslands, in terms of height and density, also is important. Bock *et al.* (1993) suggested that different nongame passerine species respond to grazing differently. At one extreme, species such as horned lark *(Eremophila alpestris)* benefitted from the effects of grazing while at the other extreme, species dependent on heavy litter cover and grass canopy, such as Savanna and Baird's sparrow *(Ammodramus bairdii),* were negatively impacted. Bobolinks, lark buntings, red-winged blackbirds, western meadowlarks *(Sternella neglecta),* and grasshopper sparrows responded positively to moderate grazing in taller grasslands (Bock *et al.,* 1993).

The total number of male passerine bird species (pooled over years and counties) on the Demonstration areas was 12. Similar numbers of passerine species were found by Johnson and Schwartz (1993) in CRP grasslands in Hettinger County, which is directly adjacent to the BCSA, and in Kidder County, which is directly adjacent to the SCSA.

In 1993, lark buntings, grasshopper sparrows, and brown-headed cowbirds were the most common bird species counted on the Demonstration Project CRP pastures. Johnson and Schwartz (1993) reported grasshopper sparrows, lark buntings, and red-winged blackbirds as the most common birds counted in CRP fields throughout their North Dakota study areas. Messmer (1990) reported that clay-colored sparrows, grasshopper sparrows, and red-winged blackbirds were the most abundant birds surveyed on native mixed-grass prairies on the Central Grasslands Research Station in Stutsman and Kidder counties, North Dakota. This similarity of dominant species in CRP versus native grassland suggests that CRP plays a vital role in supporting avian species, especially when native grassland communities are lacking in North Dakota. In other words, CRP grasslands can be a substitute habitat for some passerine species that commonly use native grasslands.

Bird species using CRP grasslands varied among North Dakota counties. For example, lark buntings were seen more often in the western counties (BCSA and WCSA) whereas bobolinks were seen more often in the eastern county (SCSA). Johnson and Schwartz (1993) also found that passerine species varied geographically in distribution and abundance in CRP grasslands in North Dakota.

Overall, mean bird density within most of the Demonstration Project CRP treatments declined from 1992 to 1993. The effects of year could represent either actual changes in the continental population size or annual shifts in distribution (Johnson and Schwartz, 1993) as a response to direct or indirect effects of precipitation and temperature (Wiens, 1973). Precipitation increased dramatically while mean maximum and minimum temperatures decreased from 1992 to 1993 on our study sites.

Overall, mean density of male birds (all species combined) were highest in the BCSA (west) and lowest in the SCSA (east). It is possible that higher bird densities in the BCSA were due to larger treatment pastures (more available interior habitat), and thus, was more attractive to nongame passerines at a landscape level. Idle tracts did not support higher bird densities than the grazed pastures in any county, indicating that at 2.1 AUM's/ha stocking rates, grazing of CRP grasslands does not preclude the use of these lands by nongame passerine birds.

Annual variation in insect biomass found during this study seems reasonable, because many species of insects are less abundant in times of cool temperatures and high precipitation. Grasshoppers composed much of the insect biomass in 1992, a drier, warmer year, than in 1993, which was colder and wetter. Although some idle fields supported high invertebrate biomass, availability of insects to foraging birds in idle fields may be limited due to the taller and denser vegetation.

Conservation Reserve Program lands are valuable habitats for wildlife, including nongame passerine birds. Conservation Reserve Program grasslands are more valuable to wildlife than the annually tilled croplands they have replaced (Bock *et al.,* 1993) and particularly to some nongame passerine bird species. Because over 3 million acres of CRP grassland occur in North Dakota (Luttschwager and Higgins, 1991), it would be unfortunate for several species of passerine birds if CRP tracts were converted to croplands [*i.e.,* changing the successional stages back to zero (Bock *et al.,* 1993)]. Grazing of CRP grasslands after contracts expire is a viable economic alternative to annual crop production that might be acceptable to landowners, and particularly so, if but a portion of the current annual CRP payments were included as an additional incentive to keep permanent cover on the land.

Results of this study indicated that at moderate stocking rates (Kennedy, 1994), grazing of CRP lands in North Dakota may be an acceptable practice; *i.e.,* a land use that provides benefits to the landowner and also to some nongame birds. Definitely, some grazing practices should be considered in contract terms or in negotiations in extensions or modifications of future CRP contracts.

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USE OF FLIGHT INTERCEPT TRAPS IN A GRASSLAND HABITAT

Courtenay K. Hoernemann and Paul J. Johnson
Plant Science Department
South Dakota State University
Brookings, SD 57007

Kenneth F. Higgins
South Dakota Cooperative Fish and Wildlife Research Unit, USGS/BRD
South Dakota State University
Brookings, SD 57007

Flight intercept traps have long been used for collecting various groups of insects (Chapman & Kinghorn 1955; Masner & Goulet 1981; Southwood 1966); however, their primary use has been in forest or woodland settings. Apparently, there are no accounts in the published scientific literature of flight intercept traps used in a prairie or grassland situation. We used flight intercept traps, modified from the design of Peck and Davies (1980), to assess insect abundance and diversity in planted grasslands that were subjected to annual grazing and haying systems. Three study sites were located in Conservation Reserve Program grasslands in North Dakota on the Missouri Coteau, which is gently rolling terrain formed by glaciation (Harris 1996).

Our flight intercept traps consisted of black nylon mesh screening 184 cm x 92 cm (6 ft. x 3 ft.) supported by two 122 cm (4 ft.) dowel rods and nylon cord guylines (Fig. 1). We modified the trap design of Peck and Davies (1980) by grommetting the corners of the screen through duct tape (Fig. 1), which

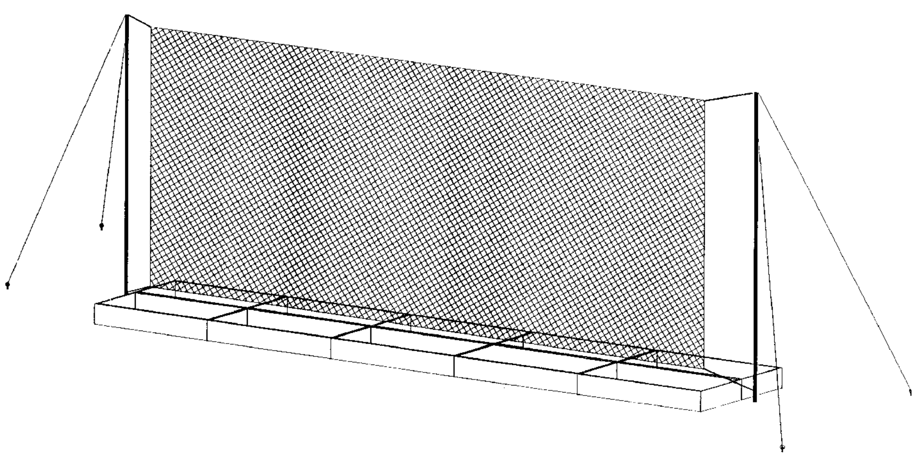

Figure 1. Design illustration of a flight intercept trap. Insects fly into the screen then fall into the collecting pans.

prevented any tearing. The cord locks helped keep tension on the guylines which in turn prevented the screen from blowing over and not functioning as a flight intercept device. The corners of the screen were grommetted through duct tape and elastic loops connected the screen with "S"-hooks to eyelet screws in the dowels. The guylines were tied to the poles and anchored to the ground with tent stakes. Cord locks were used to adjust tension on the guylines. A trench was dug beneath the screen and plastic pans 40 x 20 x 5 cm (68 x 8 x 2 in.) were placed in the trench flush with the soil surface. The pans were partially filled with propylene glycol solution (70% water, 30% glycol) which served as a killing agent and as a preservative of insect samples. The pans were checked for insects and serviced approximately every 4 weeks. Insect collections were sieved through a small aquatic dipnet and placed in Whirl-Pak™ plastic bags with 80% ethanol for temporary storage and later identification.

Two flight traps were placed in each of 18 pastures. One trap per pasture was oriented north-to-south and the other east-to-west in order to intercept insects in either flight pattern. All flight traps were enclosed within 3-stranded barbed-wire fences to prevent damage from cattle. Based on our observations of insect flight patterns, we believe the enclosures did not significantly interfere with insect flight patterns and trap catch.

A wide variety of arthropod taxa were captured with the flight intercept traps, particularly Diptera which accounted for the highest percentage of arthropods collected. Other common taxa were Hymenoptera, including Apidae, Braconidae, Ichneumonidae, and Orthoptera, primarily Acrididae. Several other groups of arthropods were quite common in the traps, but may not have been collected "in flight." For instance, ground beetles (Carabidae) and dung beetles (Scarabaeidae) were abundant in samples, but they may have walked and fallen into the collecting pans without having flown into the trap screen first. In these insect groups, the collecting pans may have served as large pitfall traps since the pans were flush with the soil surface. The flight intercept traps were used as part of a sampling regime, which also included pitfall traps, sweep netting, and soil sampling. Additional taxa of Coleoptera were collected from the flight intercept traps, which added to the numbers and diversity of specimens collected in pitfall traps. The use of flight intercept traps was advantageous to the study because insect taxa captured by them increased the overall population diversity in our samples.

There were a few challenges with the use of flight intercept traps in grasslands as opposed to woodlands. In the open, windy terrain of northern plains grasslands, the traps were periodically damaged during intensive thunderstorm events with high wind and rain. Whereas in forest habitats traps are protected from most harsh weather elements by the tree canopy. Some of the propylene glycol solution evaporated during the summer when there was no or little rainfall. In contrast, some or all of the propylene glycol solution was flushed from some pans at several traps during intensive thunderstorms.

A grassland diversity study can benefit from using flight intercept traps as part of a sampling scheme. We recommend servicing and checking the trap pans more frequently than once every 4 weeks in order to minimize sample loss due to weather events. The modifications made to the trap design improved trap durability. Use of flight intercept traps improved our measurement of arthropod diversity in grassland habitats. Also samples from the flight intercept traps provided superior information on Orthoptera over sweep netting, which is a widely used method for this group of insects. We recommend that other scientists also consider their use in future studies of grassland insects.

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DISTRIBUTION AND PRODUCTIVITY OF LEAST TERNS AND PIPING PLOVERS ON THE NIOBRARA RIVER

Stacy L. Adolf
USFWS
Des Lacs NWR
Kenmare, ND 58746

Ken Higgins
SD Coop Unit, USGS
Brookings SD 57006

Casey Kruse and Greg Pavelka
US Army Corps of Engineers
Gavins Point Project
Yankton SD

INTRODUCTION

Interior least terns *(Sterna antillarum athalassos)* and piping plovers of the Great Plains *(Charadrius melodus)* are federally listed endangered and threatened species, respectively, with both species being protected under the Endangered Species Act since 1985. They are also sympatric nesters, breeding and nesting together throughout the northern Great Plains (Ziewitz et al. 1992). Concentrations of both species can be found along the Mississippi, Missouri, Platte, Yellowstone, and Niobrara rivers (Ducey 1981, 1985, Ziewitz et al. 1992).

Least terns and piping plovers depend on sandbars that are bare or only sparsely vegetated for nesting and brood-rearing (Carreker 1985, Ducey 1985, 1989a). Terns and plovers utilize large sandbars (Kirsch 1996) that are low in elevation and often near mid-channel (Dinan et al. 1985, USACE 1987). Availability of these essential nesting habitats is declining along most rivers in the northern Great Plains. This is largely the result of dam construction (Ducey 1981), channelization projects, altered flow regimes, and changes in surrounding land use on most of the large rivers including the Missouri River (Faanes 1983, Sidle et al. 1991, Smith and Renken 1991, USFWS 1985). Dammed and channelized rivers exhibit regulated flows and the cycle of natural spring flooding is either largely controlled or totally eliminated. River channels were deepened and shortened (Whitman 1988), channel size was reduced, and vital mid-river sandbars were destroyed to straighten and control the rivers (Ducey 1981, Ziewitz et al. 1992). Typical sandbars are not created in these situations because the sediment loads are dropped as they reach the reservoirs, never continuing downstream to build new sandbars (USFWS 1985). The new, straighter river channels also allow sediments carried by the river to be swept through the channel instead of being deposited as sandbars (Dryer and Dryer 1985, Wingfield 1978, Ziewitz et al. 1992). Without this type of flooding, vegetation encroaching on the few sandbars that are left is not scoured away (Faanes 1983, Kirsch 1987, Sidle et al. 1992), making these remaining sandbar and island habitats unsuitable for nesting. When shoreline or any type of riverine habitat becomes wooded and vegetated, they cease to be dynamic. This new stability creates a narrower channel, constricts the flow, and increases flow velocity (Lingle 1988).

The Niobrara River in Nebraska and Colorado is one of the least modified rivers in the northern Great Plains that currently supports breeding populations of least terns and piping plovers. It is only marginally modified by control structures and exhibits a relatively natural flow pattern. Flows in the Niobrara are typically dominated by a brief period of plains snowmelt and then sustained by summer precipitation and steady ground water discharge (National Park Service 1995).

Least terns and piping plovers have been recorded nesting on the Niobrara River from its confluence with the Missouri River upstream to Nordon, NE since the first recorded nesting of least terns and piping plovers in the area in 1902 (Ducey 1989b). More recently the Nebraska Game and Parks Commission (NGPC) has been conducting surveys on the Niobrara River from 1978 through 1988 and then again in 1991 and 1996 (Wingfield 1984, 1988). Least terns have been monitored since 1975 (Wingfield 1978) with monitoring of piping plovers on the Niobrara River beginning in 1984 (Wingfield 1984). According to the surveys of the NGPC, the number of interior least terns and piping plovers appears to be increasing on the Niobrara River. In 1981, 97 adult least terns and 92 adult piping plovers were found during the census. However, in 1991, just 10 years later, 291 least terns and 162 piping plovers were found on the same route during the first International Piping Plover Census. In 1991, the Niobrara River supported roughly 41% of Nebraska's piping plover population and 35% of its least tern population. During the annual International Piping Plover Census in 1996, about 30% of Nebraska's piping plovers and 32% of its' least terns were found on the Niobrara River (Dinan 1996).

A paucity of data exists on least tern and piping plover reactions to natural river systems (Kreil and Dryer 1987), an exception being a study on the Yellowstone River in Montana concerning the nesting ecology of least terns (Bacon 1996). However, extensive records of least tern and piping plover nesting habitat availability on the mainstem Missouri River are almost nonexistent for the time period before dam construction (USFWS 1990). Consequently, determining the extent of change in habitat availability and suitability is difficult. By evaluating the Niobrara River's natural hydrologic regime, some insights on least tern and piping plover habitat use and productivity may be gained to help develop and improve water management strategies that would enhance the production of plovers and terns on the Missouri River. This underlying goal of increased plover and tern production along the Missouri River is a primary justification for the study of a natural river system such as the Niobrara River. Objectives of the study were 1) to determine piping plover and least tern habitats and their suitability for nesting and brood-rearing along the Niobrara River in northern Nebraska during the spring and summer of 1996 and 1997; 2) to determine the population, distribution, and reproductive success of piping plovers and least terns along the Niobrara River.

STUDY AREA

The Niobrara River is one of the most undeveloped rivers within the northern Great Plains extending approximately 719.2 kilometers (km) (447 miles) from west to east (Fig. 1). It originates in southeastern Wyoming and runs just south of the Nebraska/South Dakota border until it meets the Missouri River. The word "Niobrara" means "running water" in the Sioux language referring to the rivers' constant year-round flow. It is also considered one of the fastest flowing rivers in the world not associated with a mountainous region (Norfolk News 1964). The study area included the eastern section of the river where the valley widens enough for the channel to become braided with clustered sandbars. High spring discharges for the Niobrara River are usually between 28.31 and 42.47 cubic meters per second (cms) [1,000 and 1,500 cubic feet per second (cfs)] while low flows are usually between 9.91 and 13.02 cms (350 to 460 cfs) (Buchanan 1981) (Fig. 2). Flow extremes have ranged from a high flow of 76.44 cms (2700 cfs) and greater down to a low flow of 6.23 cms (220 cfs) or less in years of severe drought. During high flows, such as in the spring, the river exhibits a recognizable, meandering channel or thalweg. When flows diminish later in the summer and during the fall, the thalweg disappears and the Niobrara River has characteristics of a braided river system with large, flat

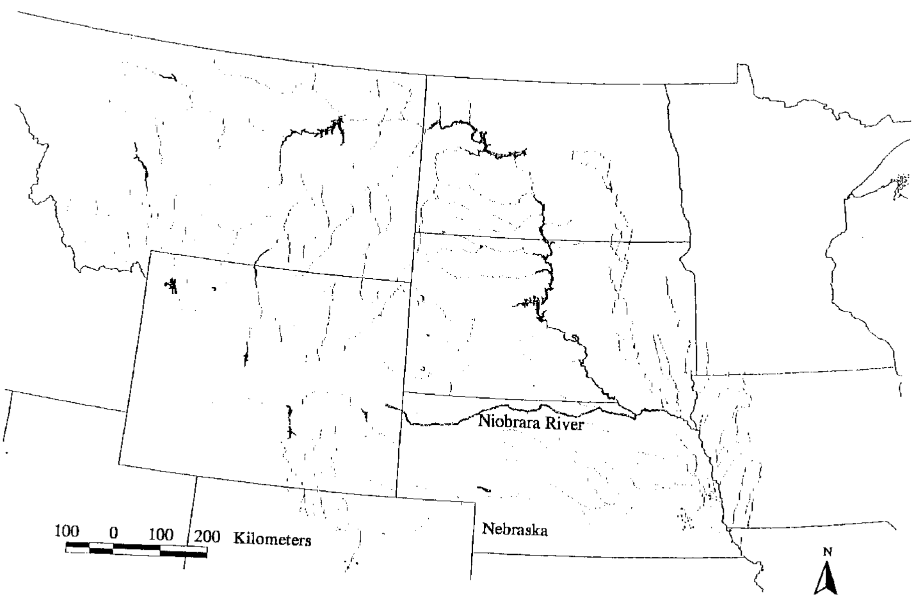

Figure 1. Niobrara River Study Area (1996–1997) within the Upper Missouri River Drainage Basin.

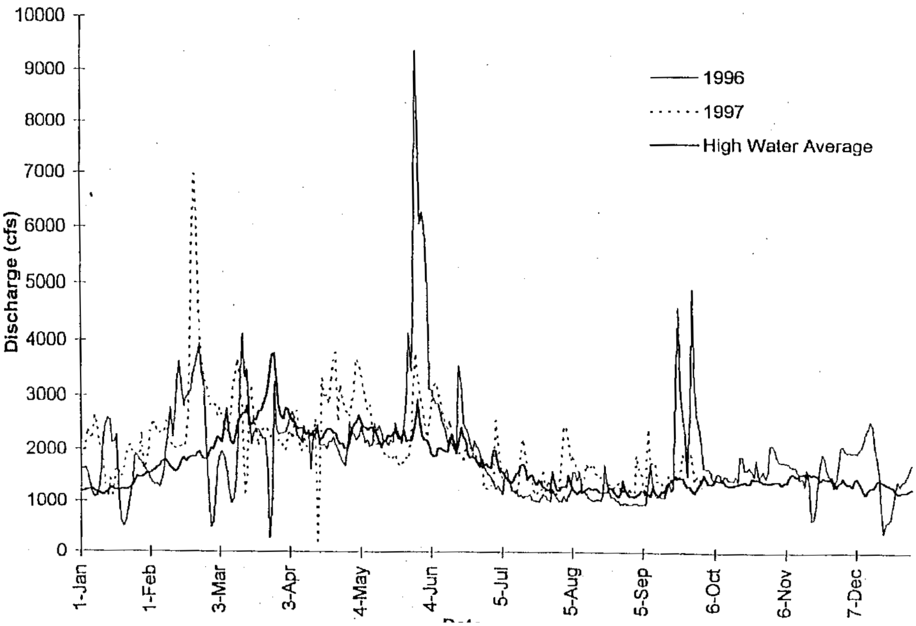

Figure 2. Hydrography of the Niobrara River for 1996, 1997, and a High Water Year Average for years 1944, 1950-54, 1957, 1960, 1962-63, 1973, 1977-78, 1982-84, 1986-88, and 1991-95.

linguoid sandbars. Water depths vary with the seasons and range from a few centimeters (inches) in summer and fall to 1.52 meters (m) (5 feet) or greater in spring (Buchanan 1981).

The early spring runoff of the Niobrara River starting in January, February, March, and April is attributed to snowmelt from the plains. During the rest of the year, the base flow of the Niobrara River is dependent on groundwater discharge, tributary inflow, and isolated heavy rain events. Groundwater discharge inputs help to produce a year-round base flow with few flood events (Bleed and Flowerday 1997).

The Niobrara River has many large and small tributaries associated with it. A few of the largest are the Keya Paha and Snake rivers, and Minnechaduza, Plum and Long Pine creeks. All except the Keya Paha are groundwater-based streams, which are regulated by surface runoff. This large number of groundwater-based creeks and rivers flowing into the Niobrara River help to keep it flowing year-round. However, before its confluence with the Missouri River, the flows of the Niobrara River are split between the main channel and the Mormon Canal.

Impoundments on the Niobrara River include the Box Butte Reservoir which was part of the Mirage Flats Irrigation project established in 1946. The Merritt Reservoir, on the Snake River, is associated with the Ainsworth Irrigation Project which started in 1964. The Snake River is a major tributary of the Niobrara River but its dam reduced the mean monthly discharge of the Niobrara River over 15%. The lower two impoundments on the Niobrara River are the Niobrara Hydroelectric Plant which in now inoperable, and the Spencer Hydroelectric Plant. The Niobrara Hydroelectric Plant is now a run-of-the-river plant which no longer affects the flows on the Niobrara (Buchanan 1981). The Spencer Hydroelectric Plant and its associated dam began operation in 1927 and although siltation has reduced the storage capacity of the reservoir, the plant is still in operation. The Spencer dam supplies supplemental power to the surrounding communities but it has caused a dramatic impact on the channel downstream since its initiation, causing channel narrowing and sandbar degradation. Other structures on the Niobrara River include several areas where pilings and rip-rap are being used to control the channel. These control structures were implemented to prevent the channel flows from affecting the dam and to keep the channel directed under various bridges (Norfolk News 1964). The construction of these dams and control structures has resulted in decreased peak flows and a change in the annual mean flow of the Niobrara River (Buchanan 1981).

The primary land use along the Niobrara River is farming and ranching. Cattle ranching is more predominate on the western half of the Niobrara River while farming is more prevalent further east along the river. The floodplain of the Niobrara River is often utilized for hay meadows while river water has been used extensively for irrigation purposes since 1938 (Buchanan 1981).

Access to the river is limited. Few roads parallel the river, and those that do are often access roads to private ranches. Bridges across the Niobrara River are between 8.1 and 17.7 km (5 and 11 miles) apart. Since bridges are the only points of regular access to the Niobrara River, the study area (Fig. 3) was separated into 11 reaches corresponding to the areas between bridges. Reach

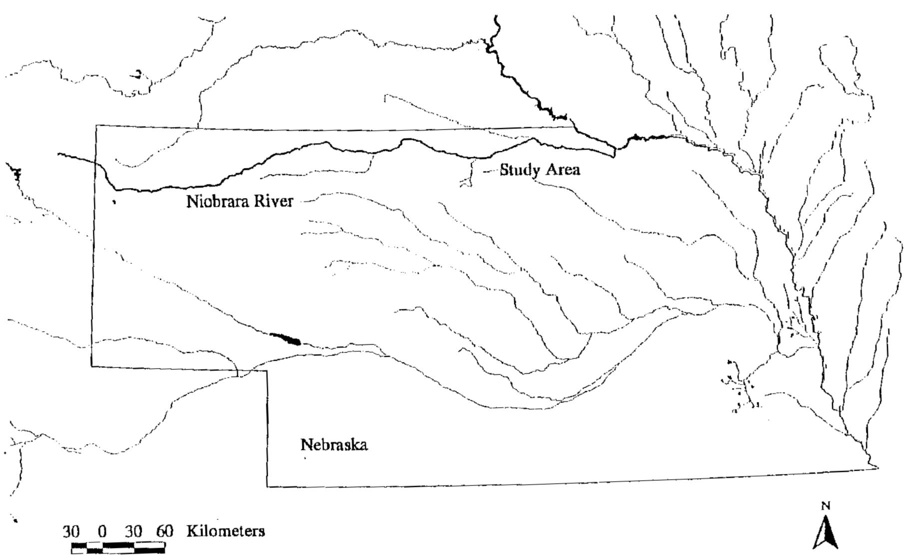

Figure 3. Study area on the Niobrara River from the Confluence with the Missouri River (R.M. 0.0) to the Norden Bridge (R.M. 120.0).

1 extended from the confluence with the Missouri River and the walking bridge over the Niobrara River upstream to Pischelville Bridge south of Verdel, NE; reach 2 extended from Pischelville Bridge to Redbird Bridge, south of Lynch, NE; reach 3 extended from the Redbird Bridge to the Highway 281 Bridge southeast of Spencer, NE; reach 4 extended from the Spencer Dam west to the Highway 11 Parshall Bridge south of Butte, NE; reach 5 extended from the Highway 11 bridge to the Grand Rapids Bridge south Naper, NE; reach 6 extended from the section west of the Grand Rapids Bridge to the Highway 137 Mariaville Bridge; reach 7 extended west from the Highway 137 Bridge to the Carns Bridge; reach 8 extended from the Carns Bridge to the Highway 7 Riverview Bridge; reach 9 extended from the Highway 7 Bridge to the Highway 183 Bassett Bridge south of Springview; reach 10 extended from the Highway 183 Bridge west to the Meadville Bridge; and reach 11 extended from the Meadville Bridge west to the Norden Bridge. Where the river could not be accessed by public bridges, cooperation from private landowners allowed access.

The 1996 study area included reaches 1 through 8 with reach 7 being monitored only for the first month of the field season due to lack of nesting piping plovers or least terns. These reaches totaled approximately 193.1 km (120 river miles (R.M.)). The 1996 International Piping Plover Census extended further west than the 1996 study area, adding reaches 9 through 11 to the census area. In 1997, the study area was reduced to reaches 2, 3, 5, and 6 or about 80.5-96.5 km (50-60 miles) to facilitate more intensive monitoring of selected habitat areas. The reaches with a history of high populations of nesting birds of both species were chosen for the 1997 field season study area.

METHODS

All adults of least terns and piping plovers were counted each year on the study area. In 1996, counts began on 17 May and continued through 13 August while in 1997, counts began on 12 May and continued through 14 August. Our counts coincided with the counts on the mainstem Missouri River system to prevent possible double counting of birds due to movements from river to river or from island to island after nest failure. During the 1996 field season, the International Piping Plover Census was conducted on the Niobrara River from 17-20 June from the Nordon Bridge east to the mouth of the Niobrara River.

Distribution of nesting birds along the Niobrara River was determined from surveys of each river reach on a 7-10 day cycle in 1996 and 1997. These original surveys were conducted to determine initial sandbar nesting site selection by terns and plovers. All islands, sandbars, and shorelines were surveyed and monitored from a canoe and/or by wading. Potential nesting sites were determined by observing territorial adults with a spotting scope or binoculars and by walking the island. Once breeding birds were known to have begun nesting, productivity monitoring started and consisted of surveying each sandbar every 7-21 days with up to 8 visits per sandbar.

The number of nests initiated, nest initiation dates, number of eggs laid, number of eggs hatched, nest fate (successful/unsuccessful), and reason for nest termination were determined for each colony nesting site. Once an individual nest was identified, it was marked with a numbered wooden tongue depressor (Smith 1987), placed approximately 1 m north of each nest bowl (Dirks 1990). The number of eggs per nest and their present incubation stage were recorded during each visit with the egg floatation technique developed by Hays and LeCroy (1971) as modified by Schwalbach (1988).

Nest initiation dates were either back calculated with incomplete clutches or calculated from estimated incubation dates for completed clutches. Hatching dates were approximated by adding 20 days to the estimated least tern nest initiation date and by adding 32 days to the estimated piping plover nest initiation date.

The nest status was also documented as either unknown, normal, abandoned, eggs missing, hatched, destroyed, or other. Nest fate was determined as either hatched, destroyed, abandoned, eggs non-viable, or nest fate unknown. Possible reasons (e.g., predation, flooding, etc.) for nest termination were also recorded. The number of eggs for either species that hatched, were addled or were destroyed was documented.

Average clutch size for least terns and piping plovers was calculated by dividing the total number of eggs found per year for each species by the total number of nests initiated. We assumed we found all the nests, therefore, nest success was calculated by dividing the number of nests hatched by the total number of nests initiated per species. Hatching success of eggs was calculated by dividing the number of eggs hatched by the total number of eggs laid by each species. Fledging success was calculated by dividing the number of number of chicks fledged for each species by the number of hatched eggs per species. Fledge ratio was calculated as number of chicks fledged per pair of adults for each species. Nest success, hatching success, and fledging success were converted to percentages by multiplying the numbers by 100. Nesting and fledging success were determined for the entire length of the study area.

The number of chicks fledged, date fledged, and possible reasons for any chick mortality were documented. Piping plover chicks 20+ days old and least tern chicks 15+ days old were considered fledged. Chick age was determined by size, general appearance, and degree of emergence of primary wing feathers as determined visually through binoculars. Monitoring of nesting islands continued until all chicks were estimated to be fledged or until the site was no longer occupied.

Various types of disturbance such as human, vehicle, or predator were recorded when evident at or around nesting sites. Predator evidence included the presence of tracks, scat, owl pellets, talon strike marks, and remains of chicks and adults. Destruction or disturbance of nests due to high or low river flows as well as damage from wind, rain, hail, etc., were also recorded when evident for each sandbar. Disturbance by biologists was kept to a minimum during all colony visits. Sandbars were not visited in extremely hot weather (> 32 C or 90°F), during rain, excessive wind (> 32 kph or 20 mph), and other adverse weather conditions to reduce the exposure of eggs and young to heat and cold extremes (Haig and Plissner 1993, Dirks 1990). Length of visits was kept to 30 minutes or less per colony. If the colony sandbar was exceptionally large, no more than 30 minutes was spent on each portion of the sandbar. The welfare of nests, chicks, and adults was deemed more important than following schedules or survey procedures. All monitoring, censussing, and nest surveys were conducted under state and federal permits in accordance with the guidelines for monitoring least terns and piping plovers.

Nest information for least terns and piping plovers was recorded on standardized nest record data cards supplied by the U.S. Army Corps of Engineers, Omaha District. Adult census data and chick data such as age and number of chicks were recorded for both species on standardized census data cards supplied by the U.S. Army Corps of Engineers, Omaha District.

RESULTS

Piping plovers totaled 107 in 1996 and 87 in 1997 and least terns totaled 321 in 1996 and 183 in 1997 along the Niobrara River (Table 1). Abundance of piping plovers and least terns were lower in 1997 than in 1996 because we surveyed only half the area monitored in 1996. Again, fewer river miles were monitored in 1996 to concentrate the monitoring to the areas holding the most birds of both species.

During 1996 and 1997, we found 543 nests (193 piping plovers; 350 least terns) on 53 colony sites (37 in 1996; 16 in 1997) (Table 2). Of these 53 colonies, 15 (28.3%) were used by only piping plovers, 2 (3.8%) by only terns, and 36 (67.9%) were used jointly by both species. The peak nest initiation period for piping plovers on the Niobrara River ranged from 1 - 26 June in 1996 and 1997, while the peak nest initiation period for least terns ranged from 3 - 25 June (Table 3).

A total of 1,603 eggs were found in the 543 nests initiated (703 piping plovers; 900 least terns) for 1996 and 1997 of which 731 (258 piping plovers; 473 least terns) occurred in successfully hatched nests for a hatching success of 45.6% (36.7% for piping plovers; 52.6% for least terns). Clutch size varied from 1.0 to 4.0 eggs/nest for piping plovers and from 1.0 to 3.0 eggs/nest for least terns. Average clutch size (eggs/nest) was 3.6 for piping plovers and 2.6 for least terns on the Niobrara River (Table 4).

Table 1. International piping plover and least tern census numbers for 1996 (River Miles 0.0 to 120.0) and partial census numbers for 1997 (River Miles 14.7 to 39.0 and 51.5 to 79.9) on the Niobrara River.

	ADULTS		CHICKS FLEDGED	
Year	**Piping Plover**	**Least Tern**	**Piping Plover**	**Least Tern**
1996	107	321	37	96
1997	87	183	55	79
Totals	*194*	*504*	*92*	*175*

Table 2. Colony sites used and numbers of nests initiated per site in 1996 and 1997 by nesting piping plovers and least terns on the Niobrara River.

		1996 NESTS		1997 NESTS	
Site	**River Mile**	**Plover**	**Tern**	**Plover**	**Tern**
101A	1.0	7	3	.	.
106A	1.8	4	15	.	.
105A	2.1	10	18	.	.
104A	7.6	3	21	.	.
103A	10.4	1	1	.	.
102A	10.8	1	3	.	.
205A	15.8	5	6	.	.
205B	16.3	.	.	1	4
204A	17.0	3	5	.	.
203B	17.4	.	.	5	17
203A	NA	0	1	.	.
202A/204B	24.0	3	8	2	6
202B	27.9	.	.	1	1
201A	28.0	6	5	.	.
201B	28.8	.	.	9	13
303A	30.0	2	7	.	.
302B	30.5	.	.	4	13
304A	30.6	1	4	.	.
302A	N.A.	1	.	.	.
303B	36.0	.	.	0	9
301A/B	37.7	2	9	1	2
403A	39.7	6	15	.	.
406A	42.7	1	.	.	.
405A	44.2	3	5	.	.
404A	44.4	2	6	.	.
401A	46.5	6	7	.	.
402A	N.A.	.	1	.	.
505B	51.7	.	.	15	9
504B	52.8	.	.	1	0
508A	53.7	5	8	.	.
507A	55.0	5	4	.	.
503B	55.2	.	.	1	0
501B	56.2	.	.	1	0
505A	58.3	5	11	.	.
503A	59.8	1	.	.	.
506A	59.0	1	.	.	.
502A	61.2	9	7	.	.
502B	61.7	.	.	13	33
501A	65.9	1	.	.	.
504A	N.A.	1	.	.	.
606A	66.9	9	13	.	.
603B	68.0	.	.	7	8
605A	71.2	3	1	.	.
604A	74.4	2	0	.	.
602B	75.3	.	.	5	18
603A	79.0	7	14	.	.
602A	79.5	1	.	.	.
601A/B	79.9	1	.	2	0
802A	90.0	6	19	.	.
801A	90.8	1	.	.	.
Total Nests[a]		*125*	*217*	*68*	*133*

[a] Yearly totals are not comparable because of study area reduction in 1997.

Table 3. Piping plover and least tern nest initiation dates, 1 May - 30 July 1996 and 1997, (including Julian dates) on the Niobrara River, NE.

Date	1996 Julian Date	1997 Julian Date	PIPING PLOVER 1996	PIPING PLOVER 1997	LEAST TERN 1996	LEAST TERN 1997
May 1-7	122-128	121-127				
May 8-14	129-135	128-134	2	1		
May 15-21	136-142	135-141	0	4		
May 22-28	143-149	142-148	4	7		
May 29-Jun 4	150-156	149-155	20	18	3	17
Jun 5-11	157-163	156-162	25	13	75	26
Jun 12-18	164-170	163-169	37	16	58	12
Jun 19-25	171-177	170-176	16	5	45	5
Jun 26-Jul 2	178-184	177-183	15	4	5	2
Jul 3-9	185-191	184-190	4		11	1
Jul 10-16	192-198	191-197		3	12	2
Jul 17-23	199-205	198-204			4	1
Jul 24-30	206-212	205-211				
Total Nests[a]			*68*	*27*	*133*	*66*

[a] Yearly totals are not comparable because of study area reduction in 1997.

Table 4. Comparison of piping plovers and least terns average clutch size, nest, hatching, and fledging success between the Niobrara and Missouri River in 1996 and 1997.

	PIPING PLOVER 1996	PIPING PLOVER 1997	PIPING PLOVER Combined	LEAST TERN 1996	LEAST TERN 1997	LEAST TERN Combined
Average Clutch Size[a]						
Niobrara River	3.58	3.75	3.64	2.51	2.68	2.57
Missouri River	2.90	3.79	3.21	1.93	2.40	2.16
Gavins Point Reach	2.43	3.74	3.05	1.89	2.55	2.27
Nest Success (%)[bc]						
Niobrara River	32.00	39.70	34.71	53.50	49.60	52.00
Missouri River	18.00	45.70	27.78	13.10	50.00	31.49
Gavins Point Reach	00.00	58.06	27.27	5.83	52.86	32.92
Hatching Success (%)[d]						
Niobrara River	35.30	39.20	36.70	54.60	49.40	52.55
Missouri River	19.41	43.77	29.56	13.97	51.27	34.57
Gavins Point Reach	00.00	54.31	31.34	4.62	55.18	37.32
Fledgling Success (%)[e]						
Niobrara River	23.40	55.00	35.66	32.30	44.90	37.00
Missouri River	51.39	43.97	46.81	61.84	45.93	48.81
Gavins Point Reach	00.00	31.75	31.75	122.22	50.25	53.40

[a] Gavins Point Reach is a combination of the Lewis and Clark lake and Missouri River below the dam and does not include captive rearing data.
[b] Total number of nests hatched/total number of nests initiated.
[c] Nest success on the Missouri River and Gavins Point Reach was the result of multiple management techniques i.e. caging of nests, no management was done on the Niobrara River.
[d] Percent of eggs hatched per 100 eggs per species.
[e] Percent of chicks fledged per 100 eggs per species

Of the 543 nests initiated in 1996 and 1997, 249 hatched (67 piping plovers; 182 least terns) for an overall nest success of 45.9% (34.7% for piping plovers; 52.0% for least terns). Of the 543 nests initiated in 1996 and 1997, a total of 294 (126 piping plovers; 168 least terns) did not hatch. The leading causes of known nest failures were predation, flooding, and sandbar erosion (Table 5). During 1996 and 1997, 267 chicks (92 piping plover; 175 least tern) (Table 1) were fledged from 731 eggs for a fledgling success of 36.5% (35.7% for piping plovers; 37.0% for least terns) (Table 4).

In comparison, at the Gavins Point reach, the reach of the Missouri River monitored by the U.S. Army Corps of Engineers nearest to the Niobrara River), there were 28 piping plover adults and 110 least tern adults during 1996, and 54 piping plover adults and 175 least tern adults on the Gavins Point reach during 1997 (Table 4). There were 138 nests found in 1996 (35 piping plover nests and 103 least tern nests). In 1997, 171 nests were found (31piping plover nests and 140 least tern nests). A total of 280 eggs were found in 1996 on the Gavins Point reach (85 piping plovers and 195 least terns) of which 9 occurred in successfully hatched nests for a hatching success of 3.21% (0.00% for piping plover nests and 4.62% for least tern nests). A total of 473 eggs were found in 1997 on the Gavins Point river reach (116 of piping plovers and 357 of least terns) of which 260 occurred in successfully hatched nests for a hatching success of 54.97% (54.31% for piping plover nests and 55.187% for least tern nests). Average clutch size in 1996 and 1997, respectively, varied from 2.43 - 3.74 on the Gavins Point reach for piping plovers and from 1.89 - 2.55 on the Gavins Point reach for least terns (Table 4). Of the 309 nests initiated in 1996 and 1997, 98 hatched (18 piping plovers and 80 least terns) for overall nest suc-

Table 5. Least tern and piping plover nest fates along the Niobrara River in Nebraska during 1996 and 1997.

	PIPING PLOVER		LEAST TERN	
	1996	1997	1996	1997
Total Nests Found	125	68	217	133
Nests with Known Fate	74	37	145	83
No. Hatched	40	27	116	66
No. Destroyed or Abandoned	34	10	29	17
Cause of Destruction[a]				
Predator	17	0	15	1
Flooding	4	3	0	3
Weather	0	0	1	1
Sandbar Erosion	6	1	12	6
Fate Unknown	51	31	72	50

[a] Only major causes are represented in table.

cess of 31.74 % (27.27 % piping plovers and 32.92 % least terns). In 1996 and 1997, 130 chicks total fledged on the 110 least tern chicks) from 269 eggs hatched.

DISCUSSION

Piping plover nest initiation normally occurs from late May to early June (Lingle 1988, Smith 1987). Schwalbach (1988) reported a median nest initiation dates of 20 June 1986 and 1 June 1987; the later date was a result of a high water year on the Missouri River. Nest initiations have been reported for interior piping plovers as early as 3 May to as late as 22 July (Faanes 1983, Lingle 1988). Least terns typically began nest initiations at the end of May (USFWS 1990) although median nest initiation dates of 23 June 1987 and 7 July 1986 were also found (Schwalbach 1988). Interior least tern nest initiation dates can range from 15 May to 24 June and even later into July. Our median nest initiation findings on the Niobrara River generally correspond with the findings of other researchers for piping plovers and least terns; however, terns on the Niobrara River nested earlier than reported by Schwalbach (1988) for the Missouri River. For the Niobrara River, the least tern median nest initiation date was 14 June for 1996 and 9 June for 1997 whereas piping plovers had a median nest initiation date of 14 June in 1996 and 7 June in 1997.

Piping plovers typically initiate nests earlier in the summer than least terns; however, terns are more synchronous nesters than plovers. A large flood peak at the end of May 1996 destroyed all active nests and caused plovers to begin renesting at approximately the same time as terns were beginning their nesting. Due to this short flood spike in 1996, piping plover nest initiation was later, resulting in least tern chicks hatching before piping plovers. This affected the time available for successfully hatched chicks to grow and fledge and for subsequent renesting attempts. During 1997, a more normal year with respect to nest initiations, piping plovers initiated their first nests before least terns, and chicks of both species began hatching out during the same time frame.

Other researchers have reported average clutch sizes of 3.5 to 3.7 eggs/nest for piping plovers (Lingle 1988, Prindiville-Gaines and Ryan 1988) and of 2.3 to 2.6 eggs/nest for least terns (Dryer and Dryer 1985, Niemi and Davis 1979, Smith and Renken 1991). Average clutch size for both years combined both species were almost identical to the findings of other researchers. Success rates of piping plovers nests has been reported between 25 - 83.5% (Dirks 1990, Kruse 1993, Patterson et al. 1991) while reported least tern nest success rates varied between 36 - 69% (Dirks 1990, Kruse 1993, Renken and Smith 1993). Our nest success rates for known fate nests of both terns and plovers for 1996 and 1997 (54% piping plovers 1996, 73% piping plovers 1997; 80% least terns 1996 and 1997) equaled or exceeded nest success rates reported in other studies.

Most piping plover and least tern nests are destroyed by predators (Dirks 1990, Kruse 1993) or by inundation (Lingle 1993). Patterson et al. (1991) found that 91% of nest losses were attributable to predation while Dryer and Dryer (1985) determined that the two major threats to least tern reproduction were disturbance and inundation. Our findings on nest losses along the Niobrara River agree with these earlier studies; however, on the Niobrara River, sandbar erosion was another factor that resulted in increased nest losses. Large islands continuously eroded away in the later part of the summer due to decreased flows and spreading of the river channel, resulting in erosion of nest sites and reduced the amount of habitat available on which chicks could evade predators or forage.

Fledgling success of least terns and piping plovers can vary from 13% to 88% (Dirks 1990, Goossen 1990). The Niobrara River was approximately midpoint in this range with 36 - 37%. This lower rate may be due mainly to predation by avian predators, such as great horned owl *(Bubo virginianus)* predation, which dramatically increased during the brood-rearing period. Other avian and mammalian predators including great blue herons *(Ardea herodias)* and mink *(Mustela vison)* also contributed to the large losses of adults, chicks, and nests (Kruse 1993). Flooding and sandbar erosion also contributed to chick loss which reduced fledgling success.

Comparing the Gavins Point Reach and the Niobrara River can be very useful considering that they are located so near one another. The Gavins Point reach was highly managed during the two study years. Almost all piping plover nests were caged and numerous nesting islands were roped off to restrict public access to the nesting locations. The Niobrara River had no management on the nests nor was access restricted from any of the nesting sites. During 1996, the Niobrara River had larger clutches overall for piping plovers and for least terns. The Niobrara River supported much higher nest success during the 1996 nesting season for both least terns and piping plovers than the Gavins Point reach as well. In 1997, though the Gavins Point reach had higher nest success than the Niobrara River but the difference between the success rates was minimal. This trend held true for hatching success and for fledgling success as well except for an odd occurrence in 1996 where fledgling success for least terns on the Gavins Point reach was over 100 percent. This was probably caused by a nest hatching that was not identified during the surveys but yet the fledged young were found. These results may have been caused by the higher than normal flows that plagued the Missouri River and the Gavins Point reach during the nesting season of 1996. Piping plovers and least terns that normally nested on the Missouri River may have chosen to nest on the Niobrara River instead due to these higher water conditions on the Missouri River. During the 1997 nesting season, the water levels were more moderate although still high on the Missouri and may have encouraged birds to return to their normal nesting areas.

Based on our results, piping plovers and least terns were able to nest and rear young fairly successfully along the Niobrara River in 1996 and 1997. These findings suggest the apparent increases in population status since the 1981 census was perhaps due to recruitment from the nesting birds and not solely by birds displaced from other areas of the northern Great Plains. However, the high flows of the Missouri River during 1996 and 1997 probably contributed a number of birds to the Niobrara River population. A survey should be completed during a year of good habitat on the Missouri River to assess what portion of the Niobrara River populations were annually linked to the Niobrara River and what portion were transferees from the Missouri river or other parts of their range.

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BREEDING BIRD ABUNDANCE AND HABITAT ON TWO LIVESTOCK GRAZING REGIMES IN NORTH DAKOTA

Natoma A. Buskness
U.S. Fish and Wildlife Service—
Long Lake National Wildlife Refuge Complex
Moffit, ND 58560

Robert K. Murphy
U.S. Fish and Wildlife Service—
Des Lacs National Wildlife Refuge Complex
Kenmare, ND 58746

Kenneth F. Higgins
U.S. Geological Survey/BRD
South Dakota Cooperative Fish and Wildlife Research Unit
South Dakota State University
Brookings, South Dakota 57007

Jonathan Jenks
Wildlife and Fisheries Sciences
South Dakota State University
Brookings, South Dakota 57007

ABSTRACT

To help sustain prairie wildlife habitat on privately owned lands in North Dakota, prescribed rotational grazing (RG) systems have been implemented as part of the Prairie Pothole Joint Venture (PPJV) of the North American Waterfowl Management Plan. However, impacts of these systems on nongame breeding birds are unmeasured. During 1996 and 1997 we assessed the relative abundance, species richness, and habitat of breeding birds especially passerines on five PPJV-prescribed RG pastures in central and northwestern North Dakota. Each RG pasture was paired with a nearby traditional, continuous-grazed (CG) pasture for comparison. Using 5-minute point counts on 100-m radius plots to survey breeding birds, we recorded 30 species in 1996 and 29 species in 1997. We detected no differences in relative abundance or species richness between grazing regimes in 1996 ($P = 0.29$ and 0.58), but relative abundance and species richness were greater on RG pastures than on CG pastures in 1997 ($P = 0.08$ and 0.04), a relatively dry year. A group of five species (savannah sparrow *[Passerculus sandwichensis]*, grasshopper sparrow *[Ammodramus savannarum]*, western meadowlark *[Sturnella neglecta],* bobolink *[Dolichonyx oryzivorus],* Baird's sparrow *[Ammodramus bairdii]*) considered sensitive to heavy grazing in previous studies had a higher collective mean abundance on RG than on CG in 1997 ($\bar{x}$ = 4.29 and 2.75 breeding pairs/point count, P = 0.03). Litter depth also was greater on RG than on CG in 1997 ($\bar{x}$= 2.4 and 1.4 cm, P = 0.04). PPJV grazing systems help conserve native prairie by improving its economic viability without diminishing habitat values for grassland passerines, and in dry years may enhance breeding bird habitat compared to that on traditional grazing systems especially for grazing-sensitive species such as bobolink and Baird's sparrow.

Keywords

Conservation programs, grassland birds, Great Plains, habitat suitability, livestock grazing, mixed-grass prairie, North Dakota, range management

INTRODUCTION

Grassland bird species are demonstrating widespread, severe population declines (Knopf 1994, Samson and Knopf 1994) generally due to conversion of grassland to cropland (Johnson and Schwartz 1993). Some grassland bird species may be attracted to fragmented habitats that act as population sinks due to relatively high rates of nest parasitism and predation (Ball et al. 1994). Large, contiguous grassland tracts with minimal disturbance during the breeding season generally benefit grassland bird populations compared to smaller, scattered grassland tracts (Herkert 1994). The northern Great Plains includes some of the most extensive tracts of native prairie left in North America (Samson and Knopf 1994). The primary land use on these grasslands is cattle grazing, usually for continuous (2- to 6-month) grazing periods. Specialized rotation grazing (RG) systems can improve livestock production and range health (Sedivec and Barker 1991), and thus increase the economic viability of native prairie and discourage its conversion to cropland. To implement RG on privately owned lands, cost-sharing of fencing and water source development has been available to ranchers through the Prairie Pothole Joint Venture (PPJV) of The North American Waterfowl Management Plan since 1987. Ranchers follow a specific RG prescription for 10 years, which includes delayed turnout dates and grazing periods of about 2.5 weeks. There are no published reports, however, on wildlife abundance on these PPJV grazing systems. Our objective was to evaluate the relative abundance, species richness, and habitat of grassland passerines on RG systems implemented through the PPJV, and compare to traditional continuous grazing (CG) regimes.

STUDY AREA AND METHODS

Study Sites

We studied a PPJV-prescribed RG system at each of three sites in western Stutsman County (47° 10' N, 99° 20' W) and at each of two sites in northern

Mountrail County (48° 20' N, 102° 20' W), in central and northwestern North Dakota, respectively. Study sites were within the Missouri Coteau, a glacial moraine covered by rolling hills and numerous wetlands (Bluemle 1991). Vegetation of pastures was northern mixed-grass prairie (Whitman and Wali 1975) composed mainly of junegrass *(Koeleria pyramidata),* green needlegrass *(Stipa viridula),* needle-and-thread *(S. comata),* blue grama *(Bouteloua gracilis),* western wheatgrass *(Agropyron smithii),* Kentucky bluegrass *(Poa pratensis),* western snowberry *(Symphoricarpos occidentalis),* and more than 60 forb species especially Fabaceae and Asteraceae (Meyer 1985, Hegstad 1973). Annual precipitation normally averages about 38 cm (Mountrail County) to 45 cm (Stutsman County), but spring precipitation was below average in 1997 especially in Mountrail County (8 cm total April-June precipitation, compared to 16 cm average; National Oceanic and Atmospheric Administration 1997).

We selected RG pastures that had been implemented through the PPJV at least 3 years before our study. RG pastures were at least 259 ha each (Table 1) and were divided into three to eight cells through which cattle were rotated twice during the grazing season. Grazing periods were 14-21 days/cell, with 45-60 days of rest between first and second grazing periods. Turnout was delayed until after 25 May and the grazing season ended in October or early November. Grazing rotation sequences were advanced one cell each year, so that the last cell grazed one year would be rested 1-2 months before being grazed the following year (Sedivec and Barker 1991).

Each RG pasture was paired with a nearby (5-10 km) CG pasture of similar size, to compare bird abundance and habitat on areas that represented RG pastures before PPJV grazing prescriptions were initiated. A treatment-control replicate consisted of one RG pasture and one CG pasture with similar soils, wetland area, topography, and surrounding land use (mainly native rangeland, dryland farming for small grains, and tame hayland). Grazing practices on CG pastures were quite variable; stocking rates generally were slightly higher and

Table 1. Characteristics of rotation-grazed pastures studied in 1996 and 1997 in western Stutsman (S) and northern Mountrail (M) counties in central and northwestern North Dakota.

Pasture	Year initiated	No. cow-calf pairs	Grazing season	No. of cells	Total area (ha)	Stocking rate[1]
S 1	1990	100	June 1–October 21	5	324	2.2
S 2	1992	190	May 26–November 2	8	518	2.3
S 3	1991	150	June 1–November 4	5	388	2.5
M 1	1993	70	June 15–September 30	4	329	0.9
M 2	1992	80	June 1–November 10	5	379	0.6

[1] Stocking rate equals the number of Animal Unit Months/ha, based on 1.25 Animal Units/cow-calf pair.

Table 2. Characteristics of rotation-grazed pastures studied in 1996 and 1997 in western Stutsman (S) and northern Mountrail (M) counties in central and northwestern North Dakota.

Pasture	No. cow-calf pairs	Grazing season	Total area (ha)	Stocking rate[1]
S 1	125	May 20–November 1	324	2.6
S 2	100	May 15–November 1	259	2.7
S 3 (1996)	80	June 1–November 1	259	1.9
S 3 (1997)	75	May 20–November 1	194	2.6
M 1	200	June 1–August 1	291	1.7
M 2 (1996)	125	June 1–July 15	259	0.9
M 2 (1997)	100	June 1–August 15	283	1.1

[1] Stocking rate equals the number of Animal Unit Months/ha, based on 1.25 Animal Units/cow-calf pair.

livestock turnout dates were earlier on CG pastures than on RG pastures (Table 2). Three CG pastures were studied both years, but locations of the other two CG pastures were changed between years due to altered grazing plans by ranchers.

Bird Data Collection

We measured bird abundance and species richness by using 5-min point count surveys on 100-m radius plots (Hutto et al. 1986, Ralph et al. 1993). Ten to 12 survey points were selected on each pasture, with two or three points per cell on RG pastures so overall effects of RG were assessed. Points were selected by using a random systematic grid and were plotted on aerial photos (1:7920). Points were at least 250 m apart, adequate for statistical independence (Hutto et al. 1986). To isolate grazing effects on upland native prairie, we included only points that were at least 150 m from developed roads, tree clumps, wooded draws, or nonpasture habitats, and at least 50 m from pasture boundaries. Some 100-m radius plots contained small amounts (≤ 5%) of seasonally or semi-permanently flooded wetland zones as defined by Cowardin et al. (1979).

Because bird sampling can vary among individuals, observers trained together prior to each field season to ensure consistent data collection (Emlen and DeJong 1992), and the same observer was used for each RG-CG replicate. Point counts were conducted from one-half hour before sunrise until 0800 hrs CST. Counts were not conducted on mornings with heavy fog or rain, or with winds > 25 kmph (Ralph et al. 1993). Each point was sampled twice each year during 15 May-30 June. Only singing males or pairs were recorded, with the

Table 3. Breeding bird species detected at 100-m radius point count plots on five pairs of rotation-grazed and continuous-grazed pastures in central and northwestern North Dakota.

Species	**Scientific name**	**% frequency[1]**	
		1996	**1997**
American goldfinch	*Carduelis tristis*	5.3	2.4
Baird's sparrow	*Ammodramus bairdii*	27.6	21.3
Bobolink	*Dolichonyx oryzivorus*	32.1	13.9
Brewer's blackbird	*Euphagus cyanocephalus*	12.5	7.3
Brown-headed cowbird	*Molothrus ater*	63.3	84.4
Brown thrasher	*Toxostoma rufum*	0.8	4.9
Chestnut-collared longspur	*Calcarius ornatus*	30.3	29.5
Clay-colored sparrow	*Spizella pallida*	75.8	79.5
Common grackle	*Quiscalus quiscula*	0	1.6
Common snipe	*Gallinago gallinago*	7.1	8.1
Common yellowthroat	*Geothlypis trichas*	3.5	5.7
Eastern kingbird	*Tyrannus tyrannus*	33.9	25.4
Grasshopper sparrow	*Ammodramus savannarum*	74.1	65.6
Horned lark	*Eremophilia alpestris*	6.2	13.9
Killdeer	*Charadrius vociferus*	3.6	3.2
LeConte's sparrow	*Ammodramus leconteii*	16.9	11.5
Mourning dove	*Zenaida macroura*	2.6	0
Marbled godwit	*Limosa fedoa*	1.7	3.2
Nelson's sharp-tailed sparrow	*Ammodramus nelsoni*	0.8	0
Red-winged blackbird	*Agelaius phoeniceus*	1.7	13.1
Savannah sparrow	*Passerculus sandwichensis*	78.6	73.8
Sedge wren	*Cistothorus platensis*	9.8	2.4
Song sparrow	*Melospiza melodia*	1.7	1.6
Sprague's pipit	*Anthus spragueii*	10.7	5.7
Upland sandpiper	*Bartramia longicauda*	24.1	11.4
Vesper sparrow	*Pooecetes gramineus*	14.2	18.8
Western kingbird	*Tyrannus verticalis*	2.6	3.2
Western meadowlark	*Sturnella neglecta*	64.2	47.5
Willet	*Catoptrophorus semipalmatus*	12.5	7.4
Willow flycatcher	*Empidonax trailii*	10.7	7.4
Yellow warbler	*Dendroica petechia*	10.7	13.9

[1] Percentage of 100-m radius point count plots at which species was detected.

exception of brown-headed cowbird, for which the total number of birds was recorded (note: scientific names of bird species are in Table 3).

Habitat Data Collection

We measured vegetation composition and structure in point count plots in late June and early July. In each plot we established two subsample sites at random distances from the point (i.e., plot center), in each of four cardinal directions (i.e., eight total subsamples per plot). We determined litter depth at each subsample site by measuring the height (to nearest cm) of dead vegetation that formed a mat-like layer continuous to the ground (Madden et al. 2000). At each subsample site we used a Robel pole to assess vegetation height-density (i.e., visual obstruction; Robel et al. 1970) by reading the pole where it was obscured by vegetation (to nearest 0.5 dm), from each of four cardinal directions and from a height of 1 m and a distance of 4 m. We also estimated the percentage areal cover of grasses, forbs, and bare ground (Daubenmire 1959) within 0.5 m of the Robel pole.

Data Analyses

Relative abundance was expressed as the mean number of indicated breeding bird pairs per point count plot for each species, based on detections of singing males or obvious breeding pairs. For each species at each point, we used whichever number of detections was greater from one of two counts conducted. Frequency was the percentage of plots at which a bird species was detected. Species richness was the mean number of bird species detected per plot.

Our data were normally distributed. We used an independent sample t-test to investigate differences in abundance and species richness between RG and CG pastures. Paired t-tests were used to assess differences in abundance of individual species between RG and CG pastures. We considered only common passerine species for this comparison, i.e., those that occurred at >20% of points at least 1 year. Because comparisons of individual passerine species were conducted simultaneously, the alpha level (0.1) was corrected by dividing by the number of tests (nine), yielding an alpha of 0.01 (Rice 1990). Five common passerine species (grasshopper sparrow, savannah sparrow, Baird's sparrow, western meadowlark, bobolink) are considered sensitive to heavy grazing in northern mixed-grass prairie (Owens and

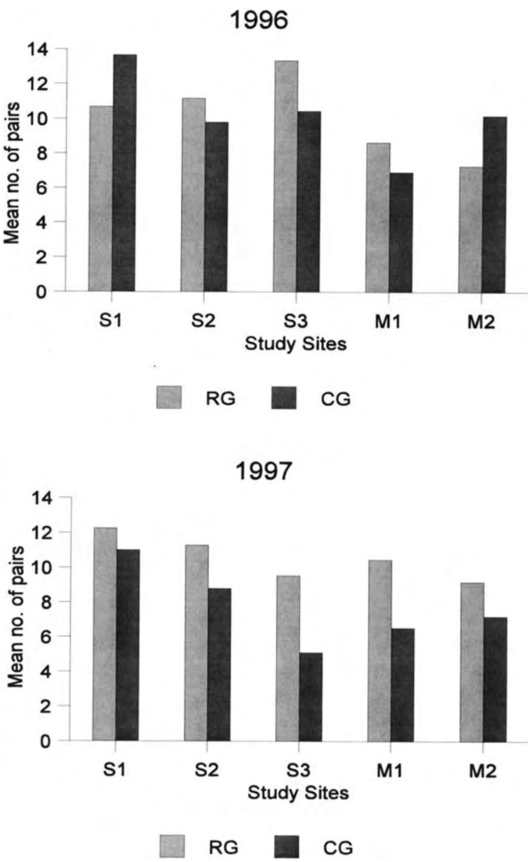

Figure 1. Overall relative abundance of breeding birds based on the mean number of indicated pairs detected per 100-m radius plot for five pairs of rotation-grazed (RG) and continuous-grazed (CG) pastures in central and northwestern North Dakota, 1996 and 1997.

Myres 1973, Kantrud 1981, Kantrud and Kologiski 1982). We used an independent sample t-test to assess differences in relative abundance of this group between grazing regimes. Last, paired t-tests were used to assess differences in vegetation between RG and CG pastures. Differences in areal cover classes (grass, forb, bare ground) were simultaneously assessed, so the alpha level was corrected (0.1/3 = 0.03; Rice 1990).

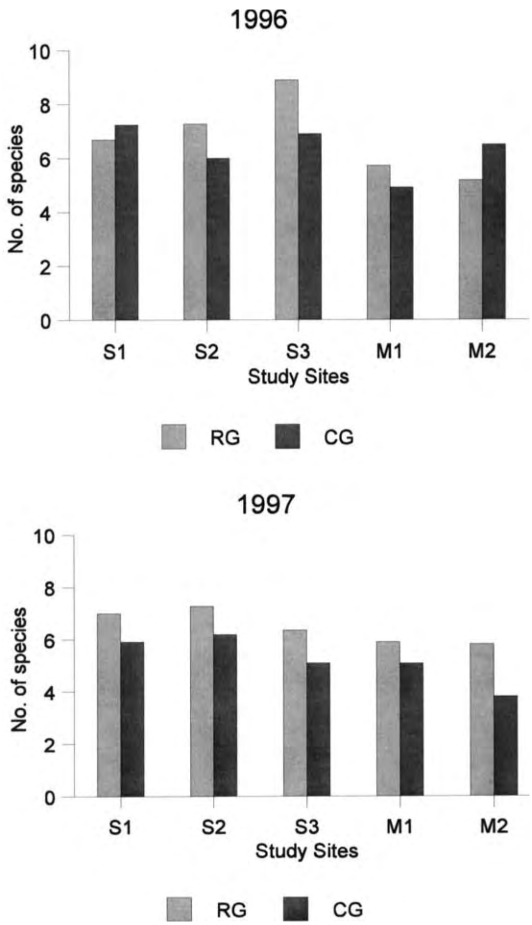

Figure 2. Species richness in terms of the mean number of species detected per 100-m radius plot for five pairs of rotation-grazed (RG) and continuous-grazed (CG) pastures in central and northwestern North Dakota,1996 and 1997.

RESULTS

We recorded 30 breeding bird species in 1996 and 29 species in 1997 (Table 3). Clay-colored sparrow, savannah sparrow, grasshopper sparrow, and brown-headed cowbird were the most abundant species both years. Other common passerine species (>20% frequency) included Baird's sparrow, bobolink (1996 only), chestnut-collared longspur, eastern kingbird, and western meadowlark. A shorebird, upland sandpiper, was common in 1996.

We detected no difference in overall relative abundance or species richness between RG and CG pastures in 1996 (P = 0.29; P = 0.58; Figs. 1 and 2). In 1997, however, relative abundance and species richness were greater on RG than on CG pastures (P = 0.08; P = 0.04). No differences in individual species abundance were detected between RG and CG pastures for any of the nine common passerine species in both years (Table 4). For five grazing-sensitive species combined, we detected no difference in relative abundance between RG and CG pastures in 1996 ($\overline{x}$ = 4.45 and 3.86 pairs/count, P = 0.62), but did in 1997 ($\overline{x}$ = 4.29 and 2.75, P = 0.03).

Table 4. Relative abundance of common passerine birds based on the mean number of indicated breeding pairs detected per 100-m radius point count[1] for five pairs of rotation-grazed and continuous-grazed pastures in central and northwestern North Dakota.

	1996					1997				
	ROTATION		CONTINUOUS			ROTATION		CONTINUOUS		
Bird species	Mean	SE	Mean	SE	P[2]	Mean	SE	Mean	SE	P
Eastern kingbird	0.42	0.14	0.33	0.09	0.50	0.45	1.00	0.12	0.63	0.03
Clay-colored sparrow	1.44	0.27	1.53	0.25	0.48	1.75	0.32	1.41	0.42	0.56
Savannah sparrow	1.40	0.25	1.27	0.28	0.76	1.23	0.27	0.94	0.11	0.28
Baird's sparrow	0.46	0.32	0.67	0.50	0.64	0.27	0.19	0.30	0.18	0.93
Grasshopper sparrow	1.19	0.17	1.04	0.21	0.60	1.68	0.39	0.88	0.30	0.14
Chestnut-collared longspur	0.49	0.26	0.53	0.30	0.78	0.45	0.39	0.79	0.62	0.08
Bobolink	0.65	0.24	0.24	0.06	0.21	0.34	0.23	0.21	0.04	0.36
Brown-headed cowbird	1.56	0.30	2.15	0.55	0.35	1.93	0.24	2.36	0.30	0.28
Western meadowlark	0.75	0.08	0.64	0.13	0.67	0.77	0.24	0.42	0.08	0.09

[1] For brown-head cowbird, means are based on total numbers of males and females detected.
[2] Probability level associated with result of paired t-test. For nine simultaneous tests of species abundance, P would be significant at 0.01 when alpha = 0.1 (0.1/9 = 0.01; Rice 1990).

On both RG and CG pastures, grass cover comprised more than one-half of total canopy coverage in 1996 but less than one-third of canopy coverage in 1997 (Table 5). However, we detected no differences in the general composition of grassland habitat between RG and CG pastures. No differences in vegetation structure were detected, except litter depth was greater on RG pastures than on CG pastures in 1997.

DISCUSSION

Abundances of individual bird species did not differ between specialized RG pastures and nearby CG pastures, but in a relatively dry year the collective abundance of five grazing-sensitive species was greater in RG pastures as was the overall abundance and species richness of breeding birds. Our sample size was low (five treatment-control pairs, 2 years); more extensive study may have uncovered differences we were unable to detect due to low statistical power. Furthermore, RG systems are inherently variable in design and practice. Because cattle rotate through consecutive cells during the grazing season, several types of vegetation structure exist at any given time. This spatial and temporal diversity in structure attracts an array of grassland bird species, but it also produces relatively high statistical variance in associated biological data, making it difficult to characterize bird abundance and habitat and to test for differences between grazing system regimes. Regardless, our data suggest that specialized RG systems have been implemented on privately-owned pastures in North Dakota without reducing the abundance and variety of breeding birds, and in dry years may create more attractive habitat for certain species than would be available on traditional, CG pastures.

Table 5. General composition and structure of vegetation on five pairs of rotation-grazed and continuous-grazed pastures, based on measurements within 100-m radius count plots.

	1996					1997				
	ROTATION		CONTINUOUS			ROTATION		CONTINUOUS		
Vegetation variable	Mean	SE	Mean	SE	P[2]	Mean	SE	Mean	SE	P
% grass cover	57.6	2.3	57.7	2.6	0.97	31.1	3.6	28.8	2.9	0.28
% forb cover	16.3	2.6	20.7	2.0	0.21	11.8	2.1	14.8	2.2	0.30
% bare ground cover	1.6	0.7	2.3	0.6	0.38	5.5	1.7	9.6	2.3	0.06
Litter depth (cm)	2.6	0.6	2.5	0.5	0.84	2.4	0.5	1.4	0.3	0.04
Visual obstruction (dm)	1.1	0.1	1.1	0.1	0.51	0.6	0.1	0.5	0.1	0.37

[1] Probability level associated with result of paired t-test. For three simultaneous tests of percentage cover (grass, forb, bare ground), P would be significant when alpha = 0.1 (0.1/3 = 0.03), using Bonferonni's correction (Rice, 1990).

Some evidence from other regions suggests certain RG prescriptions can negatively affect nesting birds, although it is difficult to generalize because many bird species respond differently to grazing in different grassland types (Saab et al. 1995). In southwestern Wisconsin, the survival of artificial nests was reduced under certain types of short-duration grazing (Paine et al. 1996), although nesting densities and vegetation height-density generally were greater on delayed, RG systems (Paine et al. 1997). Reduced nesting may be associated with the presence of livestock, as it was for upland sandpipers in North Dakota (Bowen and Kruse 1993). This generally has not been evident among grassland passerines, however (Saab et al. 1995). The structural diversity of grassland bird habitat may be reduced in RG systems because grazing pressure tends to be relatively uniform within a cell (Sedivec and Barker 1991), but areas should be available among cells within RG systems to meet various breeding season requirements such as foraging or locating suitable nest sites.

Overall passerine abundance and species richness were greater on RG pastures in 1 of 2 years of our study, possibly due to contrasts in precipitation and temperature between years. In 1997, spring precipitation was below average and the mean April temperature was below freezing (-0.1°C), which resulted in a late spring and slower plant growth. Abundance and distribution of grassland birds tend to be strongly influenced by interactions with vegetation and precipitation (Zimmerman 1992). Another factor that may have contributed to the contrast in bird abundance and richness was that turnout dates on several CG pastures were in early May both years, compared to a late May or early June turnout on RG pastures. Greater litter depth on RG pastures in 1997 probably related to this precipitation-grazing interaction. Several grassland passerine species reach their highest breeding season occurrences or abundances in northern mixed-grass prairie when moderate amounts of plant litter are available (Madden et al. 2000). For example, Baird's sparrows in northwestern North Dakota occupied areas with an average of 3.7 cm of litter (in Madden et al. 2000). This may be why the collective abundance of five grazing-sensitive species was greater on RG pastures than on CG pastures in 1997. Litter depth increased more on a twice-over RG pasture than on examples of other grazing systems during a 7-year study on a university research station in south central North Dakota (Messmer 1990). Relatively little plant litter accumulates under CG or season-long grazing, which is important for killdeer, horned lark, and chestnut-collared longspur, species that prefer short, sparse vegetation (Stewart 1975).

We found relatively high breeding abundances and intact assemblages of native passerine birds on PPJV grazing systems. Other than eastern kingbird, all passerine species that were common on RG and CG pastures were among those Stewart (1975:25) considered characteristic of upland northern mixed-grass prairie (excludes common yellowthroat and red-winged blackbird, which mainly are wetland-associated in the state [Stewart 1975]). Horned lark, Sprague's pipit, and vesper sparrow encompass the other characteristic mixed-grass passerines, and each of these were fairly common (10-20% frequency) at least 1 year of our study. Population trends of eight of these grassland-dependent passerine species, including two species endemic to northern mixed-grass prairie (Baird's sparrow and Sprague's pipit), appear to be declining (Sauer et al. 2000); most of these species are considered Species of Conservation Concern (U.S. Fish and Wildlife Service 2001). Clearly, PPJV grazing systems can play a role in helping conserve some of the most critically important breeding habitats for North American grassland birds.

Our data suggest that the abundance and species diversity of breeding passerine birds in northern mixed-grass prairie probably are not diminished after a twice-over RG prescription with a delayed turnout date is implemented in pastures formerly managed under more traditional grazing approaches. Instead, the overall abundance and diversity of passerines may be greater in dry years, especially among species sensitive to heavy grazing such as bobolink and Baird's sparrow. By helping sustain livelihoods of ranching families, specialized RG systems can help conserve extensive tracts of privately-owned native prairie for indigenous wildlife in northern mixed-grass prairie. Land managers who want to manage holistically at broad, landscape-levels for a greater diversity of bird species should continue to include specialized RG systems among their suite of tools for cooperative work on privately-owned lands.

ACKNOWLEDGMENTS

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THE GREAT PLAINS AS A NATURAL REGION: THE BASICS

Richard A. Peterson
Wewela, SD 57578

ABSTRACT

The need for this paper became apparent during a review of articles in the *Prairie Naturalist*(1986-1995), where the term, Great Plains, was used to describe many different areas/regions, most of which were outside of established natural boundaries. The Rocky Mountains have long been the agreed upon western boundary of the Great Plains and the primary factor in the development of the Great Plains; indeed, without the uplift of the Rocky Mountains there would not be a Great Plains region. Consistent natural boundaries for the Great Plains, were in general use after 1931, when Nevin M. Fenneman described the region in *Physiography of the Western United States,* and reaffirmed the eastern boundary as originally fixed by John Wesley Powell in 1895. Typical Great Plains landforms (plains and buttes) have resulted from the mountain uplift and subsequent sediment deposits that increased the elevation of the Great Plains relative to the Central Lowlands. The Great Plains, in the rain shadow of the Rocky Mountains, have been characterized by a dry subhumid to semiarid climate. The potential natural vegetation of the Great Plains has been, since the last retreat of the continental glaciers 8,000-10,000 years ago, grass/forb vegetation - mostly a mix of mid and short grasses. True Prairie has been limited to the moist side of the dry/moist boundary. These differences between the grasslands of the Great Plains and the grasslands of the Central Lowlands have resulted in differences in occurrence and abundance of grassland animal species, such as black-tailed prairie dog, black-footed ferret, swift fox, pronghorn, ferruginous hawk, prairie falcon and lark bunting. The eastern limits of these species more or less coincides with the eastern boundary of the Great Plains physiographic region and the dry/moist boundary. Given the differences described here it would be more accurate and appropriate to limit the use of the term, Great Plains, to the western Interior Plains and divide the Midcontinent grasslands into eastern (True Prairie) and western (Great Plains) sections.

Keywords

Great Plains, natural, boundary

INTRODUCTION

The Great Plains! As part of an article title the term is a real eye catcher. Is the Great Plains a real place with distinctive characteristics and limits, or is it just a handy term useful to authors to convey an image? If it is a specific region, what are the characteristics and where are the boundaries? If it is just an image, of what? Observant westbound travelers upon approaching the Great Plains may notice an abrupt rise in elevation as they encounter the escarpment of the Coteau du Missouri. Elsewhere, travelers may note the gradual change from landscapes of rolling surfaces, and hazy views of rounded hills, to landscapes of broad flat plateaus and flat surface remnants, where the skyline is distant and clear—welcome to the wide open spaces—welcome to images of cowboys and Indians, wagon trains, immense buffalo herds, homesteaders, drought and hardship.

The term Great Plains was not much used as a regional designation until 1857, when it was used in promotional articles and speeches synonymously with “pastoral region” by William Gilpin, who was appointed, in 1861, first governor of Colorado Territory. His purpose was to create a more positive image to promote settlement in the Great American Desert, as the area was generally known at the time (Lewis 1966). Since Gilpin, the Great Plains of North America have been recognized as both a natural and a cultural region by scholars in various disciplines (e.g. geology, biology, geography and history); however, consistent boundaries for the area, and its name, Great Plains, were not in general use until after 1931, when Nevin M. Fenneman described the region in *Physiography of the Western United States,* and reaffirmed the eastern boundary as originally fixed by John Wesley Powell in 1895. Prior to this the region had most often been referred to as the High Plains to distinguish it from the lower Prairie Plains of the Midwest (Brown 1948).

More recently it has become common to find the term, Great Plains, used by many natural science authors to refer to many different regions - both natural and artificial, as was found from a review of articles in *The Prairie Naturalist* (1986-1995). As well, the *Great Plains Research* journal does not limit itself to the Great Plains, but includes in its sphere most of central North America: grasslands, savannahs, and some forest. Books, such as *Flora of the Great Plains* and *Birds of the Great Plains,* include portions of other natural regions and exclude portions of the Great Plains natural region. The term, Great Plains, is also used to designate artificial regions with no apparent natural parameters, as in “Great Plains states.” Is it appropriate in natural science writing to use the term, Great Plains, that has been previously recognized as the name of a specific natural region and apply it to artifical regions? It would be simpler if the so-called Great Plains states were entirely within the Great Plains natural region, unfortunately no state is entirely within the Great Plains. Many of these Great Plains states could just as easily be called Central Lowland states, or True Prairie states, and others could be included as Rocky Mountain states.

The problem (in my opinion) that has developed by applying the term, Great Plains, to many different areas, is that now when it is used without explanation or a map, no one can be certain as to what area or region the author is referring. The following presentation describes the Great Plains as a natural region with unifying characteristics: physiographic, climatic, and vegetative.

GREAT PLAINS PHYSIOGRAPHIC CHARACTERISTICS

The Great Plains physiographic province is located in the western portion of the Interior Plains Physical Division of North America (see Fig. 1). It is different from the eastern portion of the Interior Plains (the Central Lowlands) mostly because of the development and continued presence of the Rocky Mountains which are the western boundary of the Great Plains. The marine sediments of the upper Cretaceous strata underlying the Great Plains were tilted by the uplift of the Rocky Mountains and then covered by sediments (Tertiary strata) that eroded from the mountains. Subsequent uplifts caused the streams that had been depositing sediment on the plains for more than 60 million years to cut down into these sediments, more or less beginning the creation of the current landscape with its streams, buttes, badlands, breaks and occasional broad plateaus (e.g., Staked Plains) left between the streams, according to Trimble (1980).

More recently in geologic time an area unique to the northern Great Plains was created by a dead-ice moraine that covers a highland area called the Coteau du Missouri. This coteau is the eastern limit of the sediments brought by rivers from the Rocky Mountains. An escarpment, several hundred feet high separates the Coteau du Missouri from the lower, nearly flat, drift-covered plains of the Central Lowland physiographic province to the east. This glaciated portion of the Great Plains includes the area north and east of the Missouri River. Continental ice sheets did cover some areas south and west of the current Missouri River, but only scattered boulders remain to indicate the glaciers former presence, and current conditions there are more similar to the unglaciated portions of the Great Plains than to the glaciated areas east of the river. The areas of the Great Plains regions covered by glaciers and other nontypical conditions are shown in Figure 1.

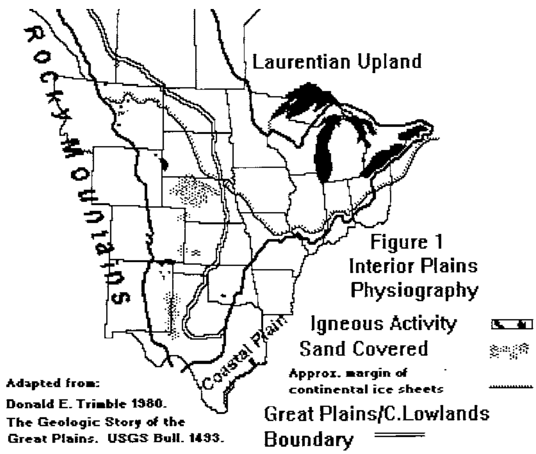

Figure 1. North American Interior Plains physiographic region divided into the Great Plains and the Central Lowlands, adapted from Trimble (1980).

Summary of Great Plains physiographic characteristics:

1. The mountain uplift *tilted* the upper Cretaceous strata and this, along with *sediment deposits* from the mountains *increased the elevation* of the Great Plains relative to the Central Lowlands.

2. Most of the Great Plains were *not glaciated.*
3. Typical landforms include: large flat surfaced remnants *(plains)* and small flat surfaced remnants *(buttes).*

GREAT PLAINS CLIMATE CHARACTERISTICS

The distinguishing climatic characteristic of the Great Plains environment is a deficiency of water. "This deficiency accounts for many of the ways of life in the West. In this deficiency is found the key to what may be called the plains civilization. It is the feature that makes the whole aspect of life west of the 98th meridian such a contrast to life east of that line (Webb 1931: 17)." And again: The Great Plains has a climate which distinguishes it from neighboring regions, and according to Borchert (1971) the most distinctive characteristics are the great droughts that have temporarily extended the arid climate of the Southwest into the Great Plains, and pushed the semiarid climate of the Great Plains eastward into the Prairie region.

Average annual precipitation in the Great Plains decreases from east to west, being least, approx. 12 inches (30cm), at the base of the Rocky Mountains. This is the result of the rain shadow effect of the mountains and increasing distance from the main moisture source, the Gulf of Mexico. The location of the moisture deficit line, the division between the moist subhumid and the dry subhumid of Thornthwaite's (1948) moisture regions (Fig. 2) can vary depending on what time period is used for the calculation as described by Borchert (1971). The annual variability of the moisture makes any short term dry/moist boundary somewhat tentative, but the long term average location of the moisture deficit line coincides well with the eastern boundary of the Great Plains physiographic province indicated in Figure 1, and even better with the mixed grass/tallgrass boundary of Figure 3. Temperature plays an important role in determining if a particular place has a moisture deficit. In the Great Plains, as would be expected, the annual temperatures are coolest in the north and warmest in the south; therefore, it takes less rainfall in the north for a location to be in the moist region.

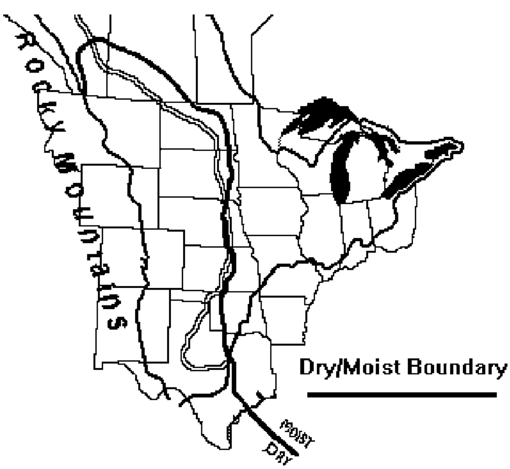

Figure 2. Moisture regions of the Interior Plains, adapted from Thornwaite (1948), Trewartha (1957), and Bailey (1979).

Summary of Great Plains climate characteristics:

1. A moisture deficit caused primarily by the rain shadow effect of the mountains—dry subhumid to semiarid climate.
2. The lower humidities increases clarity of the air—much less haze than the Central Lowlands.

GREAT PLAINS GRASSLANDS VEGETATION CHARACTERISTICS

The fact, that the Great Plains, was for all practical purposes—treeless, was in part responsible for its original image of infertility. "Scarcity of wood and water: two of the three legs of civilization," was generally considered to make settlement by an agricultural people impossible and the area suited only for pasturage (Webb 1931: 9). The Great Plains are part of the Grassland Biome of North America and have been so since the retreat of the continental glaciers and the warming of the climate some 8,000-10,000 years ago (Kaul 1986). Most descriptions of the "Mid-continent prairie" (Costello 1969: 38) distinguish between the "true prairie" in the east and the "mixed prairie" in the west (Eyre 1968: 107, and Costello 1969: 38) or true prairie (tall) and Great Plains grasslands, mid and short (Weaver 1968); some add a short grass zone in the drier western section adjacent to the Rocky Mountains (Brown 1985), and a separate category for the unique sandhills grasslands (Kaul 1986). The distribution of potential plant community types depicted in Figure 3 is adapted primarily from (Kuchler 1964).

A distinction is made by most authorities between the tall grass (true prairie) and the western portion of the Midcontinent grasslands characterized as mixed and short in Figure 3. Some ecologists consider the mixed grass prairie to be a broad transition zone in which the tall grasses of the true prairie mingle with the shorter grasses of the Great Plains (Borchert 1971 and others) in decreasing proportions to the west. This seems to be the most realistic view of the Great Plains grasslands given the dynamic nature of the plant environment with variable annual rainfall combining with variable grazing intensities to create a complex mixture. Eastern Nebraska contains the only large area of tall grass prairie within the Great Plains physiographic province; it is also the only area where the dry/moist boundary is within the Great Plains physiographic province. This is an area with a deep covering of loess which

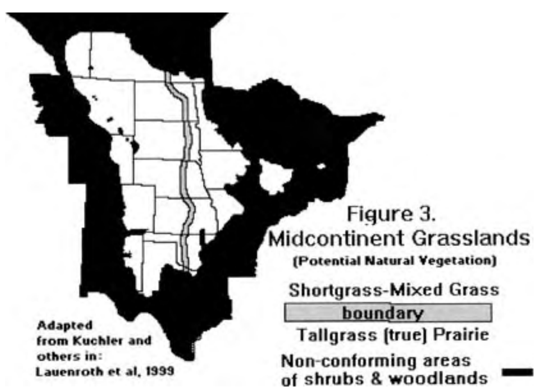

Figure 3. Potential natural vegetation of the mid-continent grasslands, adapted from Kuchler (1964), and others in Lauenroth *et al* (1999).

merges with the sandhills to the west. Some authorities include the sandhills with the tall grass area to the east, but it is well west of the dry/moist boundary and better left as a unique area within the Great Plains natural region.

It should also be noted; that although, trees are not a part of the typical Great Plains potential natural upland vegetation, tree growth does indicate another difference between the True Prairie regions and the Great Plains. In the Great Plains a considerable effort; including planting, cultivation and irrigation, is needed just to get trees started, let alone growing well. While in the true prairie, trees are natural invaders of the grasslands and prior to settlement were kept out by frequent fires, both natural and manmade.

Summary of Great Plains grasslands potential natural vegetation characteristics:

1. *Grass/forb vegetation dominant:* mostly a mix of mid and short grasses; although, tall grass species may be found in scattered favorable (moist) locations. True (tallgrass) Prairie is limited to the moist side of the dry/moist boundary (e.g., the Flint Hills are not within the Great Plains natural region).
2. *Upland shrub communities do occur:* sandsage/yucca on sandy soils in the central plains, silver sage in the northern plains, desert shrubs encroach from the southwest, and big sagebrush encroaches from the intermountain west into the northern plains.

DISCUSSION

None of the information presented above is new, and it is probably well known by most people writing about the Midcontinent grasslands: So why aren't the natural regions more widely used in the literature? Maybe too much attention has been paid to the vegetation: "hey, its all grasslands, whats the big deal." Well, it is apparently a big deal to the species whose eastern range limits more or less coincide with the eastern boundary of the Great Plains physiographic province and the dry/moist boundary, such as black-tailed prairie dog, black-footed ferret, swift fox, pronghorn, ferruginous hawk, prairie falcon. Other species, like the bison, formerly reached their greatest abundance in the Great Plains. One of the best indicator species of Great Plains conditions is the lark bunting whose normal breeding range boundaries nearly coincide with the boundaries of the natural region (National Geographic Field Guide 3rd edition). The lark bunting is found in significant numbers east of the region only during dry periods. The range of these animals is more likely to extend west from the Great Plains than into the more moist conditions to the east. As well, it is only with great effort that shelterbelt trees can be started in semiarid grasslands, while east of the dry/moist boundary the concensus seems to be that trees and shrubs were kept from taking over the original tallgrass prairies only because of the effects of fire. In addition to moisture and vegetation, landforms are a significant factor in determining the distribution many animal species (e.g. prairie falcons nesting on buttes).

There are some well established and long recognized natural divisions within North America, such as the Great Plains. It is unfortunate that this term long associated with a specific natural region has been used inappropriately in so much of the current scientific literature relating to wildlife, with many different areas being referred to as the Great Plains. The confusion that can develop with the current practice of inappropriately, and with great frequency, dropping geographic terms willy - nilly into articles could be eliminated if existing precedents, as outlined in this article, are considered before publishing.

CONCLUSION

The purpose of this presentation is to remind natural scientists of the existing precedents about the location of the Great Plains natural region and to encourage them to be careful when using the term, Great Plains, in the future. In my opinion it is most accurately and appropriately used for referring to the Great Plains natural region which can be defined by the following 3 conditions:

1. Within the Great Plains Physiograpic province as shown in Figure 1.
2. West of the dry/moist climate boundary shown in Figure 2.
3. Its dominant potential natural vegetation consists of mixed grasses (mostly mid and short) or short grasses as indicated in Figure 3: exceptions are made for special conditions like the Nebraska sandhills.

Separating the Midcontinent grasslands into eastern (moist—True Prairie) and western (dry—Great Plains) sections, and using these subdivisions when generalizing about tree coverage, species occurrence, species abundance, habitat associations, etc., would seem to be more accurate and appropriate than the current situation.

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THE IMPORTANCE OF THE SOCIAL ASPECTS OF HUNTING: A COMPARISON BETWEEN RESIDENT AND NON-RESIDENT 1999 BLACK HILLS DEER HUNTERS

Penny A. Backman, Daniel E. Hubbard, and Jonathan A. Jenks
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

Larry M. Gigliotti
South Dakota Department of Game, Fish and Parks
Pierre, SD 57501

ABSTRACT

In 1996 the South Dakota Department of Game, Fish, and Parks adopted a new management system for the Black Hills deer herd. Low satisfaction levels prompted this change in management, which was designed to produce the larger numbers of mature bucks that hunters were asking for. However, the new system placed limitations on the number of licenses sold and this had the potential to negatively impact the social aspects of Black Hills deer hunting. In order to address this concern, a detailed survey was administered to 2000 randomly selected, resident and non-resident, 1999 Black Hills deer hunters to determine the occurrence and the importance of deer hunting groups in the Black Hills. Results indicated that residents and non-residents differed from each other on a variety of points. Non-residents were more likely than residents to consider social reasons to be a very important motivation for hunting Black Hills deer, to classify themselves as "social" hunters, to be group hunters, to consider spending time with hunting companions to be very important, to apply for their licenses with a group, to report that all potential members of their hunting group received the appropriate license, to hunt in a mixed group of non-residents and residents, to share transportation to and from the hunting area, to share venison, and to get together to talk about the hunt. Residents were more likely than non-residents to consider meat reasons to be a very important motivation for hunting Black Hills deer, to classify themselves as "meat" hunters, and to indicate that they want to keep the new management system. However, residents and non-residents were equally likely to consider nature reasons, excitement reasons, trophy reasons, and challenge reasons as important motivations for hunting Black Hills deer. Additionally, residents and non-residents did not differ in their rankings of the natural beauty of the Black Hills, their rankings of the importance of the natural beauty of the Black Hills, or in levels of satisfaction. Results indicated that, although the social aspects of Black Hills deer hunting were relatively important for both residents and non-residents, non-residents were generally more socially oriented than residents.

INTRODUCTION

Providing deer hunters with satisfying hunting experiences has become an increasingly important objective of deer management in the Black Hills of South Dakota (Gigliotti 1998a). Relatively low satisfaction levels were reported in 1993 and 1995, prompting the South Dakota Department of Game, Fish, and Parks (GF&P) to make several major changes in the management of the Black Hills deer herd. The traditional system of unlimited, over-the-counter buck tags and limited lottery doe tags was replaced with a new system of limited lottery buck tags with a 2-point (on 1 side) antler restriction and limited any-deer tags. These changes were designed to produce larger numbers of mature bucks which hunters were looking for, and consequently, improve hunter satisfaction levels. However, GF&P realized that more human dimensions information was needed to monitor hunter response to these management changes, especially as the new management system had the potential to impact the social aspects of Black Hills deer hunting (not everyone that wanted to hunt would receive a license) and identify further management changes that would improve hunter satisfaction levels (Gigliotti 1998a).

Throughout the history of game management, there have been 3 different philosophies used to define and understand hunter satisfaction (Hammitt et al. 1989). When game populations were high, the amount of game harvested was equated with hunter satisfaction. However, as the numbers of hunters increased, game populations began to decline forcing managers to adopt a "days afield" approach which equated satisfaction with the number of days a hunter was able to hunt (Potter et al. 1973). In 1973, the "multiple dimensions of hunters satisfaction" approach was developed as an alternative to these 2 philosophies. The multiple dimensions approach suggests that mangers should combine their efforts and attempt to provide hunters with the full range of quality experiences that taken together produce a satisfying hunt and avoid simply concentrating on increasing harvest rates or the number of days spent in the field (Potter et al. 1973).

The multiple dimensions concept suggests that hunters seek and receive a variety of benefits from hunting (Hendee 1974). However, the specific package of benefits varies depending on the location and the type of hunt (Wright et al. 1977, Hammitt et al. 1990) as well as varying with the individual (Hendee 1974, Brown et al. 1997). The specific benefits associated with a hunt often include harvest related benefits (e.g., seeing game, harvesting game, acquiring trophies, etc.) and non-harvest related benefits (e.g., spending time with hunting companions, enjoying nature, enjoying solitude, etc.). However, relatively limited research has been conducted on the social benefits associated with hunting (Kennedy 1974b, Potter et al. 1973, Schole et al. 1973, and Decker et al. 1980).

In this study, we categorize Black Hills deer hunters by their main motivational factor (total of 7 factors) according to a scheme developed by Gigliotti (2000) and modified by Blackman (2001). We then compare resident and non-resident Black Hills deer hunters with respect to several motivational, behavioral, and perceptual variables.

METHODS

A self-administered mail questionnaire was administered to 1,700 resident and 300 non-resident 1999 Black Hills deer hunters randomly selected from the list of successful 1999 Black Hills deer license applicants. Each group was sampled in proportion to available license types and units, however, a higher proportion of non-residents were selected to ensure that an adequate number of non-residents were sampled for statistical comparisons with residents.

Specific questions were modeled after questions previously utilized for studying Black Hills deer hunters (Gigliotti 1997a, 1997b, and 1998b). Prior to finalization, the survey instrument was initially pre-tested among 10 graduate students in the Department of Wildlife and Fisheries Sciences at South Dakota State University and circulated among several GF&P employees. The questionnaire was then test-administered to 500 Black Hills deer hunters in 1998. Both the 1998 test-survey and the 1999 survey were administered following the procedures outlined by Salant and Dillman (1994) and were mailed on the last day of the 1998 and 1999 Black Hills deer seasons, respectively. The final questionnaire consisted of 38 questions and is reprinted in Backman (2001).

Data were analyzed using Systat software functions (SPSS 1999). Frequencies and percentages of responses were calculated for each item and chi-square contingency-table analyses were used to determine differences in proportions of independent variables between groups. When significance was found, the 95% confidence interval technique was used to determine which variables, specifically, were significantly different (Byers et al. 1984). For all analyses a relationship was considered to be significant if $p<0.05$.

RESULTS

A final corrected sample size of 1,992 surveys (minus 8 undeliverables) was achieved. A total of 1,827 surveys were returned by the deadline for a final return rate of 91.7%. Because response rate for the survey was greater than 90%, effects of non-response bias should be minimal (Houseman 1953).

Although social reasons were considered to be an important motivation for both resident and non-resident hunters, non-residents (61%) were more likely ($p<0.025$) than residents (51%) to consider social reasons to be a very important motivation for hunting Black Hills deer in 1999 (Table 1). Consequently, non-residents (31%) were more likely ($p<0.012$) to classify themselves as "social" hunters, based on their main motivation for hunting Black Hills deer, than were residents (26%) (Table 2). In addition, non-residents also were more likely ($p<0.039$) to rate solitude reasons, overall, as slightly more important than were residents (Table 3).

Reflecting on non-residents' higher rankings of the importance of the social aspects of hunting Black Hills deer, more non-residents (93%) than residents (86%) classified themselves as group hunters ($p<0.02$) and more non-residents (79%) than residents (67%) considered spending time with hunting companions to be very important ($p<0.004$) (Tables 4 and 5). Non-residents (70%)

also were more likely (p<0.001) to apply for their licenses with a group than were residents (50%), and consequently, non-residents (80%) were more likely (p<0.034) than residents (74%) to report that all potential members of their hunting groups drew the appropriate license that allowed them to hunt with the group (Tables 6 and 7). Non-residents (47%) also were more likely (p<0.001) to hunt in a mixed group of residents and non-residents than were residents (8%) (Table 8).

Non-residents (71%) were more likely (p<0.001) to share transportation to and from the hunting area than were residents (58%) (Table 9). They were also more likely (45%) to share venison with a fellow unsuccessful group member not living in the same household (p<0.001) than residents (31%). Non-residents (60%) also were more likely (p<0.013) to get together at any time to talk about the hunt than were residents (50%).

Residents (16%) were more likely (p<0.001) to consider meat reasons to be a very important motivation for hunting Black Hills deer than were residents (7%) (Table 10). In addition, although few residents or non-residents considered this motivation to be important and even fewer considered it to be their main motivation, residents (10%) also were more likely (p<0.012) to classify themselves as "meat" hunters than were non-residents (3%) (Table 2). More resident hunters (64%) than non-residents hunters (56%) (p<0.042) also indicated that they wanted to keep the new management system and, finally, more residents (52%) were found to spend the night at home during their hunts (p<0.01) than were non-residents (8%) (Tables 11 and 12).

Residents and non-residents did not differ in their rankings of the importance of "to enjoy nature, the outdoors, and the beauty of the area" (nature reasons, p<0.240), "for the excitement that hunting provides, e.g., the feeling one gets when you see deer" (excitement reasons, p<0.439), "to bring home a nice buck to hang on the wall or otherwise to demonstrate hunting skills and accomplishment" (trophy reasons, p<0.358), or "for the challenges associated with out-smarting a deer and dealing with the elements" (challenge reasons, p<0.532) as motivations for hunting Black Hills deer (Table 13). Residents and non-residents also did not differ in their ratings of the natural beauty of the Black Hills (96% combined indicated that it was average or above, p<0.148) or in their ratings of the importance of the natural beauty of the Black Hills to their overall 1999 hunting experiences (84% combined indicated that it was very/moderately important, p<0.405) (Tables 14 and 15). Additionally, residents and non-residents did not express different levels of satisfaction (77% satisfied, 23% dissatisfied combined) with their 1999 Black Hills deer hunts (p<0.145) (Table 16).

The average number of members in a hunting group (4.6 people) did not differ between resident and non-resident hunters (p<0.800). Resident and non-resident group hunters also did not exhibit different levels of participation for hunting cooperatively (i.e., deer drives) (p<0.098) or for helping with after-the-hunt chores (i.e., dragging out harvested animals, processing meat) (p<0.409) (Table 17). Finally, the influence of the harvest success of a specific other group member on individual hunters satisfaction (66% combined indicated that it had increased, p<0.128) and the degree to which satisfaction was influenced

(87% combined indicated that it had greatly/moderately increased, $p<0.519$) did not differ between residents and non-residents (Tables 18 and 19).

DISCUSSION AND RECOMMENDATIONS

The social aspects of hunting Black Hills deer were important to the majority of resident and non-resident 1999 Black Hills deer hunters, however, they were more important to non-residents than residents. Non-residents were more likely to consider social reasons to be a very important motivation for hunting Black Hills deer and to classify themselves as "social" hunters (26%) than residents (31%). Gigliotti (2000) reported that non-resident Black Hills deer hunters (42%) were even more likely to be "social" hunters compared to residents (22%) in 1997 and comparable percentages of South Dakota West River big game resident (25%) and non-resident (30%) hunters (deer and antelope) were "social" hunters (Gigliotti 1998c and Gigliotti 1998d).

Non-residents also were more likely to be group hunters ($p<0.02$), to consider spending time with hunting companions to be very important ($p<0.004$), to apply for their licenses with at least 1 other person ($p<0.001$), to report that all potential group members received the appropriate licenses allowing them the hunt with the group ($p<0.034$), and to hunt in a mixed group ($p<0.001$) of residents and non-residents. As for drawing first choice licenses, results from Gigliotti's 1997 survey of Black Hills deer hunters indicated that most residents and non-residents did receive their first choice licenses, however, slightly fewer non-residents drew their first choice licenses for license types 400A-02 (97% of residents vs. 96% of non-residents), and 401-404-01 (96% of residents vs. 90% of non-residents) (Gigliotti 1998b). For license types 401-404-04 slightly more non-residents (74%) received their first choice license than residents (72%) (Gigliotti 1998b). Additionally, non-residents also were more likely to share transportation to and from the hunting area ($P<0.001$) and get together to talk about the hunt ($p<0.0013$). These results indicate that overall, the social aspects of Black Hills deer hunting were more important to non-residents than residents.

Contrastingly, resident 1999 Black Hills deer hunters (10%) were more likely ($p<0.001$) to classify themselves as "meat" hunters than were non-residents (3%). Similarly, although slightly more divergent, more resident (13%) than non-resident (1%) Black Hills deer hunters classified themselves as "meat" hunters in 1997. About the same proportions of resident (14%) and non-resident (3%) South Dakota West River big game hunters (deer and antelope) classified themselves as "meat" hunters (Gigliotti 1998d and Gigliotti 1998c). Residents (64%) also were more likely ($p<0.042$) than non-residents (56%) to want to keep the new management system, which is thought to have had negative impacts on Black Hills deer hunting groups (fewer licenses available). In 1997, fewer residents and non-residents liked the new management system, however, residents (55%), compared to non-residents (50%), were still more likely to approve of the new management system (Gigliotti 1997c).

Residents and non-residents did not differ in their rankings of nature reasons, excitement reasons, trophy reasons, or challenge reasons as motivations for hunting Black Hills deer. Both residents and non-residents rated the natural beauty of the Black Hills highly (96%) and indicated that the natural beauty of the Black Hills was an important part of their Black Hills deer hunting experience (84%). Both residents and non-residents also were satisfied (77%) with their 1999 Black Hills deer hunts ($p<0.145$).

Resident and non-resident group hunters also did not have different levels of engagement in cooperative hunting activities or activities involving after-the-hunt chores. Finally, many residents and non-residents (66%) indicated that the success of a fellow group member influenced their own satisfaction and most indicated that it had been greatly to moderately increased. Similar results were reported by Langenau (1981) and Hammitt et al. (1990) and illustrate that individual success is not the only success-related variable that can influence satisfaction levels.

Results indicate that the social aspects of Black Hills deer hunting were important to both resident and non-resident hunters in 1999, but non-residents were even more socially oriented than residents. However, satisfaction levels of residents and non-residents were similar and indicate that many hunters are relatively pleased with the new management system, even though it has the potential to negatively impact the social aspects of Black Hills deer hunting by limiting available licenses. Apparently, residents and non-residents are both willing to sacrifice some of the social benefits of Black Hills deer hunting in favor of producing more and larger bucks. However, future management changes should be designed to limit their impact on hunting groups and it also may be prudent to investigate management schemes that would facilitate social interactions as they might have value as methods to maintain or increase Black Hills deer hunter satisfaction levels.

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Table 1. Importance of the reason: "enjoying the time spent with friends and family" as a motivation for hunting Black Hills deer in 1999.

	RESIDENTS		NON-RESIDENTS	
Importance[a]	**N**	**%**	**N**	**%**
0 (Not Important)	9	0.6%	1	0.4%
1[b]	22	1.5%	1	0.4%
2	25	1.8%	7	2.6%
3[b]	34	2.4%	2	0.7%
4	95	6.7%	12	4.5%
5[b]	187	13.1%	23	8.9%
6	327	23.0%	59	22.0%
7[b] (Very Important)	725	50.9%	163	60.8%
Total	*1424*	*100.0%*	*268*	*100.0%*

[a] Chi-square 16.051; df=7; p<0.025
[b] Residents differed significantly from non-residents based on a 95% CI (p<0.001)

Table 2. Main reason for hunting Black Hills deer in 1999.

	RESIDENTS		NON-RESIDENTS	
Reason[a]	**N**	**%**	**N**	**%**
Meat[b]	144	10.1%	9	3.3%
Nature	355	24.9%	70	26.0%
Excitement	299	21.0%	63	23.4%
Social[b]	373	26.2%	82	30.5%
Trophy	72	5.0%	18	6.7%
Solitude	43	3.0%	7	2.6%
Challenge	140	9.8%	20	7.4%
Total	*1426*	*100.0%*	*269*	*100.0%*

[a] Chi-square 16.403; df=6; p<0.012
[b] Residents differed significantly from non-residents based on a 95% CI (P<0.001)

Table 3. Importance of the reason: "to spend time alone in the woods" as a motivation for hunting Black Hills deer in 1999.

	RESIDENTS		NON-RESIDENTS	
Importance[a]	**N**	**%**	**N**	**%**
0 (Not Important)	49	3.4%	5	1.9%
1	53	3.7%	8	3.0%
2[b]	58	4.1%	2	0.7%
3	106	7.4%	22	8.2%
4[b]	194	13.6%	52	19.4%
5	282	19.8%	50	18.7%
6	326	22.9%	64	23.9%
7 (Very Important)	356	25.0%	65	24.3%
Total	*1424*	*100.0%*	*268*	*100.0%*

[a] Chi-square 14.786; df=7; $p<0.039$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 4. Occurrence of group hunting among resident and non-resident 1999 Black Hills deer hunters.

	RESIDENTS		NON-RESIDENTS	
Response[a]	**N**	**%**	**N**	**%**
Yes[b]	1241	86.0%	238	93.0%
No[b]	202	14.0%	18	7.0%
Total	*1443*	*100.0%*	*256*	*100.0%*

[a] Chi-square 9.36; df=1; $p<0.02$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 5. Importance assigned by 1999 Black Hills deer group hunters to the time spent with hunting companions to their overall 1999 Black Hills deer hunting experience.

	RESIDENTS		NON-RESIDENTS	
Response[a]	**N**	**%**	**N**	**%**
Very Important[b]	823	67.3%	192	78.7%
Moderately Important[b]	307	25.1%	44	18.0%
Slightly Important[b]	81	6.6%	7	2.9%
Not at all Important[b]	12	1.0%	1	0.4%
Total	*1223*	*100.0%*	*244*	*100.0%*

[a] Chi-square 13.595; df =3; $p<0.004$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 6. 1999 Black Hills deer group hunters that applied for their licenses with at least 1 other hunter.

	RESIDENTS		NON-RESIDENTS	
Response[a]	**N**	**%**	**N**	**%**
Yes[b]	615	49.8%	173	70.0%
No[b]	621	50.2%	74	30.0%
Total	*1236*	*100.0%*	*247*	*100.0%*

[a] Chi-square 34.011; df=1; $p<0.001$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 7. 1999 Black Hills deer group hunters who reported that all of the potential members of their hunting group received the licenses that allowed all of them to hunt at the same time in the same location.

	RESIDENTS		NON-RESIDENTS	
Response[a]	**N**	**%**	**N**	**%**
Yes[b]	897	74.1%	195	80.6%
No[b]	313	25.9%	47	19.4%
Total	*1210*	*100.0%*	*242*	*100.0%*

[a] Chi-square 4.494; df =1; $p<0.034$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 8. Resident and non-resident 1999 Black Hills deer hunters that hunted in a mixed group of residents and non-residents.

	RESIDENTS		NON-RESIDENTS		
Response[a]		**N**	**%**	**N**	**%**
Yes[b]	100	8.1%	113	46.9%	
No[b]	1128	91.9%	128	53.1%	
Total	*1228*	*100.0%*	*241*	*100.0%*	

[a] Chi-square 243.945; df=1; $p<0.001$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 9. Frequency of resident and non-resident engagement in specific group hunting activities during the 1999 Black Hills deer season.

SHARING TRANSPORTATION

Response[a]	RESIDENTS N	%	NON-RESIDENTS N	%
Never[b]	60	4.9%	3	1.2%
Sometimes[b]	130	10.6%	14	5.7%
Half of the Time[b]	122	10.0%	10	4.1%
Usually	207	16.9%	43	17.6%
Always[b]	705	57.6%	174	71.3%
Total	*1229*	*100.0%*	*244*	*100.0%*

SHARING VENISON

Response[c]	RESIDENTS N	%	NON-RESIDENTS N	%
Never	117	9.7%	19	7.8%
Sometimes[b]	293	24.2%	41	16.9%
Half of the Time[b]	94	7.8%	8	3.3%
Usually	330	27.2%	65	26.7%
Always[b]	378	31.2%	110	45.3%
Total	*1212*	*100.0%*	*244*	*100.0%*

TALKING ABOUT THE HUNT

Response[d]	RESIDENTS N	%	NON-RESIDENTS N	%
Never	6	0.5%	1	0.4%
Sometimes[b]	145	11.8%	18	7.4%
Half of the Time[b]	58	4.7%	4	1.6%
Usually	403	32.8%	74	30.3%
Always[b]	615	50.1%	147	60.2%
Total	*1227*	*100.0%*	*244*	*100.0%*

[a] Chi-square 25.546; df=4; p<0.001
[b] Residents differed significantly from non-residents based on a 95% CI (P<0.001)
[c] Chi-square 23.164; df=4; p<0.001
[d] Chi-square 12.676; df=4; p<0.013

Table 10. Importance of the reason: "to bring meat home for food" as a motivation for hunting Black Hills deer in 1999.

	RESIDENTS		NON-RESIDENTS	
Importance[a]	N	%	N	%
0 (Not Important)	145	10.1%	31	11.6%
1[b]	131	9.1%	35	13.1%
2[b]	174	12.1%	43	16.1%
3	184	12.8%	29	10.9%
4[b]	216	15.0%	50	18.7%
5[b]	233	15.5%	34	12.7%
6	131	9.1%	27	10.1%
7[b] (Very Important)	236	16.4%	18	6.7%
Total	*1440*	*100.0%*	*267*	*100.0%*

[a] Chi-square 25.253; df=7; $p<0.001$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 11. Hunter opinions concerning whether to keep the new management system or return to the traditional management system.

	RESIDENTS		ON-RESIDENTS	
Response[a]	N	%	N	%
Keep[b]	884	63.8%	144	55.6%
Return[b]	333	24.0%	78	30.1%
No Opinion	169	12.2%	37	14.3%
Total	*1386*	*100.0%*	*259*	*100.0%*

[a] Chi-square 6.340; df=2; $p<0.042$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 12. Where 1999 Black Hills deer group hunters spent the night during their 1999 Black Hills deer hunt.

	RESIDENTS		NON-RESIDENTS	
Response[a]	N	%	N	%
Home[b]	682	52.3%	19	7.9%
Hotel/Motel[b]	289	24.1%	118	49.0%
Friend's Home[b]	110	9.2%	31	12.9%
Relative's Home[b]	72	6.0%	36	14.9%
Deer Camp/Campsite[b]	102	8.5%	37	15.4%
Total	*1201*	*100.0%*	*241*	*100.0%*

[a] Chi-square 166.352; df =4; $p<0.01$
[b] Residents differed significantly from non-residents based on a 95% CI ($p<0.001$)

Table 13. The importance of the reasons: "to enjoy nature, the outdoors and the beauty of the area" (nature reasons), "for the excitement that hunting provides, e.g., the feeling one gets when you see deer" (excitement reasons), "to bring home a nice buck to hang on the wall or otherwise to demonstrate hunting skills and accomplishments" (trophy reasons), and "for the challenges associated with out-smarting a deer and dealing with the elements" (challenge reasons) as motivations for hunting Black Hills deer.

	NATURE REASONS[a]		EXCITEMENT REASONS[b]		TROPHY REASONS[c]		CHALLENGE REASONS[d]	
Importance[a]	N	%	N	%	N	%	N	%
0 (Not Important)	5	0.3%	8	0.5%	164	9.7%	30	1.8%
1	6	0.4%	4	0.2%	163	9.6%	31	1.8%
2	10	0.6%	5	0.3%	195	11.5%	41	2.4%
3	33	1.9%	41	2.4%	228	13.6%	92	5.4%
4	86	5.8%	103	6.1%	280	16.5%	202	11.9%
5	254	14.9%	293	17.3%	242	14.3%	343	20.3%
6	465	27.3%	452	26.7%	187	11.0%	421	24.9%
7 (Very Important)	848	49.7%	801	47.3%	235	13.9%	533	31.5%
Total	*1707*	*100.0%*	*1695*	*100.0%*	*1694*	*100.0%*	*1693*	*100.0%*

[a] Resident vs. Non-resident Chi-square 9.176; df=7; p<0.240
[b] Resident vs. Non-resident Chi-square 4.815; df=7; p<0.439
[c] Resident vs. Non-resident Chi-square 7.714; df=7; p<0.358
[d] Resident vs. Non-resident Chi-square 6.066; df=7; p<0.532

Table 14. Ratings of the natural beauty of the Black Hills.

	RESIDENTS		NON-RESIDENTS		COMBINED	
Response[a]	N	%	N	%	N	%
Less Than Average	65	4.5%	7	2.6%	72	4.2%
Average or Above	1367	95.5%	262	97.4%	1629	95.8%
Total	*1432*	*100.0%*	*269*	*100.0%*	*1701*	*100.0%*

[a] Chi-square 2.096; df=1; p<0.148; original response categories collapsed into two categories.

Table 15. Importance of the natural beauty of the Black Hills to hunters' overall 1999 Black Hills deer hunting experiences.

	RESIDENTS		NON-RESIDENTS		COMBINED	
Importance[a]	N	%	N	%	N	%
Very/Moderately	1285	89.8%	146	88.2%	1431	84.2%
Slightly/Not	237	10.2%	32	11.9%	269	15.8%
Total	*1431*	*100.0%*	*269*	*100.0%*	*1700*	*100.0%*

[a] Chi-square 0.693; df=1; p<0.405; original response categories collapsed into 2 categories.

Table 16. Hunter satisfaction (categories collapsed to satisfied vs. dissatisfied; "neutral" and "no opinion" categories excluded) with the 1999 Black Hills deer season.

	RESIDENTS		NON-RESIDENTS		COMBINED	
Satisfaction[a]	**N**	**%**	**N**	**%**	**N**	**%**
Satisfied	957	76.6%	195	80.9%	1152	77.3%
Dissatisfied	292	23.4%	46	19.1%	338	22.7%
Total	*1249*	*100.0%*	*241*	*100.0%*	*1490*	*100.0%*

[a] Chi-square 2.121; df=1; p<0.145

Table 17. Frequency of engagement in specific group hunting activities during the 1999 Black Hills deer season.

	HUNTING COOPERATIVELY[a]		HELPING WITH AFTER-THE-HUNT CHORES[b]	
Response	**N**	**%**	**N**	**%**
Never	85	5.8%	26	1.8%
Sometimes	303	20.6%	88	6.0%
Half of the Time	208	14.1%	73	5.0%
Usually	383	26.0%	363	24.8%
Always	493	33.5%	915	62.5%
Total	*1472*	*100.0%*	*1465*	*100.0%*

[a] Resident vs. Non-resident Chi-square 7.832; df=4; p<0.089
[b] Resident vs. Non-resident Chi-square 3.980; df=4; p<0.409

Table 18. Influence of the success (harvesting a deer) of a specific other hunting group member on individual group hunter satisfaction.

	RESIDENTS		NON-RESIDENTS		COMBINED	
Response[a]	**N**	**%**	**N**	**%**	**N**	**%**
Yes	604	67.4%	121	61.7%	725	66.4%
No	292	32.6%	75	38.3%	367	33.6%
Total	896	100.0%	196	100.0%	1092	100.0%

a Chi-square 2.322; df=1; p<0.128

Table 19. Degree individual satisfaction levels were increased by the success of a specific fellow group member.

Response[a]	RESIDENTS N	RESIDENTS %	NON-RESIDENTS N	NON-RESIDENTS %	COMBINED N	COMBINED %
Slightly	83	13.9%	13	10.8%	96	13.4%
Moderately	292	49.0%	57	47.5%	349	48.7%
Greatly	221	37.1%	50	41.7%	271	37.8%
Total	*596*	*100.0%*	*120*	*100.0%*	*716*	*100.0%*

[a] Chi-square 1.313; df=2; $p<0.519$

EFFECTS OF GRAZING AND HAYING ON ARTHROPOD DIVERSITY IN NORTH DAKOTA CONSERVATION RESERVE PROGRAM GRASSLANDS

Courtenay K. Hoernemann and Paul J. Johnson
Plant Science Department
South Dakota State University
Brookings, SD 57007

Kenneth F. Higgins
SD Cooperative Fish and Wildlife Research Unit
USGS/BRD
South Dakota State University
Brookings, SD 57007

ABSTRACT

A study of arthropod populations in North Dakota CRP grasslands was conducted to determine the impact of grazing and haying management practices on the arthropod fauna. Four sampling methods were used to collect arthropods: flight intercept traps, pitfall traps, sweep net, and soil samples. The three study sites occurred in Bowman, Ward, and Stutsman counties, North Dakota. Each site consisted of three pastures under a twice-over rotation grazed system, one pasture grazed seasonlong, a hayed field, and an idle area which served as a control. Shannon's Index showed there were no significant differences in diversity among pastures or county sites. Correspondence analysis (COA) showed Diplopoda (millipedes) and Formicidae (ants) were correlated to idle and hayed treatments in which both groups had a higher mean abundance. Stutsman County had the highest mean abundance of millipedes. Two beetle families, Elateridae (click beetles) and Curculionidae (weevils), showed a trend toward the idle area from COA, but neither group had a significantly higher mean abundance in idle areas. Ward County had the highest mean abundance of both click beetles and weevils. Miridae (plant bugs) showed a strong trend to hayed fields where they had a significantly higher mean abundance. A significantly higher mean abundance of plant bugs was found in Bowman County. Acrididae (grasshoppers) were found equally abundant in all pasture types in 1995, but fewer were found in idle areas in 1996. The lowest mean abundance of grasshoppers was collected in Ward County. Grasshopper densities did not reach threatening levels in either year of this study. Based on the overall results grazing and haying appear to be viable options for post-contract uses of CRP lands with regard to management of arthropod populations.

INTRODUCTION

The Conservation Reserve Program (CRP) was created under the Food and Security Act of 1985 and was a 10-year cropland retirement program designed to protect the nation's most highly erodible and fragile cropland. About 2.9 million acres were retired in North Dakota. The objectives of the CRP were to reduce water and wind erosion, improve water quality, create better habitat for fish and wildlife through improved food and cover, and provide income support for participants in the program (Blackburn et al. 1991). As the CRP contracts expire, landowners will be faced with the decision of converting the acreage back to cropland or sustaining the existing cover for grazing or haying production. A grazing and haying demonstration was set up in 1992 enabling researchers to investigate the potential of these as post-contract uses of CRP.

A limited number of studies have been conducted on the effects of grazing and haying management on insect communities. Total insect abundance can increase under grazing pressure (Smith 1940) and mowing or haying (Dunwiddie 1991). However, an increase in abundance may be accompanied by a decrease in species richness (Gibson et al. 1992). Faunal differences occur between grazed and ungrazed areas (Morris 1968; Horn & Dowell 1974) even though there are no significant differences in insect diversity. Phytophagous species tend to benefit from grazing pressure, while predatory species favor lack of management (Morris & Rispin 1988; DeBano 1994) due to complex trophic level interactions. This demonstrates that the effects of grazing will vary depending on the group of insect studied. Thus, it is necessary to evaluate specific groups of insects separately in response to grazing treatments.

One group of phytophagous insects which shows an increase in abundance from grazing (Smith 1940; Horn & Dowell 1974) and mowing (Morris & Lakhani 1979; Morris 1981b; Dunwiddie 1991) treatments is Heteroptera (planthoppers and true bugs). Grassland management practices that include grazing and haying alter the sward structure and floristic composition which is important for determining the fauna of Heteroptera. Due to their plant community associations and response to management practices, leafhoppers and other Auchenorrhyncha are used as indicators of prairie reserve quality (Hamilton 1995).

Another group of phytophagous insects that is given much consideration by grassland managers is Orthoptera (grasshoppers). Orthoptera respond similarly to planthoppers and plant bugs with an increase in abundance from grazing (Horn & Dowell 1974; Smith 1940) and mowing (Dunwiddie 1991). This effect lead Capinera and Sechrist (1982a) to suggest modification of grasshopper abundance through regulation of cattle grazing intensity. However, changes in abundance could be accompanied by a shift in the grasshopper species complex (Quinn & Walgenbach 1990; DeBano 1994). Differences in grasshopper species complexes are a result of the differences in plant community composition. Fielding and Brusven (1993) determined plant communities composed of annual vegetation may have low species diversity, whereas sites dominated by introduced perennial grasses have higher species diversity. Fielding & Brusven (1993) suggest that rehabilitation of annual grasslands with perennial grasses would support more diverse grasshopper communities with lower proportions of pest species, thus reducing outbreaks.

In contrast to phytophagous insects, predatory beetles favor lack of management when comparing grazed and ungrazed areas (DeBano 1994). Predacious species of beetles also favor lack of management when comparing hay fields to control areas (Morris & Rispin 1987). In a second study by Morris & Rispin (1988), predacious beetles once again favored lack of management, while haying tended to benefit phytophagous species of beetles.

Grassland management decision-making needs to consider these options with regard to their impacts on the arthropod fauna. Morris (1971) suggested that the insect fauna must be relatively well known, taxonomically and ecologically, if its consideration is to be a factor in management of grasslands. Arthropod diversity should be maintained in order to prevent the potential population outbreak of one or a few pest species. Rotational management has been suggested by several researchers as a way to meet manager's goals and maintain arthropod diversity (Smith 1940; Morris 1968). Rotational management through cutting has also been proposed as a way to reach economic goals and maintain insect species richness and diversity (Morris & Lakhani 1979; Morris 1979, 1981a, 1981b; Morris & Rispin 1987, 1988). Rotational grazing would enable removal of the maximum amount of vegetative material each season and maintain the pasture in its most productive condition.

There are concerns among landowners that CRP may be serving as a reservoir for pest species, such as wireworms and grasshoppers, which would lead to possible outbreaks if the land is returned to cropland. In 1992 and 1993, Kennedy (1994) evaluated the effects of management on nongame birds, vegetation structure, and insect biomass in the CRP lands of the same demonstration project as this study. A more detailed study of the arthropod populations of the CRP demonstration sites was conducted in 1995 and 1996 in order to gain an understanding of the insect fauna present and to address questions regarding potential pest species. The objectives of this study were to: (1) taxonomically identify the fauna present, (2) determine arthropod abundances, (3) determine which groups responded to grazing and haying treatments, (4) identify any potential pest species, and (5) make recommendations for post-contract uses of CRP lands with regard to maintaining high arthropod diversity.

STUDY SITES

The three study sites for this project were located in Bowman, Ward, and Stutsman counties, North Dakota. These sites were enrolled in the Conservation Reserve Program in 1987 and have been in a grazing and haying demonstration since 1992. There were six experimental tracts per site, each with five treatments: three pastures in a twice-over rotation system (TOR-A, TOR-B, and TOR-C), one pasture grazed seasonlong (SL), and one hayed field (H). An idle field (I) that had been undisturbed since enrollment in the program served as a control plot. For a detailed illustration of the study plots on each site see Harris (1996: Figs. 1-4). Cattle in the twice-over rotation system were rotated between pastures every 21 days and completed the cycle twice each season. Hayed fields were mowed twice, once in June and again in July.

The Bowman County site is 16 km (10 mi) south of Bowman, North Dakota. It is located on the Missouri Plateau which is a gently sloping plain with buttes and hills having a semiarid, continental climate (USDA-SCS 1975). Most of North Dakota is characterized by mixed grassland containing both medium and tall grass species. Bowman County occurs in the region where the dominant grasses are wheatgrass (*Agropyron* and *Elytrigia* spp.) and needlegrass (*Stipa* spp.) (GPFA 1986). The soil association of the region is Rhoades-Moreau with well drained, loamy soils with a claypan (USDA-SCS 1975). At this site 150 ha (370 acres) were planted in the fall of 1988 with a mixture of crested wheatgrass, intermediate wheatgrass, and alfalfa (See Appendix A for botanical nomenclature of CRP planting mixtures). The grazing schedule for the Bowman County site is listed in Table 1.

The Ward County site is 48 km (30 mi) southwest of Minot, North Dakota. It is located on the Missouri Coteau (Bluemle 1991) with rolling morainic hills in a subhumid, continental climate (USDA-SCS 1974). The dominant vegetation of the area is wheatgrass, little bluestem *(Schizachyrium scoparium),* and needlegrass species (GPFA 1986). The Max-Williams association of soil prevails and indicates a well drained, loamy soil formed in glacial till (USDA-SCS 1974). In the spring of 1987, 99 ha (245 acres) of western wheatgrass, slender wheatgrass, and alfalfa were planted in the Ward county site. The grazing schedule of the Ward County site is given in Table 2.

The Stutsman County site is 3.2 km (2 mi) west of Streeter, North Dakota. This area is situated on the Missouri Coteau (Bluemle 1991) with gently rolling terrain and a subhumid, continental climate (USDA-NRCS 1995). The primary grass species of the region are wheatgrass, bluestem, and needlegrass (GPFA 1986). The soil is a Barnes-Buse Association which is a well drained and medium textured soil (USDA-NRCS 1995). In the spring of 1987, 136 ha (337 acres) were planted with tall wheatgrass, intermediate wheatgrass, smooth brome,

Table 1. Grazing schedule for 1995 and 1996 at the Bowman County study site. Stocking rates were 46 cow/calf pairs in the twice-over rotation (TOR) and 20 cow/calf pairs in the seasonlong grazed. Cattle were rotated every 21 days for a 126 day grazing season both years.

Pasture	PERIOD OF GRAZING 1995
TOR-A	May 25 - June 13
TOR-B	June 14 - July 4
TOR-C	July 5 - July 25
TOR-A	July 26 - August 15
TOR-B	August 16 - September 5
TOR-C	September 6 - September 26
Seasonlong	May 25 - September 26

Pasture	PERIOD OF GRAZING 1996
TOR-A	May 23 - June 12
TOR-C	June 13 - July 3
TOR-B	July 4 - July 24
TOR-A	July 25 - August 14
TOR-C	August 15 - September 4
TOR-B	September 5 - September 25
Seasonlong	May 23 - September 25

alfalfa, and yellow and white sweet clover. Table 3 gives the grazing schedule for Stutsman County.

METHODS

Experimental Design

Marshall et al. (1994) recommended methods of sampling, both active and passive, when conducting inventories of arthropod populations. Several methods are necessary to collect arthropods from all aspects of the community. Four methods recommended by Marshall et al. (1994) were used in this study: flight intercept traps, pitfall traps, soil samples, and sweep net. Traps were randomly placed within each pasture and other sampling was conducted in the area surrounding the traps. There were five sampling periods in 1995, once each month from May through September and four periods May through August in 1996. During each period soil and sweep net samples were taken and flight intercept and pitfall traps serviced. In order to facilitate sample sorting, material was sorted to morphospecies which was defined by Oliver and Beattie (1996) as taxa readily separable by morphological differences that are obvious to individuals lacking exten-

Table 2. Grazing schedule for 1995 and 1996 at the Ward County study site. Stocking rates were 49 cow/calf pairs in the twice-over rotation (TOR) and 16 cow/calf pairs in the seasonlong grazed. Cattle were rotated every 21 days for a 126 day grazing season in 1995 and a 78 day grazing season in 1996. The 1996 season was shorter due to lack of forage production.

Pasture	PERIOD OF GRAZING 1995
TOR-A	May 17 - June 6
TOR-B	June 7 - June 27
TOR-C	June 28 - July 18
TOR-A	July 19 - August 8
TOR-B	August 9 - August 29
TOR-C	August 30 - September 19
Seasonlong	May 17 - September 19
Pasture	**PERIOD OF GRAZING 1996**
TOR-B	May 24 - June 13
TOR-C	June 14 - July 4
TOR-A	July 5 - July 25
TOR-B	July 26 - August 9
Seasonlong	May 24 - August 9

Table 3. Grazing schedule for 1995 and 1996 at the Stutsman County study site. Stocking rates were 55 cow/calf pairs in the twice-over rotation (TOR) and 32 cow/calf pairs in the seasonlong grazed. Cattle were rotated every 21 days for a 126 day grazing season both years.

Pasture	PERIOD OF GRAZING 1995
TOR-A	May 11 - May 31
TOR-B	June 1 - June 21
TOR-C	June 22 - July 12
TOR-A	July 13 - August 2
TOR-B	August 3 - August 23
TOR-C	August 24 - September 14
Seasonlong	May 11 - September 14
Pasture	**PERIOD OF GRAZING 1996**
TOR-B	May 17 - June 6
TOR-C	June 7 - June 27
TOR-A	June 28 - July 18
TOR-B	July 19 - August 8
TOR-C	August 9 - August 29
TOR-A	August 30 - September 20
Seasonlong	May 17 - September 20

sive taxonomic knowledge. All specimens were stored in 80% ethanol for preservation purposes. The Severin McDaniel Insect Research Collection at SDSU was used as a reference aid in identification of many taxa, along with Borror, Triplehorn, and Johnson (1989). Diplopoda were identified using Keeton (1960). Acrididae were identified using Pfadt (1994). Formicidae were identified using Wheeler and Wheeler (1963). Carabidae were identified using Lindroth (1961-1969).

Flight Intercept Trap

The flight intercept trap (FIT) design was adapted from Peck and Davies (1980) (Fig. 1). The trap is designed to collect aerial arthropods such as flies (Diptera), beetles (Coleoptera), and bees and wasps (Hymenoptera). Black nylon mesh screening 184 cm x 92 cm (6 ft. x 3 ft.) was supported by two 122 cm (4 ft.) dowel rods and nylon cord guylines. All four corners of each screen were grommetted through duct tape and elastic loops from the grommet connected the screen to an eyelet screw with an s-hook to the poles. The guylines were tied to the poles and anchored to the ground with plastic tent stakes. Cord locks were used to adjust tension on the guylines. Plastic pans 40 x 20 x 5 cm (16 x 8 x 2 in.) were positioned lengthwise two-by-two beneath the mesh screen within a trench and flush with the soil surface. Ten pans were used with half painted yellow so the trap was more attractive to a greater variety of insects. The collecting pans were partially filled with propylene glycol which acts as a killing agent and preserves the samples between trap servicings. Recovered samples were sieved through a small aquatic dipnet and placed in Whirl Pac® plastic bags with 80% ethanol for initial working and temporary storage. There were two traps within each tract designated FIT 1 and FIT 2. FIT 1 was oriented north-to-south and FIT 2 was east-to-west. Barbed wire fences were set-up around each trap as exclosures to prevent damage from cattle.

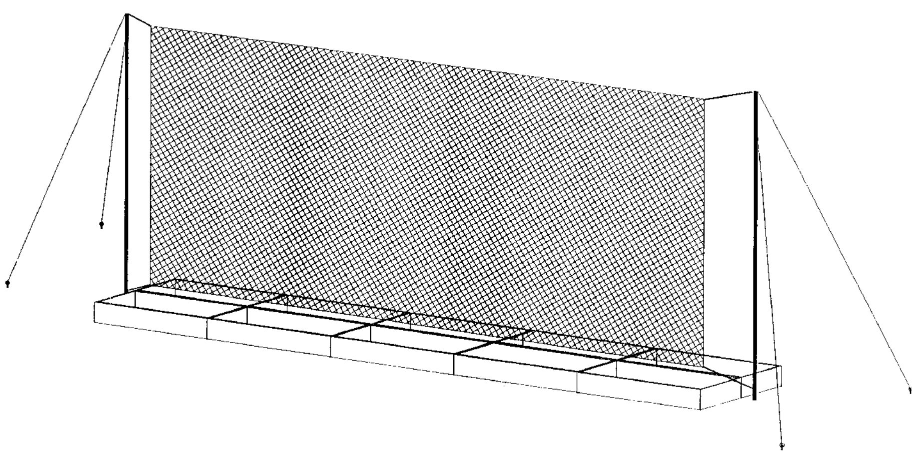

Figure 1. Design illustration of a flight intercept trap. Insects fly into the screen then fall into the collecting pans.

Pitfall Traps

Pitfall trap methodology was adapted from Majer (1978). These traps target ground-dwelling taxa that include beetles (Coleoptera), ants (Hymenoptera), and spiders (Araneae). Pitfall traps consisted of an 18 cm (7 in) section of 3/4 in. diameter PVC tubing and a glass test tube 1/4 filled with propylene glycol. The PVC tubing protects the test tube and facilitates changes and sample recovery. A steel soil probe was used to create a hole for the tubing to be placed in the ground, flush with the soil surface. Within each tract, nine pitfall traps were used in three sets of three arranged 30 cm apart in a triangle. Each set was placed ten paces from the FIT exclosure within the 1,000 square meter sampling area and marked with an orange painted wooden stake. In hayed fields, pitfall traps were placed inside the FIT exclosure or near obstruction in order to minimize mower and trap damage. These traps were marked with red plastic flags instead of wooden stakes so haying machinery was not damaged.

Soil Sampling

Soil samples were taken in order to collect below-surface arthropods such as mites (Acari) and springtails (Collembola). Six soil samples were extracted randomly from each tract, removing any turf and the top 3 in. of soil. The samples were taken with a square shovel and stored in brown paper bags in coolers to prevent heating and desiccation. Samples 1-3 were taken around FIT 1 and samples 4-6 were taken around FIT 2. Sampling was possible only in spring and late summer months. Mid-summer sampling was not conducted in 1996 because at each site the ground was too dry and difficult to penetrate, and 1995 mid-summer sampling provided inconsistent or no results. Later in a laboratory setting, these samples were placed in Tullgren funnels for heat extraction of arthropods.

Sweep Net Samples

Sweep netting was done to obtain arboreal arthropods occurring in the vegetation canopy. Insects collected using this method included grasshoppers (Orthoptera), true bugs (Heteroptera), and planthoppers (Auchenorrhyncha). Sweeps were made in two 100m x 3m transects in each tract, one from north to south and one from east to west to encompass a 600 square meter sampling area. Sweep netting was not possible during rain events or when the grass was too wet. Samples were placed in plastic locking bags, stored in a cooler to reduce activity, and subsequently put in a freezer for killing purposes.

Statistical Analysis

Correspondence Analysis (COA) (SAS Institute, Inc. 1990) was used to search for possible relationships between insect groups and grazing treatments. This ordination technique was used because it is the best way to summarize complex multi-attribute invertebrate community data (ter Braak 1987). COA is a weighted principal component analysis which reciprocally double-transforms community data (by taxon and sampling units) and then employs eigenanalysis to produce corresponding species and sampling unit ordinations (Ludwig & Reynolds 1988). Trends from COA were tested by analysis of variance (ANOVA) with county sites used as replications and pastures as treatments. Normal probability tests were performed to ensure the data were normally distributed. If a morphospecies occurred less than ten times in either 1995 or 1996 or less than 20 times in the combined data set, it was considered rare and excluded from the analysis. The number ten was chosen due to a gap in the data at that level of abundance.

Shannon's Index (Shannon & Weaver 1949) was used to calculate species diversity for pastures and counties. The equation for generating the index is H= (-1) multiplied by P times the log 10(P) where P is the number of species that occurred in each sample. Diversity may be defined as a function of the number of species present (species richness or abundance) and the evenness with which individuals are distributed among species (species evenness or equitability) (Margalef 1958). A diversity index attempts to combine data on abundance within species in a community into a single number (Washington 1984). Shannon's Index was used in addition to COA to further investigate possible differences between pastures and county sites. An ANOVA was used on the diversity indices generated in order to test for significant differences.

RESULTS

Appendix B gives a complete listing of all organisms collected and identified from 1995 and 1996. Figure 2 compares numbers collected for major insect orders for the two seasons. A combined total of 82,246 specimens were collected during 1995 and 1996. The two most abundant groups were Hymenoptera (primarily ants) and Diptera (flies). Ants (Formicidae) accounted for 23.9% of the total species, while Diptera accounted for 20.2%. Two other highly abundant groups were the Carabidae (ground beetles) which made up 8.3% of the total collection and spiders at 7.7%.

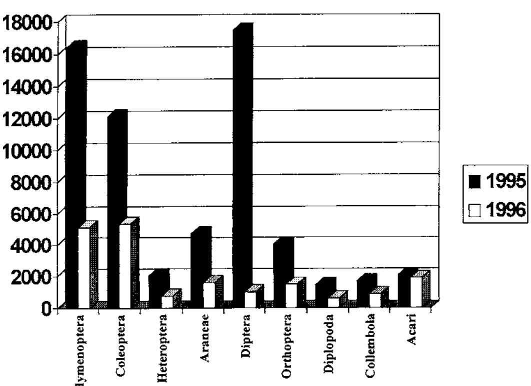

Figure 2. Relative and approximate numbers collected from the major arthropod orders in 1995 and 1996.

Although fewer insects were collected in 1996, separate analysis showed similar trends for both 1995 and 1996. Thus, data from both sampling seasons were combined in order to perform statistical analyses, and all COA ordination plots shown and abundances listed are based on both data sets pooled.

Figure 3 is the COA ordination for the major insect orders. The four grazing treatments and most orders do not separate out on the ordination plot. The idle and hayed treatments separated into a cluster with the Diplopoda and Hymenoptera. The COA ordination of each county site supports the trend of Diplopoda and Hymenoptera related to the idle and hayed treatments. In Bowman County (Fig. 4), the idle area along with the two groups separated from the others in a cluster while the hayed is somewhat separated. The COA for Stutsman County (Fig. 5) shows the hayed field, Diplopoda, and Hymenoptera in a cluster, whereas the idle area is separated from the rest of the plot in relation to the hayed. In Ward County (Fig. 6) the relation is not as clear. The idle and hayed treatments are closely related and are both being influenced by the Diplopoda and only somewhat influenced by Hymenoptera. Though causes for this relationship are not clear, it is supported by higher relative abundances of these groups in these treatment areas.

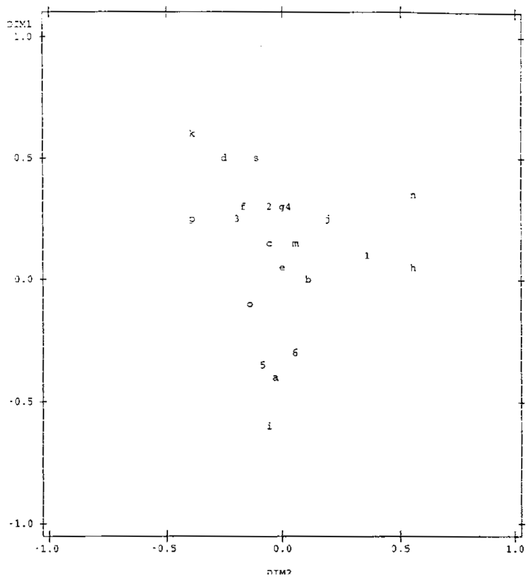

Figure 3. COA ordination for major arthropod orders. Numbers refer to treatments: TOR-A(1), TOR-B(2), TOR-C(3), Seasonlong(4), Idle(5), Hayed(6). Letters refer to groups of arthropods: Hymenoptera(a), Coleoptera(b), Heteroptera(c), Lepidoptera(d), Araneae(e), Diptera(f), Orthoptera(g), Ephemeroptera(h), Diplopoda(i), Odonata(j), Ixodidae(k), Collembola(m), Tetranychidae(n), Symphyla(o), Thysanoptera(p), Chilopoda(s).

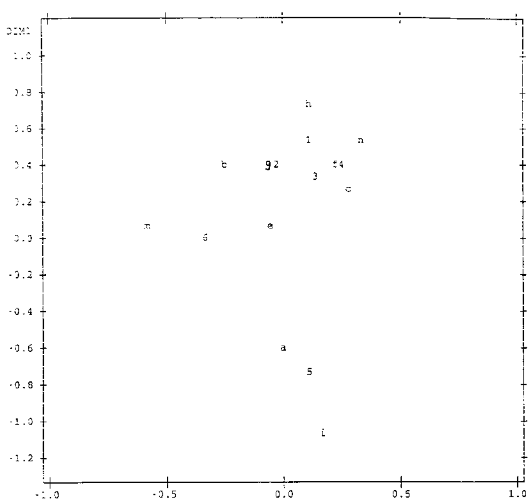

Figure 4. COA ordination for arthropods collected in Bowman County. Numbers refer to treatments: TOR-A(1), TOR-B(2), TOR-C(3), Seasonlong(4), Idle(5), Hayed(6). Letters refer to groups of arthropods: Hymenoptera(a), Coleoptera(b), Heteroptera(c), Araneae(e), Diptera(f), Orthoptera(g), Ephemeroptera(h), Diplopoda(i), Collembola(m), Tetranychidae(n).

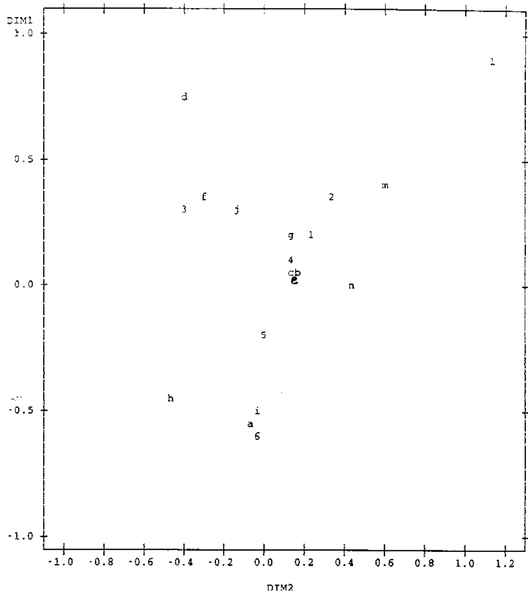

Figure 5. COA ordination for arthropods collected in Stutsman County. Numbers refer to treatments: TOR-A(1), TOR-B(2), TOR-C(3), Seasonlong(4), Idle(5), Hayed(6). Letters refer to groups of arthropods: Hymenoptera(a), Coleoptera(b), Heteroptera(c), Lepidoptera(d), Araneae(e), Diptera(f), Orthoptera(g), Ephemeroptera(h), Diplopoda(i), Odonata(j), Collembola(m), Tetranychidae(n).

The difference in mean abundance of the millipede *Narceus annularis* between pastures was significant (F=5.58, df=14, P=0.0218, Table 4). Idle and hayed treatments were statistically different from all grazing treatments, but were not statistically different from each other (P= 0.6707). Abundances of Diplopoda were also statistically different between county sites (F=11.50, df=14, P= 0.0061). Stutsman County had the highest abundance, but no millipedes were collected from the TOR-A, TOR-C, and SL pastures in Bowman County.

Correspondence analysis on the order Hymenoptera determined which families were more abundant in the idle and hayed treatments (Fig. 7). From the ordination plot, it appears that ants are correlated with idle and hayed fields. An ANOVA indicated a significant trend in mean abundance of ants between the non-grazed versus grazed treatments (F=2.60, df=17, P= 0.0934, Table 5). There was no significant difference in mean abundance between county sites (F=0.13, df=17, P= 0.8828).

Several other orders in addition to Hymenoptera contain many families, therefore COA was used to detect possible trends at family levels. The ordi-

Table 4. Mean abundance and density per square meter of Narceus annularis in each of the six treatments for 1995 and 1996 combined. The symbol (—) in the table refers to a mean and density of zero for that treatment.

Pasture	Mean	Density (#/sq m)
TOR-A	—	—
TOR-B	38.3	0.03
TOR-C	15.8	0.01
Seasonlong	—	—
Idle	224.6	0.22
Hayed	253.6	0.25

nation of beetles (Fig. 8) shows a cluster containing the idle fields with the Elateridae and Curculionidae. Cicindelidae appear associated with the idle treatment, however tiger beetles were found in few numbers in all treatments with just slightly higher numbers collected in the idle and TOR-C. So the Elateridae and Curculionidae are having the most influence on the position of the idle on the ordination plot because both groups were collected in high numbers.

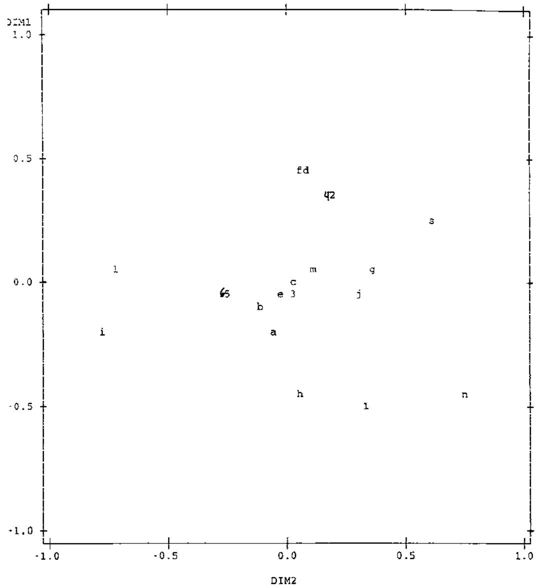

Figure 6. COA ordination for arthropods collected in Ward County. Numbers refer to treatments: TOR-A(1), TOR-B(2), TOR-C(3), Seasonlong(4), Idle(5), Hayed(6). Letters refer to groups of arthropods: Hymenoptera(a), Coleoptera(b), Heteroptera(c), Lepidoptera(d), Araneae(e), Diptera(f), Orthoptera(g), Ephemeroptera(h), Diplopoda(i), Odonata(j), Collembola(m), Tetranychidae(n), Chilopoda(s).

The differences in mean abundance of Elateridae (click beetles) (Table 6) from one pasture to another were not significant in 1995 (F=1.00, df=17, P= 0.4631) or in 1996 (F=1.71, df=17, P= 0.2201). Mean click beetle abundances were significantly different between counties in both years (F=4.71, df=17, P= 0.0361 for 1995; F=6.75, df=17, P= 0.0139 for 1996). Ward County had the greatest abundance and was statistically different from Bowman (P= 0.0126) and Stutsman (P= 0.0217) counties.

Mean abundance of Curculionidae (weevils) did not differ significantly between pastures (F=0.91, df=17, P= 0.5097, Table 7). However, county differences were significant (F=10.83, df=17, P= 0.0031) with the highest abundance

Table 5. Mean abundance and density per square meter of Formicidae for each of the six treatments for 1995 and 1996 combined.

Pasture	Mean	Density (#/sq m)
TOR-A	672.33	0.67
TOR-B	578.00	0.57
TOR-C	702.00	0.70
Seasonlong	480.33	0.48
Idle	2246.66	2.24
Hayed	1885.00	1.88

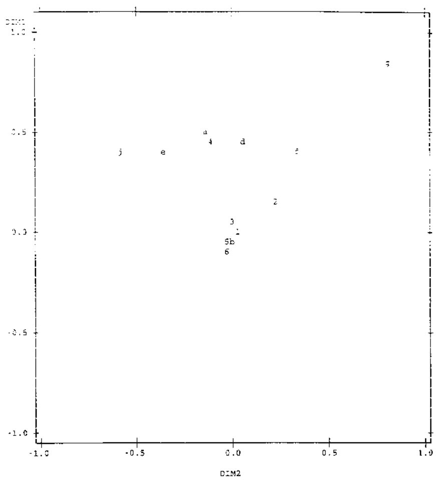

Figure 7. COA ordination for Hymenoptera. Numbers refer to treatments: TOR-A(1), TOR-B(2), TOR-C(3), Seasonlong(4), Idle(5), Hayed(6). Letters refer to families of Hymenoptera: Apidae(a), Formicidae(b), Halictidae(d), Chrysididae(e), Braconidae(f), Ichneumonidae(g), Vespidae(j).

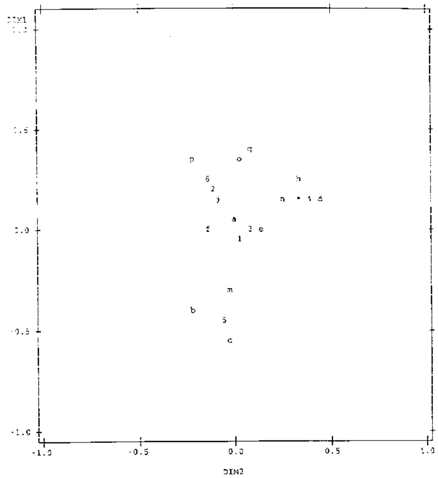

Figure 8. COA ordination for Coleoptera. Numbers refer to treatments: TOR-A(1), TOR-B(2), TOR-C(3), Seasonlong(4), Idle(5), Hayed(6). Letters refer to families of Coleoptera: Coccinellidae(*), Carabidae(a), Cicindelidae(b), Elateridae(c), Scarabaeidae(d), Staphylinidae(e), Cantharidae(f), Chrysomelidae(h), Cerambycidae(j), Curculionidae(m), Lampyridae(n), Tenebrionidae(o), Silphidae(p), Meloidae(q).

Table 6. Mean abundance and density per square meter of Elateridae in each of the six treatments for 1995 and 1996.

	1995		1996	
Pasture	**Mean**	**Density**	**Mean**	**Density**
TOR-A	37.67	0.03	61.00	0.06
TOR-B	26.00	0.02	21.67	0.02
TOR-C	49.00	0.04	31.33	0.03
Seasonlong	11.00	0.01	21.00	0.02
Idle	130.00	0.13	77.00	0.07
Hayed	41.00	0.04	20.33	0.02

Table 7. Mean abundance and density per square meter of Curculionidae in each of the six treatments for 1995 and 1996 combined.

Pasture	Mean	Density (#/ sq m)
TOR-A	145.33	0.14
TOR-B	119.33	0.11
TOR-C	123.33	0.12
Seasonlong	63.00	0.06
Idle	259.33	0.25
Hayed	119.00	0.11

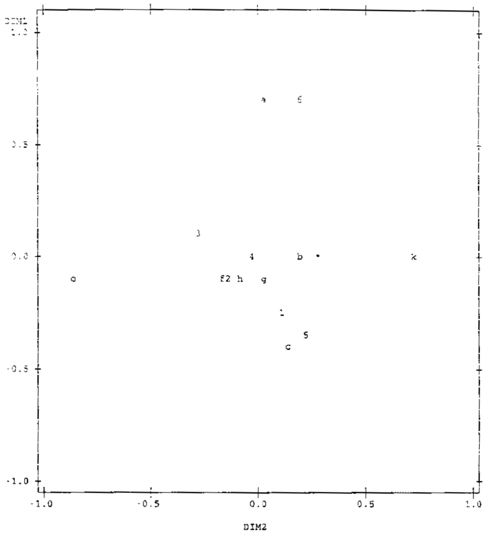

Figure 9. COA ordination for Heteroptera. Numbers refer to treatments: TOR-A(1), TOR-B(2), TOR-C(3), Seasonlong(4), Idle(5), Hayed(6). Letters refer to families in Heteroptera: Pentatomidae(*), Miridae(a), Cercopidae(b), Nabidae(c), Cicadellidae(f), Phymatidae(g), Aphidae(h), Membracidae(k), Coreidae(o).

Table 8. Mean abundance and density per square meter of Miridae in each of the six treatments for 1995 and 1996 combined.

Pasture	Mean	Density (#/ sq m)
TOR-A	12.33	0.02
TOR-B	20.66	0.03
TOR-C	35.00	0.05
Seasonlong	22.33	0.03
Idle	3.90	0.01
Hayed	57.66	0.09

Table 9. Mean abundance and density per square meter of Acrididae in each of the six treatments for 1995 and 1996. The symbol (—) in the table indicated a mean and density of zero calculated for that treatment.

	1995		1996	
Pasture	Mean	Density	Mean	Density
TOR-A	11.00	0.01	15.66	0.02
TOR-B	56.79	0.09	26.00	0.04
TOR-C	12.00	0.02	17.33	0.02
Seasonlong	5.66	0.01	28.66	0.04
Idle	0.79	0.01	—	—
Hayed	15.00	0.02	21.66	0.03

in Ward County being statistically different from Bowman (P=0.0016) and Stutsman (P= 0.0039) counties.

The COA ordination of the order Heteroptera is shown in Figure 9. The family Miridae (plant bugs) separates from all others and is associated with the hayed treatment. ANOVA indicated the difference in mean plant bug abundance between the hayed treatment and others was statistically significant (F=3.61, df=16, P= 0.0456, Table 8). The difference in mean abundance between counties was significant (F=4.75, df=16, P= 0.0391). Bowman County had the greatest abundance which was statistically significant from Ward (P= 0.0369) and Stutsman (P= 0.0208) counties.

The potential of grasshopper (Acrididae) problems in CRP is an important one among grassland managers. Even though Acrididae did not show a strong relationship to any one treatment (Fig. 3), an ANOVA was used to test for significance. Differences among pastures (F=1.48, df=15, P= 0.2959) and county sites (F=2.66, df=15, P= 0.1300) were not significant in 1995. In 1996, pasture differences were significant (F=3.54, df=16, P= 0.0479) due to the very small numbers collected in the idle (Table 9). When the idle treatment is removed from the analysis, the P value is no longer significant (F=1.20, df=14, P= 0.3803). There was a significant trend between county abundances (F=3.72), statistically different from Bowman (P= 0.0197) and a significant trend from Stutsman (P= 0.0684) counties.

There were no significant differences in overall arthropod diversity between pastures (F=0.85, df=17, P= 0.5439) or counties (F=0.36, df=17, P= 0.7072) for either 1995 or 1996. A greater mean diversity index was observed for all of the grazed treatments over the idle and hayed areas (Table 10) with the idle having the lowest mean diversity. Bowman County had a lower mean diversity index than the other two county sites with Ward county samples having a slightly higher index than Stutsman county samples (Table 10).

Table 10. Mean insect diversity index for each pasture and county in 1995 and 1996 combined.

Pasture	Mean Diversity Index
TOR-A	1.17
TOR-B	1.17
TOR-C	1.13
Seasonlong	1.15
Idle	0.96
Hayed	1.06

County	Mean Diversity Index
Bowman	1.07
Ward	1.14
Stutsman	1.11

DISCUSSION

Comparison of 1995 and 1996 sampling seasons

Arthropod abundance differed greatly between the two sampling seasons. This was probably a result of unusually low precipitation in the summer of 1996. This drought caused cattle to be removed from the Ward County site in early August due to lack of adequate forage. Snowfall in late May in Bowman County may also be responsible for the low numbers collected. The low mid-summer precipitation in 1996 at all three locations caused excessive evaporation of the propylene glycol in some flight intercept traps resulting in less trap catches. Cattle damage was also partly responsible for a lower trap catch. On a few occasions, calves entered the FIT exclosures and demolished traps. There were also several instances where cattle broke or pulled stakes marking pitfall locations, therefore making finding traps very difficult.

Arthropod responses to grazing and haying management

Studies have shown specific groups of insects will respond differentially to grazing intensities. In this study several groups, such as millipedes and ants, were more abundant in ungrazed areas. The plant bugs responded positively to the haying treatment and were significantly more abundant. Morris & Lakhani (1979) showed Hemiptera abundance and species richness could be maintained only by early cuttings. The hayed fields in this study were cut twice, once in June and again in July, and caused an increase in plant bug numbers. A possible reason for their increase could be the population benefitted from regenerated growth of the vegetation after haying. In response to the cutting, plants will produce new succulent growth that plant bugs can easily feed upon.

Results showed that ants did not seem to benefit from grazing disturbance. In a study by Majer and Beeston (1996) rangeland grazing reduced ant diversity and changed community composition in modified areas of native vegetation in western Australia. An apparently similar decrease in mean ant abundance was due to grazing in the CRP demonstration sites (Table 5), however ant species composition does not seem to be altered. Six species of ants were recovered from the CRP demonstration sites which is lower than the 20 species reported from mixed-grass rangeland in Slope County, North Dakota and Harding County, South Dakota (Catangui et al. 1996). These locations are adjacent to the Bowman County site in this study. Three species were reported from both studies, *Lasius neoniger, Solenopsis molesta,* and *Myrmica americana.* Catangui et al. (1996) reported six species of *Formica,* while only three were recovered from CRP lands in this study. The lower species richness observed in CRP could be a reflection of the low plant diversity in CRP as a result of its early successional stage. Soil compaction as a result of cattle trampling or the disturbance from the presence of cattle may also discourage ants from building nests and inhabiting grazed areas.

Millipedes *(Narceus annularis)* also did not benefit from cattle grazing. These millipedes were found in much lower densities in grazed areas. Soil compaction from cattle trampling may discourage millipedes from inhabiting grazed areas. There have been recordings of millipedes living in the nests of ants (Holldobler & Wilson 1990; Murakami 1965; Rettenmeyer 1962), but there are no records of *N. annularis* co-occurring with ants. Whether the presence of the millipedes may be attributed to the ants is only speculation at this time. Millipedes may occur in higher densities in Stutsman County due to higher precipitation and soil moisture there than the other sites. Bowman County, on average, is drier than the other two sites and millipedes were not collected from three grazed treatments in Bowman county.

Click beetles were more abundant in idle areas, predominantly in Ward County, but between pasture differences were not significant. The overall greater abundance of click beetles in Ward County could be attributed to the soil conditions. Click beetle immatures prefer well drained loamy soils. In contrast, the claypan soils of Bowman County did not appear to support high numbers of click beetles. Wireworms are of concern to landowners because they sometimes feed on the roots of young plants and could lead to pest problems if CRP land is converted to cropland. Of the click beetle species collected, only a few have a history as pests. *Aeolus mellillus* (the flat wireworm) has long been considered a pest of agricultural crops such as wheat, corn, and sugar beets (Stirret 1936). Although it has a history as a pest in Canada (Beirne 1971) and in the United States (Glen et al. 1943), it has not caused significant damage in recent years. This may be due to its recognition as a predator of other click beetle species and as a facultative phytophage. *Ctenicera destructor* (prairie grain wireworm) and *Hypnoides bicolor* are the most widespread species responsible for economic damage in the Canadian prairies (Doane 1977). However, both of these two species occurred at very low densities (Table 6). If CRP is returned to cropland, wireworms could be a pest of minor significance in the Northern Great Plains for the first two or three years, but can be easily managed with appropriate non-susceptible crops such as oats and alfalfa.

Grasshoppers receive much attention from rangeland managers due to their potential as pest species. At outbreak densities, they compete with livestock for forage. Grasshopper populations in the CRP demonstration sites suffered in 1995 due to a cold and wet spring. The lower numbers collected in Ward County were likely a result of poor feeding conditions due to little precipitation and the lack of forage production. Because fewer grasshoppers were collected in all pasture types there was no significant difference between treatments. In 1996 there was a significant difference between the idle and grazed areas because few grasshoppers were collected in idle areas. Even though grasshoppers occurred in greater numbers in grazed areas, the densities calculated are extremely low (Table 9) and in no way resemble pest level densities. The findings in this study are in opposition to others because fewer grasshoppers were collected in idle areas than in grazed areas. This may be due to the high volume of forage consisting of species which are not palatable to grasshoppers and also to grasshopper growth being inhibited early in the season due to cooler than average temperatures. Fielding & Brusven (1995) recorded higher mean grasshopper density on ungrazed sites than on grazed sites. Capinera & Sechrist (1982b) also recorded higher numbers of grasshoppers in ungrazed or lightly grazed pastures and reiterated observations that grasshopper abundance was higher in ungrazed or lightly grazed pastures relative to moderately to heavily grazed pastures. Inadequate rotation and high stocking rates may cause range quality to decrease and weeds to increase, thus causing grasshopper numbers to increase. The increase in abundance may be accompanied by a shift in the species complex resulting in more obligate grass-feeding species. The grazing regimes used in the CRP demonstration maintained substantial forage and did not support high densities of pest species.

Several of the grasshopper species collected are characteristic of disturbed land (Pfadt 1994), these being *Melanoplus differentialis* (differential grasshopper), *Melanoplus packardii* (Packard's grasshopper), and *Melanoplus sanguinipes* (migratory grasshopper). The differential grasshopper is considered a severe pest of cultivated crops, but is of little importance in grasslands due to the absence of preferred host plants (McDaniel 1987). Therefore, potential problems from this species in CRP are not likely. Packard's grasshopper is known to be well adapted to ruderal habitats such as CRP land where sweetclover and smooth brome are available as host plants. However, because this species usually occurs in low densities on rangeland and has a preference for poor forage plants, it causes little damage and is not a major threat (Pfadt 1994). In contrast, the migratory grasshopper is a serious pest of both crops and grasslands. High densities infesting rangeland can deplete forage for livestock, including blue grama, western wheatgrass, and bluegrasses (Pfadt 1994). Population outbreaks usually occur on weedy rangeland which has been overgrazed. Usually in healthy rangeland weather conditions and natural enemies (ground beetles, birds, etc.) keep populations of the migratory grasshopper in check (Pfadt 1994).

Two other species, *Chorthippus curtipennis* (meadow grasshopper) and *Anabrus simplex* (Mormon cricket), were uncommon. Although the meadow grasshopper feeds on valuable forage grasses, it is not known to cause significant damage (Pfadt 1994). Mormon crickets feed on cultivated crops as well as rangeland plants, but few were collected. Whether this indicates either a low point in their population cycle or normal populations in the study area cannot be determined from the data sets.

Correspondence analysis was done on the order Diptera (flies), but all treatments and families appear together with no separate clusters to interpret. Flies that are characterized as inhabiting grasslands were collected in small numbers. In contrast, Calliphoridae (blow flies) and Scathophagidae (dung flies) were extremely abundant, but their occurrence is attributed to the presence of cattle. Due to the layout of the demonstration sites, grazed pastures are in close proximity to ungrazed. Because these flies are transient in behavior, associated with dung, and were collected from all treatments, they are a poor indicator group of between pasture differences.

Carabidae (ground beetles) were not significantly affected by grazing or haying treatments because they showed no distinguishable trend to any one treatment from COA ordination (Fig. 8). Ground beetles have received considerable attention in agricultural systems because they are the dominant group of epigaeic predators in temperate regions and can affect the population dynamics of phytophagous insects (Potts & Vickerman 1974). Because ground beetles are taxonomically diverse and can aid in natural control of insect pests, the effects of various management practices on ground beetles are well studied (e.g., Carcamo 1995; Carcamo et al. 1995; Weiss et al. 1990). Overall sixteen species of ground beetles were identified from this study. This represents a diverse group of potential predators in CRP to provide some level of pest control to groups such as grasshoppers. Since ground beetles were not significantly affected by grazing or haying disturbance, then these practices would be suitable for post-contract CRP lands with respect to this major group of predatory insects.

Arthropod diversity

A diversity index was used as well as an ordination technique to compare results obtained from two different analyses. Shannon's index was chosen because it is one of the best known indices and one of the most commonly used measures. This index indicated no significant difference in arthropod diversity among pastures or county sites based on species richness and evenness. However, COA revealed there were a few specific groups of arthropods that differed significantly in abundance between grazed and ungrazed areas. Therefore, COA revealed ecological trends which could not have been determined with a diversity measure alone. However, the diversity index indicated the between pasture differences in abundance were not great enough to significantly alter overall arthropod diversity.

Although county sites did not differ significantly in diversity, there were differences in mean abundance of some groups between the sites. Differences could be expected due to the varying climates, soil types, and precipitation between the sites. Bowman County on average receives less precipitation than Ward or Stutsman counties, so Bowman County may be expected to have a significantly lower diversity index. Even though differences exist physiographically, the CRP planting mixtures were similar among the sites. Based on the overall results any apparent differences were not sufficient to cause significant differences between the sites.

When comparing CRP to other grassland types insect species richness appears to be low (e.g. Frank 1971; Capinera & Sechrist 1982b; Catangui et al. 1996). There are several possible reasons for this trend. One is the early successional stage of CRP grasslands. The sites used in this study were seeded only 10 years ago. Insect diversity may increase if the habitat is allowed to remain intact and evolve to a later successional stage. Another possibility to explain low insect diversity could be the plant diversity in CRP planting mixtures. If more species of grasses and forbs were planted, insects that prefer these species as host plants may colonize CRP. Another way to encourage higher plant diversity would be to allow the stands to reach later stages of succession. Changes in the plant cover of the demonstration sites have already been documented since the CRP plantings (Nyren et al. 1995). Given time, other species of grasses or forbs may move into CRP and become established and improve the quality of CRP for insects and other wildlife.

CONCLUSIONS AND RECOMMENDATIONS

The methods for this study were designed to collect arthropods from most strata and guilds of the community. Subsequent studies with methodology targeted at specific groups of arthropods would allow questions to be addressed regarding a single species or groups of species. For instance, grasshoppers were collected using sweep nets because all arboreal arthropods were of interest. In order to conduct a thorough study of the grasshopper fauna, quadrat counts or a similar method is recommended for accurate population estimates. If a study similar to this one was conducted on native prairie using the same methodology, direct faunal comparisons between a native habitat and an artificial one (CRP) could be made. A study of this nature is necessary to indicate the real potential of artificial perennial grasslands as wildlife habitat.

The Conservation Reserve Program has succeeded in protecting highly sensitive lands with respect to erosion and water quality. The best alternative for landowners may be to extend the program through 2002 if the plan is approved by the government. This would enable landowners to continue to benefit from CRP and allow for further investigations of management options. Ants and millipedes were the only groups adversely affected by grazing and haying management. The majority of the arthropod fauna was apparently not adversely affected in abundance or diversity when subjected to moderate levels of grazing and haying. Maintaining diverse arthropod populations ensures food for other wildlife species in CRP habitats and prevents population outbreaks by potential insect pest species. The stocking rates and rotations used in the demonstration project appeared to maintain habitat integrity. Results from this study suggest grazing and haying of CRP lands are viable post-contract uses with regard to maintaining diverse arthropod populations.

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Appendix A. Common and scientific names for grasses and legumes planted in Conservation Reserve Program grasslands of the demonstration project in North Dakota. Botanical nomenclature follows Flora of the Great Plains (1986) and The Jepson Manual (1993).

Common Name	Scientific Name and Author
crested wheatgrass	*Agropyron cristatum* (Linnaeus) Gaertner
intermediate wheatgrass	*Elytrigia intermedia* (Host) Nevski
western wheatgrass	*Pascopyrum smithii* (Rydberg) A.Love
slender wheatgrass	*Elymus trachycaulus* (Link) Shinners
tall wheatgrass	*Elytrigia elongata* (Host) Nevski
smooth brome	*Bromus inermis* Leysser
alfalfa	*Medicago sativa* Linnaeus
yellow sweet clover	*Melilotus officinalis* (Linnaeus) Palles
white sweet clover	*Melilotus alba* Medikus

Appendix B. Taxonomic list of all organisms collected during 1995 and 1996 in CRP Grazing and Haying Demonstration sites in North Dakota.

Taxon	Species and Author
Araneae	Thomisidae
	Lycosidae
Opiliones	
AcariIxodidae	
	Tetranychidae—2 species
	Oribatidae

Appendix B continued.

Taxon	Species and Author
Pseudoscorpiones	
Diplopoda	*Narceus annularis* (Rafinesque)
Chilopoda	Lithobiidae
Symphyla	
Hylidae	*Pseudacris triseriata*
Gastropoda	
Collembola	Entomobryidae
	Sminthuridae
Diplura	Japygidae
Ephemeroptera	
Odonata	
Anisoptera	Libellulidae
Zygoptera	Coenagrionidae—2 species
Orthoptera	
Acrididae	*Chorthippus curtipennis* (Harris)
	Melanoplus differentialis (Thomas)
	Melanoplus packardii Scudder
	Melanoplus sanguinipes (Fabricius)
Tettigoniidae	*Conocephalus* species
	Scudderia furcata furcata (Brunner)
Gryllacrididae	*Ceuthophilus alpinus* Scudder
Gryllidae	*Gryllus assimilis*
	Oecanthus species
Psocoptera	Liposcelidae
Heteroptera	
Miridae	*Adelphocoris* species
	Polymerus species
Nabidae	*Nabicula subcoleoptrata* (Kirby)
	Nabis species
Reduviidae	
Phymatidae	*Phymata* species
Coreidae	*Catorhinta mendica* Stal.
	Leptocoris trivittatus (Say)
Alydidae	*Alydus conspersus* Montandon
Pentatomidae	*Coenius* species
	Euschistus species
Membracidae	*Campylenchia* species
	Cyrtolobus species
Cercopidae	*Philaenus* species
Cicadellidae	*Chlorotettix* species
	Dorycephalus species
	Draeculacephala species
	Empoasca species
Aphididae	
Thysanoptera	Phlaeothripidae
Neuroptera	
Chrysopidae	*Chrysopa* species
Coleoptera	
Cicindelidae	*Cicindela punctulata* Oliv.
	Cicindela scutellaris Say

Appendix B continued.

Taxon	Species and Author
Carabidae	*Agonum cupreum* (Dejean)
	Agonum nigriceps (LeConte)
	Amara cupreolata Putzey
	Amara obesa Say
	Brachinus fulminatus Erwin
	Calleida viridis amoena LeConte
	Calosoma calidum Fabricius
	Carabus maeander Fischer
	Carabus taedatus Fabricius
	Chlaenius platyderus Chaudoir
	Cratacanathus dubius (Beauvois)
	Cymindis borealis LeConte
	Diplocheila striatopunctata LeConte
	Harpalus ocacipennis Haldeman
	Pasimachus elongatus LeConte
	Pterostichus diplophryus Chaudoir
Dytiscidae	
Silphidae	*Heterosilpha ramosa*
	Nicrophorus marginatus
Staphylinidae	*Bledius* species
	Paederinae species
	Platydracus species
	Quedius species
	Tachyporous species
Histeridae	*Spilodiscus* species
Scarabaeidae	*Aphodius fimetarius* Dejean
	Aphodius species
	Ataenius species
	Bolbocerosoma bruneri
	Canton laevis (Drury)
	Cremastocheilus species
	Diplotaxis species
	Ochodaeus species
	Onthophagus hectate Panz.
	Trox species
Elateridae	*Aeolus mellillus* (Say)
	Agriotes species
	Conoderus auritus (Herbst)
	Ctenicera destructor (Brown)
	Hemicrepidius memnonius (Herbst)
	Hypnoidus bicolor (Eschscholtz)
	Limonius ursinus (Van Dyke)
Lampyridae	*Lucidota* species
Cantharidae	*Chauliognathus pennsylvanicus* DeG.
	Podabrus tomentosus (Say)
Coccinellidae	*Coccinella septumtata*
	Hippodamia parenthesis Say
	Hippodamia tredecimpunctata (Say)
Tenebrionidae	*Eleodes hispilabris*
	Eleodes opaca
	Embaphion miricatum
Meloidae	*Epicauta pennsylvania*
	Lytta nuttalli

Appendix B continued.

Taxon	**Species and Author**
Cerambycidae	*Typocerus* species
Chrysomelidae	*Disonycha* species
	Microrhopala species
	Pachybrachis species
	Zygogramma exclamationis (Fab.)
Curculionidae	*Brachyrhinus ovatus* Linnaeus
	Lixus species
	Notaris wyomingensis Chitt.
	Notaris species
	Sitona scissifrons Say
Diptera	
Tipulidae	2 species
Bibionidae	*Bibio* species
Psychodidae	
Culicidae	
Chironomidae	
Tabanidae	*Chrysops* species
Rhagionidae	*Chrysopilus* species
Stratiomyidae	*Stratiomys* species
Asilidae	*Tolmerus* species
Bombyliidae	*Systoechus vulgaris* Loew
Syrphidae	*Sphaerophoria cylindrica* (Say)
Otitidae	*Tritoxa* species
Tephritidae	*Euaresta bella* (Loew)
Scathophagidae	*Scatophaga stercoraria* (Linnaeus)
Muscidae	*Musca* species
Calliphoridae	*Calliphora* species
	Cynomyopsis species
Tachinidae	*Peleteria* species
	Voria species
Lepidoptera	
Pieridae	*Pieris rapae* (Linnaeus)
Hymenoptera	
Tenthredinidae	
Braconidae	*Chelonus* species
Ichneumonidae	*Gambrus* species
	Gelis species
	Netelia species
Chrysididae	
Sphecidae	*Sphex* species
Halictidae	*Halictus* species
Apidae	*Apis mellifera* Linnaeus
	Bombus species
Mutillidae	
Pompilidae	*Psammochares* species
Vespidae	*Polistes* species
Formicidae	*Formica (fusca* group)
	Formica (exsecta group)
	Formica (Raptiformica)
	Lasius neoniger
	Myrmica americana Weber
	Solenopsis molesta (Say)

BIOREMEDIATION OF HYDROCARBON CONTAMINATED SOILS

David Vaughan
4513 470th Street
Mallard, IA

Diane Rickerl and Patricia Wieland
Plant Science Department
South Dakota State University
Brookings, SD 57007

Susan Gibson
Biology & Microbiology Department
South Dakota State University
Brookings, SD 57007

Courtenay Hoernemann
USDA, ARS, Grain Marketing and Production Research Center
Manhattan, KS 66502

ABSTRACT

In South Dakota, hydrocarbon contaminated soil (HCS) must be transported to a designated landfill for disposal. In this study, soil contaminated with diesel and used motor oil from a railroad roundhouse were excavated from a low-lying dump site and transported to the Brookings County Landfill, SD. Greenhouse studies were used to determine the effects of HCS and added compost on soil microbial populations and plant emergence (34 species) and growth (8 species). Field studies at the landfill were used to determine compost, tillage, and vegetation (oat/vetch) effects on soil hydrocarbon concentration, soil nematode numbers, plant growth, and mycorrhizal colonization. Viable counts for soil microorganisms, prior to greenhouse studies, showed higher populations of heterotrophs and hydrocarbon degraders in HCS than non-contaminated soils. Plant emergence in greenhouse studies was highly variable and impacts by soil treatments were not consistent. However, in greenhouse growth studies, legume dry weight and nodulation were generally negatively impacted by HCS compared to non-contaminated soil. In the landfill study, total petroleum hydrocarbons decreased over time, but decreases were significant only with the addition of compost. Adding compost to HCS improved plant top growth, but did not significantly affect mycorrhizal colonization. The addition of compost would be a relatively cheap and efficient method of reducing contamination in HCS.

Keywords

Waste oil, compost, viable counts, mycorrhizae, nematodes

INTRODUCTION

The use of petroleum as a fuel and/or lubricant has resulted in waste products that, if handled improperly, may result in hydrocarbon contamination of soil. Near Huron, South Dakota, nonvolatile petroleum hydrocarbons, which included diesel and used motor oil from a railroad roundhouse, were disposed of into a low-lying area from 1911 to 1994. In 1995, the area was declared an Environmental Protection Agency Superfund Cleanup Site.

In South Dakota, hydrocarbon contaminated soil (HCS) must be transported to one of five regional landfills that will accept HCS. One of the costs of remediation of a contaminated site is that the contaminated soil must be excavated and transported to the landfill. Not only does this add to the cost of cleanup, it may result in the relocation of a potential problem.

Landfills in North Dakota and Montana report that they have added 20% lawn compost along with 5% turkey manure to 75% hydrocarbon contaminated soil. The amendments increased microbial activity to degrade hydrocarbons (Goldstein and Riggle 1995). Lawn compost is readily available at most landfills and could be used as a carbon source to improve growth of microbes and thereby enhance hydrocarbon degradation. Most composts are relatively low in nitrogen content. To complete microbial nutrient needs, nitrogen could be provided from Rhizobia by a mutualistic association of *Rhizobium* with a legume cover crop.

The degradation of hydrocarbons by soil microbes is termed bioremediation. Soil microbes can interact with plant roots and utilize root exudates. Mycorrhizae fungi are root colonizers that can metabolize carbon compounds (Schnoor et al. 1995). In the rhizosphere, mycorrhizae utilize different enzymatic pathways to degrade hydrocarbons.

Hydrocarbons have shown varying effects on plant germination and growth. Radwin, Sorkhah, and El-Nemr (1995) found that some plants had tolerance to hydrocarbons and these plants could be grown in HCS that contained less than 10% oil sediments (by weight). If the level of oil sediments was higher than 10% the addition of non-contaminated soil was required to dilute the hydrocarbon level.

The goal of our research was to find an inexpensive, effective method of decreasing hydrocarbon concentrations in contaminated soil. Studies were conducted in the field and greenhouse. The objectives of the greenhouse studies were to:

a) Determine soil treatment effects on soil microbial populations.
b) Determine effects of HCS, with and without added compost, on plant emergence.
c) Determine effects of HCS on early plant growth and nodulation of legumes.

The objectives of the field study were to:

a) Determine if the level of hydrocarbons in contaminated soil could be decreased in one growing season with different landfill treatments.
b) Determine the effects of compost and tillage on plant growth in HCS.
c) Determine the effects of HCS treatments on the numbers of nematodes and the percent of mycorrhizal colonization.

METHODS

Emergence Study

The soil treatments for greenhouse studies were, non-contaminated soil (S), hydrocarbon contaminated soil (HCS), non-contaminated soil + compost (S+C), and hydrocarbon contaminated soil + compost (HCS+C). Non-contaminated soil was collected from a cropped field adjacent to the landfill. The average hydrocarbon concentration in contaminated soil used in the studies was 8100 mg kg^{-1}. Compost was added on a 10% dry weight basis. A soil test analysis of each soil treatment is presented in Table 1. Concentrations have been adjusted for the compost dilution effect.

Microbial viable counts (colony forming units g^{-1} wet wt, CFU's) were done on the four soil sets prior to use for germination studies. Serial 1:10 dilutions of each soil were done in sterile 0.075 M tetrasodium pyrophosphate at pH 7.2. The initial dilution was prepared by adding 10 g of soil to 95 ml of sterile 0.075 M tetrasodium pyrophosphate at pH 7.2. Two duplicate dilution series were prepared from each soil sample. Each initial soil suspension was shaken for 20 minutes on a wrist action shaker or on an orbital shaker. Triplicate spread plates were made from 0.1 ml samples from appropriate dilutions on nutrient agar (BBL) + 0.1 g l^{-1} cycloheximide for general heterotrophic bacteria, on Rose-Bengal Medium (DIFCO), and on a variation of oil agar medium (Atlas 1993). The oil agar medium was modified by omission of the amphotericin B and by using #2 diesel fuel for the hydrocarbon component. In order to get proper solidification of the medium, it was necessary to autoclave the medium components (including the phosphate and the agar but omitting the diesel fuel) in half of the volume of water. The diesel fuel sorbed to silica powder was autoclaved in the other half of the water. After autoclaving, the two were combined and poured into plates. Plates were incubated in the dark at room temperature.

Thirty-four grass and legume species were evaluated in the greenhouse plant emergence study (Table 3). Seeds were sown at five or ten seeds per pot (4 replicate pots) depending upon the seed size. Pots were approximately 9 cm diameter. Pots were watered daily with enough water to provide adequate moisture for growth. The temperature in the greenhouse was approximately 22°C. Emergence was recorded two weeks after plants were sown. This was a factorial experiment with a completely random design using four replications (pots) per treatment.

Growth Study

Soil treatments in the plant emergence study were repeated for the plant growth study (S, S+C, HCS, HCS+C). Greenhouse conditions and plant establishment were also similar to the emergence study. Eight plant species were selected for the growth study. Selection was based on emergence and appearance of growth in the emergence study and the ability to plant the seeds with equipment presently used at the Brookings Municipal Landfill. Four grasses including oat (*Avena sativa* L.), smooth bromegrass (*Bromus inermis* Leyss.), switchgrass (*Panicum virgatum* L.), and winter wheat (*Triticum aestivum* L.) and four legumes including alsike clover (*Trifolium hybridum* L.), field pea (*Pisum sativum* ssp. *arvense* (L.) Poir), hairy vetch (*Vicia villosa* Roth), and soybean (*Glycine max* (L.) Merr) were grown. This was a factorial experiment with a completely random design using four replications (pots) per treatment.

Plant top growth, root growth, and nodulation were determined after eight weeks. Plants were severed at the soil line. Top and root dry weights were determined from samples dried at 106°C and then weighed. Nodules were removed from legume roots, counted and dry weight determined.

Statistical analyses were completed, where appropriate, using SAS (1986 GLM procedures) software.

Field Study

A field test was conducted at the Brookings County Landfill. This was designed using three replications in a randomized complete block design with 6 x 6 meter plots. The five treatments included HCS with no additional treatments (check), HCS that was tilled (HCST), HCS that was seeded (HCSP), HCS + C that was tilled (HCSCT), and HCS + C that was seeded (HCSCP).

HCS was hauled in via dump truck and applied approximately 15 - 20 cm deep across the test area. The tilled plots were disked on August 5 and September 10. The seeded plots were seeded on June 17 to approximately 90 kg ha-1 of oats and 22 kg ha-1 hairy vetch. The plots that received compost had compost applied at approximately 10% compost on a dry weight basis. The soil was worked with a disk-chisel to incorporate the compost on June 12.

Soil samples for hydrocarbon analyses were collected June 11 and October 3, 1997 from each of the 15 plots. Sampling was done by Geotek Engineering and Testing Services, Inc. using a random number table applied to each plot (each plot divided into blocks labeled from 1 to 100). Five samples were taken with a shovel to a depth of 15 cm after the top 3 cm of surface soil was scraped away. Samples were analyzed for total hydrocarbon content using gas chromatography (ASTM 1982) procedures. Hydrocarbon analyses were adjusted to account for compost dilution. Geotek Engineering and Testing Services, Inc. conducted the analyses.

Plant top growth was determined by clipping top growth from three, 170 cm2 areas from each plot on July 23. Plant tops were dried at 106°C. Dry weights were recorded.

Roots were dug (July 23) from the top growth sample area, washed, and frozen until laboratory analyses could be completed. Roots were thawed, cut into one cm segments, cleared and stained for microscopic examination (Philips and Hayman 1970). Mycorrhizal colonization was assessed using the grid line intersect methods of Giovannetti and Mosse (1980).

HCS plots were sampled for nematodes on July 23 and October 3. Ten soil subsamples were collected from each plot to a depth of 20 cm and pooled. Samples were stored in a cooler at 2°C and nematodes were extracted from soil samples using separatory funnels (Thorne, 1961).

Statistical analyses were completed, where appropriate, using SAS (1986 GLM procedures) software.

RESULTS

Initial Soil Analyses

The mean hydrocarbon concentration in soils used for greenhouse studies was 8100 mg kg^{-1}. Initial soil test analyses were completed for soil treatments prior to initiation of greenhouse studies (Table 1). Non-contaminated soil had higher levels of nitrates than the hydrocarbon soils as might be expected since the HCS came from a wetland and was presumably anaerobic. Phosphorous was lower in the S (collected from crop fields adjacent to the landfill) than other soil treatments, most likely because of past removal through crop harvest. Much higher concentrations of sulfur, chlorine, and salts were found in the HCS than the S.

Microbial viable CFU's for soil microorganisms, at the initiation of the plant emergence study, indicated higher populations of heterotrophs, fungi, and hydrocarbon degraders in HCS than in S (Table 2). Higher populations may have been a response to higher concentrations of carbon in the contaminated soil.

Table 1. Preliminary soil test for soils used in plant emergence and growth studies.

Treatment[a]	NO_3-N	Olsen P	K	Fe	Cu	S	Cl	OM	pH	1:1 Salts
	ppm							%		mmho cm^{-1}
S	39.6	12	117	107	1.5	14	5	1.6	7.2	0.6
S + C	47.6	41	392	101	1.5	19	58	2.6	7.2	0.8
HCS[b]	10.8	34	538	80	5.0	641	175	3.3	7.7	2.5
HCS + C	18.0	48	386	78	4.8	318	193	3.9	7.8	2.5

[a] S = uncontaminated soil; S + C = uncontaminated soil + 10% compost (dry weight basis); HCS = hydrocarbon contaminated soil; HCS + C = hydrocarbon contaminated soil + 10% compost (dry weight basis).
[b] Average waste oil concentration was 8,100 mg kg^{-1}.

Table 2. Viable counts (colony forming units g^{-1} wet wt.) of soil microbes in treatments at the initiation of the greenhouse emergence study.

	SOIL TREATMENT[a]							
	S		S + C		HCS		HCS + C	
Media	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Total heterotrophs (nutrient agar)								
mean	4.2E + 06	3.6E + 06	9.2E + 06	6.2E + 06	4.7E + 07	5.4E + 07	8.4E + 07	8.1E + 07
st dev	9.6E + 05	9.0E + 05	1.2E + 06	5.1E + 05	6.0E + 06	8.7E + 06	7.6E + 06	1.1E + 07
days[b]	19	22	20	22	21	22	21	23
Fungi (Rose-Bengal)								
mean	-	6.3E + 03	9.3E + 03	7.7E + 03	1.6E + 04	3.4E + 03	4.8E + 04	4.8E + 04
st dev	-	1.2E + 03	1.5E + 03	2.1E + 03	9.2E + 03	3.2E + 02	5.7E + 03	1.1E + 04
days	-	22	20	22	21	22	21	23
Arthrobacter (Arthrobacter medium)								
mean	1.3E + 05	7.7E + 04	7.0E + 05	4.5E + 05	8.0E + 06	8.5E + 06	1.3E + 07	1.4E + 07
st dev	2.5E + 04	2.7E + 04	8.1E + 04	2.3E + 04	5.6E + 05	2.3E + 06	1.2E + 06	1.1E + 06
days	19	22	20	22	21	22	21	23
Hydrocarbon degrader (diesel medium)								
mean	9.1E + 05	7.5E + 05	5.0E + 05	5.5E + 05	7.0E + 06	5.6E + 06	6.5E + 06	9.1E + 06
st dev	2.1E + 04	1.1E + 05	3.1E + 04	2.8E + 05	1.5E + 05	2.8E + 06	2.1E + 06	3.4E + 06
days	30	30	30	30	30	30	30	30

[a] S = uncontaminated soil; S + C = uncontaminated soil + 10% compost (dry weight basis); HCS = hydrocarbon contaminated soil; HCS + C = hydrocarbon contaminated soil + 10% compost (dry weight basis).
[b] days = time from plated until counted.

Plant Emergence Study

In the greenhouse plant emergence study there was a significant interaction between plant species and soil treatment (Table 3). Five legumes and three grasses had better emergence in the HCS than the S. Compost added to soil improved emergence significantly for pinto bean, orchardgrass and rye when compared to soil alone. Comparing compost treatments, four legumes had greater emergence in the HCS + C than the S + C. There were no consistent trends in emergence due to soil treatment, however the low phosphorus concentrations in the S only treatment may have been a limiting factor.

Growth Study

In the greenhouse growth study, there was a significant interaction between species and soil treatment. The HCS treatment (compared to S) reduced the top growth of all the legumes in the study except hairy vetch, which was significantly increased (Table 4). Hydrocarbon soil compared to S reduced the top growth of all grasses tested, but the differences were not statistically significant.

Table 3. Effects of waste oil contaminated soil on plant emergence (%).

PLANT SPECIES		SOIL TREATMENT[a]			
Scientific name	**Common name**	**S**	**S+C**	**HCS**	**HCS+C**
Andropogon gerardii Vitman	Big bluestem	20	15	25	20
Avena sativa L.	Oat	98	100	100	100
Brassica napus L.	Canola	68	65	40	82
Bromus inermis Leyss.	Smooth bromegrass	80	92	95	85
Cicer arietinum L.	Chickpea	25	10	70	75
Dactylis glomerata L.	Orchardgrass	28	56	48	52
Dalea leporina (Ait.)Bullock	Foxtail dalea	10	5	18	20
Desmodium canadense (L.) DC.	Canada tickclover	22	32	25	32
Glycine max (L.) Merr.	Soybean	75	90	95	95
Helianthus annuus L.	Sunflower	70	70	60	60
Hordeum vulgare L.	Barley	78	98	98	90
Lens culinaris Medik.	Lentil	52	45	42	52
Linum usitatissimum L.	Flax	22	30	30	48
Lolium multiflorum Lam.	Annual ryegrass	75	88	72	88
Lotus corniculatus L.	Birdsfoot trefoil	28	32	52	32
Medicago sativa L.	Alfalfa	12	25	58	40
Melilotus alba Medik.	White sweetclover	5	15	25	15
Panicum virgatum L.	Switchgrass	45	55	70	70
Pennisetum americanun (L.)Leeke	Pearl millet	22	35	70	58
Phalaris arundinacea L.	Reed canarygrass	48	63	45	35
Phaseolus vulgaris L.	Navy bean	15	10	55	65
Phaseolus vulgaris L.	Pinto bean	30	65	90	80
Phaseolus vulgaris L.	Red kidney bean	60	60	85	95
Pisum sativum ssp. *arvense* (L.) Poir.	Field pea	25	10	70	75
Poa pratensis L.	Kentucky bluegrass	85	65	48	52
Secale cereale L.	Rye	28	63	68	60
Sorghum bicolor (L.) Moench	Sorghum	95	95	88	90
Sorghum bicolor (L.) Moench	Sudan grass	48	52	55	68
Trifolium hybridum L.	Alsike clover	82	82	62	70
Trifolium pratense L.	Red clover	5	12	5	2
Triticum aestivum L.	Winter wheat	98	90	100	80
Vicia faba L.	Faba bean	50	75	80	80
Vicia villosa Roth	Hairy vetch	62	78	80	90
Zea mays L.	Corn	90	85	95	90

$LSD_{.05}$ = 25

[a] S = uncontaminated soil: S + C = uncontaminated soil + 10% compost (dry weight basis); HCS = hydrocarbon contaminated soil; HCS + C = hydrocarbon soil + 10% compost (dry weight basis). Average of four replications.

Table 4. Plant top and root dry weight (g) 8 weeks from planting the greenhouse growth study.

	SOIL TREATMENT[a]							
	S		S + C		HCS		HCS + C	
Plant species	Top[b]	Root[c]	Top	Root	Top	Root	Top	Root
Alsike clover	0.21	0.09	0.54	0.23	<.01	0.01	0.01	0.02
Field pea	0.66	0.22	1.42	0.24	0.16	0.09	0.18	0.04
Soybean	0.89	0.34	1.47	0.43	0.26	0.21	0.31	0.26
Hairy vetch	0.31	0.27	0.84	0.30	0.93	0.12	0.26	0.14
Smooth bromegrass	0.08	0.17	0.21	0.31	0.01	0.02	0.01	0.03
Switchgrass	0.08	0.08	0.14	0.11	0.01	0.02	0.01	0.03
Oat	0.36	0.18	0.66	0.20	0.20	0.10	0.20	0.10
Winter wheat	0.19	0.32	0.39	0.42	0.06	0.11	0.07	0.12

$LSD_{.05}$ Top = 0.19 Root = 0.11

[a] S = uncontaminated soil; S + C = uncontaminated soil + 10% compost (dry weight basis); HCS = hydrocarbon contaminated soil; HCS + C = hydrocarbon contaminated soil + 10% compost (dry weight basis).
[b] Top = Plant top growth oven dry weight (g).
[c] Root = Plant root growth oven dry weight (g).

Compost significantly increased the top growth of alsike clover, field peas, soybeans, hairy vetch, oats and winter wheat in the non-contaminated soil. However, there was very little increase when it was added to HCS and a significant decrease in top growth of hairy vetch occurred with the addition of compost.

Hydrocarbon soil significantly decreased the amount of root growth in field peas, soybeans, hairy vetch, smooth bromegrass and winter wheat when compared to the non-contaminated soil (Table 4.). The addition of compost significantly increased the root dry weight of alsike clover and smooth bromegrass in the non-contaminated soil, but had no effect on root growth in HCS.

The HCS decreased the number of nodules over the non-contaminated soil in all species and significantly in the field peas and hairy vetch (Table 5.). The addition of compost increased the nodule numbers in both S and HCS, but the addition was significant only for field peas and hairy vetch in S.

Hydrocarbon soil generally reduced the dry weight of nodules when compared to the non-contaminated soil (Table 5.). The reduction in nodule dry weight due to HCS was significant for soybean. Compost added to soil significantly increased nodule dry weight in soybean.

Field Study

Total petroleum hydrocarbons decreased over time in all treatments, but decreased significantly only in the plots with compost (Table 6). At the completion of the study, the hydrocarbon concentration was significantly lower in the compost/planted treatments than the other treatments.

The addition of compost to HCS at the landfill increased top growth compared to HCS, but the difference was not significant statistically (Table 7). Root

Table 5. Nodule numbers and dry weight (g per plant) in the greenhouse growth study.

	SOIL TREATMENT[a]							
	S		S + C		HCS		HCS + C	
Plant species	**No.[b]**	**Wt.[c]**	**No.**	**Wt.**	**No.**	**Wt.**	**No.**	**Wt.**
Alsike clover	59	0.01	102	0.02	2	<.01	11	<.01
Field pea	136	0.02	265	0.06	1	<.01	8	<.01
Soybean	46	0.08	102	0.02	2	<.01	11	0.01
Hairy vetch	96	0.02	349	0.06	9	0.01	66	0.03

$LSD_{.05}$ No. = 66 Wt. = 0.02

[a] S = uncontaminated soil; S + C = uncontaminated soil + 10% compost (dry weight basis); HCS = hydrocarbon contaminated soil; HCS + C = hydrocarbon contaminated soil + 10% compost (dry weight basis).
[b] No. = Nodule numbers per root system.
[c] Wt. = Nodule oven dry weight (g) per root system.

Table 6. Total petroleum hydrocarbons as affected by landfill treatments and time.

	TOTAL PETROLEUM HYDROCARBONS (mg kg^{-1})[a]		Percent
Treatment	**Initiation (June 11)**	**Completion (Oct. 3)**	**reduction[b]**
Hydrocarbon soil	5134	3831	25
Hydrocarbon soil + plant	4911	3434	30
Hydrocarbon soil + compost + plant	5387	2190	59
Hydrocarbon soil + tillage	5432	3652	33
Hydrocarbon soil + compost + tillage	7177	3324	54

Time $LSD_{.05}$ = 2292
Treatment $LSD_{.05}$ = 710

[a] Corrected for dilution by compost.
[b] Percent reduction compared to initiation of study.

Table 7. Landfill treatment effects on plant top growth and root colonization by vesicular arbuscular endomycorrhizae.

	Top dry weight	ROOT COLONIZATION (%)	
Treatment	**(kg ha^{-1})**	**vetch**	**oat**
Hydrocarbon soil + compost + plant	219	1.6	10.0
Hydrocarbon soil plant	70	5.5	11.4
$LSD_{.05}$	NS	NS	NS

Table 8. Landfill treatment effects on total nematode numbers (per 100 cc soil).

Treatment	July 23, 1997	Oct. 23, 1997
Hydrocarbon soil	3	2
Hydrocarbon soil + plant	3	5
Hydrocarbon soil + tillage	1	1
Hydrocarbon soil + compost + plant	69	92
Hydrocarbon soil + compost + tillage	36	34
LSD .05	43	58

colonization by endomychorrhizae was not influenced by the addition of compost to HCS (Table 7). Root colonization tended to be higher in oat than vetch. The difference in colonization between species was significant at Pr > F = 0.0509.

Rhabditida and *Psilenchus* were the predominant nematodes found in the samples. Both of these groups are microbial feeders and are not plant pathogenic. The addition of compost to planted treatments increased nematode numbers at both sample dates (Table 8). Planted plots with compost had the highest nematode numbers, which agrees with findings of Yeats (1997).

DISCUSSION

The practical application of this study is that if hydrocarbon contaminated soil were mixed with a compost amendment (10% on a dry weight basis), hydrocarbon concentrations would be significantly reduced. This could possibly eliminate the need for transport to regional landfills and allow land farming at the site of contamination. In our study, the addition of plants did not significantly reduce hydrocarbon contamination, but it would reduce wind and water erosion.

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WETLAND INVERTEBRATE ABUNDANCES AND CORRELATIONS WITH WETLAND WATER NUTRIENTS

Brandon J. Jahnke
15118 Co. Rd. 79
Elk River, MN 55330

Diane H. Rickerl
Plant Science Department
South Dakota State University
Brookings, SD 57007

Tom Kirschenmann
Pheasants Forever
Worthing, SD 57077

Daniel E. Hubbard
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

David Kringen
Davison Conservation District
Mitchell, SD 57301

ABSTRACT

Invertebrates are important in aquatic food chains, forming the link between phytoplankton and higher level consumers such as waterfowl. We hypothesized that high concentrations of nutrients in wetland water would lead to high invertebrate abundances through transfer of nutrients and energy up the food chain. Three seasonal wetlands in agricultural landscapes of eastern South Dakota were sampled monthly from May through August in 1994 and 1995. Wetland water nitrate-N and orthophosphate concentrations were determined using a Hach DR 2000 spectrophotometer. Aquatic invertebrates were sampled using activity traps placed midway in the water column for 24 hours. Nitrate-N concentrations were low, ranging from 0.0 to 0.2 mg L^{-1} in both years. Orthophosphate concentrations were higher than those reported in non-agricultural wetlands, ranging from 0.65 to 1.65 mg L^{-1} . Ten taxa of invertebrates exhibited correlations with nutrients in the water column. Culicids ($r = 0.72$), copepods ($r = 0.49$) and *Hydroporous* spp. ($r = 0.58$) had significant positive correlations with nitrate-N concentrations. Several genera of aquatic beetles had positive correlations (r values from 0.42 to 0.55) with orthophosphate concentrations. One beetle genus (*Agabus* $r = 0.48$) had a negative correlation with orthophosphate. Our results suggest that there are correlations between invertebrate abundances and nutrient concentrations in Prairie Pothole wetlands. However, the correlations are probably indirect and dependent on plant responses to nutrients available in the wetland.

Keywords

Aquatic invertebrates, wetlands

INTRODUCTION

The Prairie Pothole Region (PPR) of North America is considered one of the most important wetland regions in the world. It is estimated that 50 to 75% of all waterfowl produced in North America comes from this region (Mitsch and Gosslink 1993). The abundance and variety of wetland sizes in this region make it ideal habitat for waterfowl (Mitsch and Gosslink 1993). These wetlands have the ability to provide the necessary requirements for waterfowl including nesting cover and food resources (Swanson and Meyer 1973; Murkin and Wrubleski 1988).

Eutrophication is the gradual increase in concentration of plant nutrients in an aquatic environment. Nitrogen and phosphorus are the two primary nutrients responsible for the process of eutrophication (Boney 1975). Prairie Pothole wetlands are typically a lentic environment. The water and sediment that enter the basin are contained, along with the nutrients they carry, until they are transformed or cycled through the environment. Wetlands naturally cycle nutrients but accelerated sediment and nutrient loading from agricultural runoff is occurring (Dieter 1991).

Wetlands are very effective at "filtering" sediments, nitrogen and phosphorus. They serve as sinks for nutrients and/or sediment (Van der Valk and Davis 1978). Denitrification occurs under anaerobic conditions typical of wetland sediment. This process converts nitrates to molecular nitrogen and gaseous nitrous oxides that are lost from the wetland environment into the atmosphere (Mitsch and Gosslink 1993).

Phosphorus can enter wetlands as soluble phosphorus in the aqueous phase or as sorbed phosphorus attached to soil particles. Soluble phosphorus can be precipitated (insoluble) under aerobic conditions in the wetland with ferric iron, calcium or aluminum. This makes the phosphorus unavailable to aquatic plants and microorganisms (Mohanty and Dash 1982). Phosphorus sorbtion is affected by the type of mineral surface in the soil. The equilibrium between sorbed and soluble phosphorus is influenced by the pH. Typically phosphorus is not biologically available unless it is in the soluble inorganic form.

Nitrogen and phosphorus are necessary nutrients for algae and aquatic plant growth and generally an increase in nutrient concentration results in an increase in algae and/or plant biomass. Neely and Baker (1989) found that excess nitrogen and phosphorus in wetlands resulted in stimulation of plant production, enrichment of plant tissue and acceleration of decomposition. Plants serve as a link in the food chain between nutrients and aquatic invertebrates.

Submerged plants increase invertebrate production and diversity by providing a substrate for colonization and a food source for herbivores (Muttkowski 1918; Krecker 1939; Andrews and Hassler 1943; Rosine 1955; Gerking 1957; Dvorak and Best 1982; Engel 1985; Schramm et al. 1987). Plants also provide oviposition sites for the invertebrates and other aquatic organisms (Mcgaha 1952; Westlake 1961; Breder and Rosen 1966; Sozska 1975; Lagler et al. 1977; Pandit 1984; Engel 1985, 1988).

High levels of aquatic macrophyte production in wetlands provide plant material to the system as detritus (Murkin and Wrubleski 1988). Detritus, algae and microorganisms are consumed by larger herbivorus invertebrates. These larger invertebrates are key to the secondary productivity of a marsh ecosystem (Eldridge 1990). The invertebrates form the crucial link in the food chain between the detritus, production resources (macrophytes) and higher order consumers (Murkin and Wrubleski 1988).

Although much research has investigated wetland food chains, little information exists on wetland nutrient concentrations in agricultural landscapes of the PPR and nutrient relationships with invertebrates. The objectives of this study were:

1. to determine nitrate-N and orthophosphate concentrations in wetlands surrounded by agriculture;
2. to determine aquatic invertebrate abundances within the wetlands and;
3. to determine correlations between nutrient concentrations and aquatic invertebrate abundances.

METHODS

Study Area

Lake County South Dakota (SD) is located in eastern SD within the PPR. Three palustrine seasonal (Cowardin et al. 1979) wetlands in Lake County SD (T-105N, R-53W, S-26, 27, & 34) were selected for this study. The wetlands were selected based on similarities in soil type, and surrounding agricultural crops. Upland soil types were predominantly an Eagen-Beadle complex and wetland soils were a Whitewood silty clay loam. The fields surrounding the wetlands were cropped in corn (*Zea mays,* L.) and soybean (*Glycine max,* L. Merr).

Sample Collection

All three wetlands were sampled to determine wetland water nitrate-N and orthophosphate concentrations and aquatic invertebrate abundances. Sample collection began in late May and continued until the end of July during 1994 and 1995. Each wetland was sampled during four periods for each of the two seasons that the study occurred. In 1994 sample periods were: One (5/24-

6/3/94), Two (6/6-6/20/94), Three (6/21-7/1/94) and Four (7/6-7/15/94). In 1995 sample periods were: One (5/24-6/7/95), Two (6/13-6/23/95), Three (6/28-7/18/95) and Four (7/11-8/1/95).

Water nitrate-N and orthophosphate

Surface water samples were collected during the four sample periods in 1994 and again in 1995. Two samples were taken from each wetland and analyzed individually. The average of the two samples was used in the statistical analyses. Sampling was done using a one-liter glass jar covered with two-ply medical gauze to strain out coarse particulate matter.

Water for nitrate-N analysis was separated into plastic bags and placed on ice during transport to the laboratory. Orthophosphate analysis was completed in the field. Water samples were analyzed using a Hach DR2000 spectrophotometer following the procedures 8039 for nitrate-N and 8048 for orthophosphate (Hach 1992).

Invertebrates

Collection of the invertebrate samples (during the same periods as the water sampling) was accomplished by using slightly modified activity traps similar to the ones described by Riley and Bookhout (1990). The only modification to the trap consisted of the entrance being widened to 14 cm. Traps (seven in wetlands 1 and 2, and 10 in wetland 3) were arranged in a systematic manner along the longest axis of the wetland. The traps were placed mid-way in the water column and left for 24 hours. When the traps were retrieved and emptied, the contents were strained through a #20 mesh plankton net. The contents were then stained and preserved with a rose bengal and 80% ethanol mix.

Invertebrates were identified using a binocular dissecting scope and keys written by Pennak (1989), Cvancava (1983), Merrit and Cummins (1984) and Thorp and Covich (1991). Invertebrates were also assigned to functional feeding groups according to Merritt et al.(1999) (Table 1).

Statistical analyses were performed using SAS/STAT program for personal computers. Analysis for separation of means was done using an ANOVA (SAS 1990). The correlation procedure (SAS 1990) was utilized to determine if a correlation existed between nutrient concentration and invertebrate abundance.

RESULTS AND DISCUSSION

Water nitrate-N and orthophosphate

No significant differences for wetland water nitrate-N concentrations were found due to sample period, year, or year by period interaction (Table 2). Nitrate-N concentrations ranged from 0.0 to 0.2 mg L^{-1} with a mean value of 0.1 mg L^{-1} for each of the 1994 and 1995 seasons.

Table 1. Invertebrate functional feeding groups and representative taxa sampled in 1994-95.

Functional feeding group[a]	Order	Family	Genus	Species
One	Amphipoda	Taltitridae	*Hyallela*	*azteca*
Two	Coleoptera	Hydrophilidae	*Heleporus*	
			Enochrus	
			Berosus	
Three	Basommatophora	Lymnaeidae	*Lymnaea*	*stagnalis*
			Stagnicola	*caperata*
				elodes
		Physidae	*Physa*	*gyrina*
				jennessi
		Planoribidae	*Armiger*	*crista*
			Gyralus	*parvus*
	Hemiptera	Corixidae		
		Notonectidae		
		Velidae		
Four	Coleoptera	Haliplidae	*Peltodytes*	
			Haliplus	
Five	Cladocera	Daphnidae	*Daphnia*	
			Simocephalus	
		Ceriodaphnidae		
		Chydoridae		
		Macrothricidae	*Bunops*	
	Diptera	Culicidae		
	Hydroida			
Six	Haplotaxida			
	Harpacticoida			
	Podocopa			
	Diptera	Chironomidae		
Seven	Acari			
	Coleoptera	Dytiscidae	*Acilius*	
			Agabus	
			Celina	
			Colymbetes	
			Dytiscus	
			Hydaticus	
			Hydroporus	
			Hygrotus	
			Ilybius	
			Laccophilius	
			Liodessus	
			Uvarus	
		Hydrophilidae	*Hydrochara*	
			Hydrophilius	
	Cyclopoida			
	Diptera	Ceratopogonidae		
		Chaoboridae		
	Odonata	Aeshnidae	*Aeshna*	
			Anax	
		Lestidae	*Lestes*	
		Libellulidae	*Libellula*	
	Rhynchobdellida			

[a] Functional feeding groups as defined by Merritt et al. 1999: One = detritivore shredders; Two = herbivore shredders; Three = scrapers; Four = plant piercers; Five = filtering collectors; Six = gatherer collectors; Seven = predators.

Table 2. Nitrate-N and orthophosphate concentrations (mg L^{-1}) in wetland water in 1994 and 1995.

Year	Sample period[a]	Nitrate-N	Orthophosphate
1994	One	0.0[b]	1.35
	Two	0.1	1.60
	Three	0.2	1.18
	Four	0.1	1.11
1995	One	0.2	0.42
	Two	0.1	1.01
	Three	0.2	1.12
	Four	0.0	1.00

[a] 1994 sample periods: One = 5/24 - 6/3/94; Two = 6/6 - 6/20/94; Three = 6/21 - 7/1/94; Four = 7/6 - 7/15/94. 1995 sample periods: One = 5/24 - 6/7/95; Two = 6/13-6/23/95; Three = 6/28 - 7/18/95; Four = 7/11-8/1/95.
[b] 0.0 = values < 0.05.

No significant differences for wetland water orthophosphate concentrations were found due to sample period, year or year by period interaction (Table 2). Orthophosphate concentrations for the 1994 season ranged from 1.11 to 1.60 mg L^{-1} with a mean value of 1.31 mg L^{-1}. In 1995 there was a slight decrease (compared to 1994) in orthophosphate concentrations with a range of 0.42 to 1.12 mg L^{-1} and a mean value of 0.88 mg L^{-1}.

Driver and Peden (1977) showed nitrate-N concentrations in prairie ponds in Canada that ranged from 0.01 to 0.73 mg L^{-1} and orthophosphate concentrations that ranged from 0.03 to 0.29 mg L^{-1}. Low nitrate-N concentrations reported by Driver and Peden (1977) were similar to ours and probably reflect the effectiveness of wetland soils to denitirify. However, the orthophosphate concentrations Driver and Peden (1977) determined were much lower than our values. Driver's wetlands occurred in a natural setting where the wetlands were not exposed to agricultural runoff. Runoff and P fertilizer application directly to the wetland during dry seasons could have elevated P concentrations in our study.

Invertebrates

Sixteen orders, 20 families and 32 genera made up the taxonomic hierarchy found in this study. Although more than 32 genera were found during the sampling seasons, only those with more than ten individuals (during both seasons) are listed. Tables 3 and 4 list invertebrates, by taxonomic group, along with mean abundance's (number of invertebrates per genera divided by number of traps, summed across samples dates and divided by number of wetlands) and mean dominance (% of total collected).

The orders that exhibited the highest abundances in 1994 and 1995 (Table 3) were Cladocera, Cyclopoida and Podocopa (Ostracods). During 1994 these orders made up 92% of the total invertebrates collected, and in 1995 they made

Table 3. Abundance and dominance of aquatic orders found in seasonal wetlands in 1994 and 1995.

	ABUNDANCE[a]		DOMINANCE[b]	
Order	**1994**	**1995**	**1994**	**1995**
Acari	2	79	0.11	0.86
Amphipoda	27	0	1.44	0.00
Basommatophora	20	12	1.07	0.13
Cladocera	793	5332	42.41	58.10
Coleoptera	64	23	3.42	0.25
Collembola	0	1	0.00	0.01
Cyclopoida	263	1685	14.06	18.38
Diptera	32	37	1.71	0.40
Dorylaimida	0*	53	0.00	0.57
Haplotaxida	3	200	0.16	2.18
Harpacticoida	2	43	0.11	0.46
Hemiptera	4	5	0.21	0.05
Hydroida	0	1	0.00	0.01
Odonata	3	7	0.16	0.07
Podocopa	657	1689	35.13	18.42
Rhynchobdellida	2	2	0.11	0.02
Total	*1870*	*9171*	*100*	*100*

[a] Abundance = number of invertebrates in each order divided by number of traps, summed across sample dates and divided by 3 (the number of wetlands).
[b] Dominance = % of total collected.

up 95% of the total invertebrates collected. Abundances of Cladocera were greater than other orders during 1994 and 1995. Podocopa abundance was higher than Cyclopoida in 1994, but they were similiar in 1995. Generally abundances were higher in 1995 than in 1994.

Studies by Voigts (1976) and Euliss et al. (1991) indicated that Copepods and Cladocerans were abundant invertebrates collected from wetlands. Voigts (1976) indicated that Gastropods were one of the more abundant invertebrates collected in his study while Podocopa were not. Podocopa may not have appeared to be abundant due to the sampling methods used in Voigts' (1976) study. Euliss et al. (1991) did not list Gastropods as one of the more abundant invertebrates but did find that Podocopa were very abundant. Euliss's research occurred in agricultural drainwater ponds that had high salinity concentrations, an unfavorable environment for Gastropod (snail) populations (Pennak 1989).

During 1994 Daphnidae was the dominant family, making up 82% of the total invertebrates collected (Table 4). In 1995, Ceriodaphnidae dominated at 75% of the total and Daphnidae was second at 13 % (Table 4) of the invertebrates collected. The invertebrate taxa collected that exhibited the highest abundances in our study are very common in aquatic environments of the PPR. Most can be found in many types of water bodies, including wetlands. Although our study dealt with invertebrates, one vertebrate family (Gasterosteidae) was very prominent in the activity traps in 1994.

Table 4. Abundance and dominance of aquatic families found in seasonal wetlands in 1994 and 1995.

Family	ABUNDANCE[a] 1994	ABUNDANCE[a] 1995	DOMINANCE[b] 1994	DOMINANCE[b] 1995
Aeshnidae	2	1	0.23	0.01
Ceratopogonidae	0	3	0.00	0.04
Ceriodaphnidae	0	4155	0.00	75.43
Chaoboridae	22	13	2.56	0.24
Chironomidae	8	22	0.93	0.39
Chydoridae	0	396	0.00	7.18
Corixidae	3	4	0.35	0.74
Culicidae	0	2	0.00	0.04
Daphnidae	707	730	82.40	13.25
Dytiscidae	57	21	6.64	0.37
Haliplidae	0	1	0.00	0.02
Heleidae	2	0	0.23	0.00
Hydrophilidae	6	1	0.70	0.01
Lestidae	1	3	0.11	0.04
Libellulidae	0	3	0.00	0.05
Lymnaeidae	9	8	1.05	0.14
Macrothoricidae	0	139	0.00	2.53
Notonectidae	1	0	0.12	0.00
Physidae	9	4	1.05	0.07
Planoribidae	2	0	0.23	0.00
Talitridae	27	0	3.15	0.00
Velidae	1	0	0.12	0.00
Trichocoridae	0	2	0.00	0.03
Total	*858*	*5508*	*100*	*100*

[a] Abundance = number of invertebrates in each family divided by number of traps, summed across sample dates and divided by 3 (the number of wetlands).
[b] Dominance = % of total collected.

Invertebrate functional feeding group abundances were analyzed to see if significant differences among groups occurred (Table 5). The filtering collectors were significantly (P = 0.0001) more abundant than all other groups during 1994. During 1995 the filtering collectors and the predators (not significantly different from each other) were significantly (P = 0.0006) more abundant than all other groups. Abundance of filtering collectors may have been favored by the type of sampling device utilized. Activity traps sample the water column only, and most of the filtering collectors are active swimmers.

Correlations between wetland water nutrients and invertebrates

Three Orders of invertebrates exhibited a significant positive correlation with nitrate-N concentrations in the wetland water. These Orders (families and genera if identified) are listed in Table 6, along with their corresponding significance values and r values. The range of positive r values was 0.49 to 0.72.

Table 5. Functional feeding group abundances during 1994 and 1995.

Functional feeding group[a]	ABUNDANCE[b] 1994	1995
Detritivors shredders	24	1
Herbivore shredders	0[c]	1
Scrapers	21	14
Plant piercers	1	1
Filtering collectors	1198	1767
Gathering collectors	5	185
Predators	318	1660
$LSD_{.05}$	338	863

[a] As defined by Merritt et al. 1999.
[b] Total abundance per year of each group, divided by number of sample periods and wetlands (N = 12).
[c] 0 = values < 0.5.

The Orders that showed correlations with nitrate-N have varying feeding habits. Aquatic Coleoptera (beetles) are usually predaceous, feeding on other insects, invertebrates and small fish. The family of beetles that showed significance with nitrate-N was Dytiscidae. One genus *(Hydroporus)* that exhibited a correlation with nitrate-N was in the larval form. High concentrations of nitrate-N may have caused plant and phytoplankton biomass to increase in response to nutrient availability. An increase in plant and phytoplankton biomass would provide more food for the Dytiscid's prey species, which could then lead to an increase in abundance of predatory Dytiscids.

The Cyclopoida (copepods) are omnivores and feed on zooplankton and phytoplankton. Copepods responded positively to higher nitrate-N concentrations (Table 6). Nitrate-N is a necessary nutrient for phytoplankton growth and reproduction. A higher concentration of nitrate-N could also have resulted in the phytoplankton responding positively. The positive response by the phytoplankton would then create a larger food resource for the copepods resulting in higher abundances.

The Diptera (mosquito larvae) gather nutrients by feeding on algae and microscopic bits of organic matter in the water. Mosquito larvae also have the ability to absorb nutrients in solution, via ingestion (Klots and Klots 1972). This may explain the high correlations (0.72) between mosquito larvae and nitrate-N concentrations. Mosquitoes were most abundant early in the sampling seasons. The completion of the pupal stage that leads to emergence from the aquatic habitat, explains the lower abundances found later in the season. Mosquitoes also are prey species for small fish and other invertebrates. The hatching of fish fry and other invertebrates could have also led to the lower numbers later in the season.

Table 6 lists invertebrate taxa that exhibited a significant correlation with orthophosphate concentrations. All correlations were positive except for one genus of Coleoptera *(Agabus),* which showed a negative correlation. The range of positive r values was 0.42 to 0.55.

Table 6. Invertebrate taxa that exhibited a significant correlation with wetland water nitrate-N and orthophosphate concentrations during 1994 and 1995.

Nutrient	Order	Family	Genus	P	r[a]
Nitrate-N	Coleoptera	Dytiscidae	*Hydroporus*[b]	0.0045	0.58
	Cyclopoida			0.0193	0.49
	Diptera	Culicidae		0.0173	0.72
Orthophosphate	Coleoptera			0.0093	0.52
		Dytiscidae	*Acilius*	0.0445	0.42
			Agabus[c]	0.0192	0.48
			Celina[d]	0.0067	0.54
			Dytiscus[e]	0.0303	0.45
			Hydaticus	0.0451	0.42
			Hydroporus	0.0059	0.55
		Hydrophilidae	*Hydrophilius*	0.0236	0.47
	Rhynchobdellida			0.0209	0.47

[a] Pearson correlation with each coefficient using nitrate-N values or orthophosphate values for each date (n = 8) and each wetland (n = 3) as the independent variable (n = 24); and invertebrate abundances for each trap (n = 24) and sample date (N = 8) used as the dependent variable (n = 192).
[b] Found only in 1995.
[c] Negative correlation.
[d] Found only in 1994.
[e] Larval form when collected.

The orders that showed significant correlations to orthophosphate have varying feeding habits. The Dytiscids (order Coleoptera) that exhibited a correlation are all predaceous, feeding on other invertebrates and sometimes, small vertebrates. Adult and larval forms of Coleoptera were found during both seasons. Correlation analysis included Coleoptera in both adult and larval forms. Hydrophilidae (Genus *Hydrophilius*) is predaceous only in the larval stage, and as an adult is a scavenger feeding on dead or decaying vegetation. Rhynchobdellida (leeches) are mostly scavengers, but sometimes will feed upon living organisms.

CONCLUSION

Results from our study and comparisons from the literature suggest that eutrophication of wetlands in agricultural landscapes may be accelerated by elevated levels of phosphorus from run-off, erosion, or direct application of fertilizer. Nitrate-N concentrations in the water column remain low, probably due to the efficiency of denitrification in the wetland.

Increased nutrient availability in wetlands can result in an increase in numbers and biomass of herbivores according to Campeau et al. (1994). Gabor et al. (1994) indicated that invertebrates or the zooplankton community were able to respond quickly to increased algal food availability due to short generation times. In our study, correlation between nitrate-N and invertebrates was highest for mosquito larvae, which can ingest nutrients directly from the water. Iincreases in primary consumers would then lead to increases in secondary consumers or predators.

Wetland food chains were once thought to be detritus driven (Eldridge 1990). The abundance of detritus in wetlands is a result of decaying macrophytes, and was thought to form the first crucial link for nutrient and thus energy transfer. However, recent research using stable isotopes has indicated that algae and phytoplankton may be a more important food resource for invertebrates than macrophyte litter (Euliss et al. 1999). Carbon 13 stable isotope studies have indicated that signatures for invertebrates matched signatures for algae more closely than the signatures for macrophyte litter (Euliss et al. 1999). This indicated that algal resources are acting as the principle food and carbon resource for invertebrates.

Agricultural wetland ecosystems could be further researched, to determine effects of specific agricultural management practices on wetland ecosystems.

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AQUATIC AND AERIAL INVERTEBRATES ASSOCIATED WITH SELECTED GLACIAL WETLANDS IN EASTERN SOUTH DAKOTA

Rebecca L. Rasmussen, Lester D. Flake, and Daniel E. Hubbard
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

ABSTRACT

Aquatic and aerial invertebrate taxa (Families) were identified from two wetland basins and two sites within a third large basin in 1998 and four wetlands (two sites each within the two largest basins) in 1999 during June and July (i.e., peak of waterfowl brood rearing period) in eastern South Dakota. In addition, the abundance and volume (size) of aquatic and aerial invertebrates and their association with habitat variables or conditions (i.e., wind and temperature) was explored. Aquatic and aerial invertebrates were collected using submersed funnel and floating sticky traps, respectively. Forty-three aquatic invertebrate families were found during the sampling period of 1998 and 35 were collected during 1999. In both years, the most common taxa encountered were cladocerans, copepods, and ostracods. Seventy-six aerial invertebrate taxa, dominated by collembolans, chironomids, and ephydrids, were collected. In 1998, there was no apparent association between aquatic and aerial total invertebrate abundance (r^2=0.022, P=0.197) or total volume (r^2=0.003, P=0.655). Similar results were found for aquatic and aerial invertebrate abundance (r^2=0, P=0.995) and volume (r^2=0.001, P=0.850) in 1999. The capture of many aerial invertebrate taxa not linked to aquatic life stages may have masked possible relationships. Aquatic invertebrate abundance was positively associated with air temperature in both years. Likewise, aquatic invertebrate volume was positively associated with submerged vegetative cover and distance from emergent vegetation in both years. Aerial invertebrate abundance increased with an increase in the surrounding air temperature as well as an increase in submerged vegetative cover. Wind speed was the predominant variable positively associated with aerial invertebrate volume during 1998 and 1999, probably because wind blew the flying insects against the sticky traps. The absence of association between aquatic and aerial invertebrate abundance or volume helps illustrate the importance of knowing both invertebrate communities before determining the suitability of a wetland for Anatini broods.

Keywords

Invertebrates, aquatic, aerial, Chironomidae, wetlands, glacial, South Dakota

INTRODUCTION

The glacial wetlands of eastern South Dakota are especially important to waterfowl productivity. A diverse and abundant assemblage of waterfowl use these wetlands for breeding and brood-rearing activities (Brewster et al. 1976, Duebbert and Frank 1984, Swanson and Duebbert 1989). Mallard brood-rearing habitat in the prairie regions has highly variable characteristics with few consistencies between wetlands selected by broods (Rotella and Ratti 1992). Suitable brood rearing habitat, however, must contain three key elements: available water, substantial emergent escape cover, and a reliable food source (Sedinger 1992). Invertebrates are important components and may influence the use of certain wetlands by broods (Sedinger 1992). For example, high concentrations of midge (Chironomidae) larvae were found by Talent et al. (1982) to be a common characteristic of mallard brood rearing wetlands. The availability of invertebrates, both aquatic and aerial, may be one of the most important determinants of suitable brood-rearing habitat.

During the first two weeks of life, most duck species rely on invertebrates as their main food source (Collias and Collias 1963, Sugden 1973) because they contain protein with the appropriate amino acid ratios necessary for rapid growth and development. Class Ia dabbler ducklings (1-6 days) consume primarily aerial invertebrates (Chura 1961, Sugden 1973, Pehrsson 1979, Sedinger 1992). They obtain these invertebrates by jumping above the water surface up to three times their height (Chura 1961). Aquatic invertebrates become a more important food source for Class Ib dabbler ducklings (7-12 days). Growth of their necks and bills allows ducklings to utilize tip-up and head-submersion techniques to obtain food below the water surface. Both aquatic and aerial invertebrates are critical to a young duckling's diet, yet most research has focused solely on aquatic invertebrates. Only recently has the role of aerial invertebrates as potential duckling food been investigated (King and Wrubleski 1998; King and Brazner 1999).

The objectives of our research were to: 1) evaluate the abundance and volume by taxa (Family) of available aquatic and aerial invertebrates (including surface invertebrates up to 15 cm above the water surface) in the feeding range of young dabbler (Tribe Anatini) ducklings; and 2) determine the relationship of selected habitat variables to invertebrate abundance and volume.

STUDY AREA

Three study areas within the Coteau des Prairies physiographic region of eastern South Dakota were selected (Fig. 1). In 1998, invertebrates were collected from wetlands in 2 study areas: Oakwood Lakes area and Mickelson Memorial Wetland. The Oakwood Lakes area is in northwest Brookings County (T111N R52W S1 & 12; T111N R51W S4-9; T112N R52W S25 & 36; T112N R51W S30-31) and consists of 2330 ha of lacustrine habitat interspersed with palustrine wetlands and uplands. Three palustrine emergent wetlands (Cowardin et al. 1979), Oakwood A, Oakwood B, and Moe, were selected within the

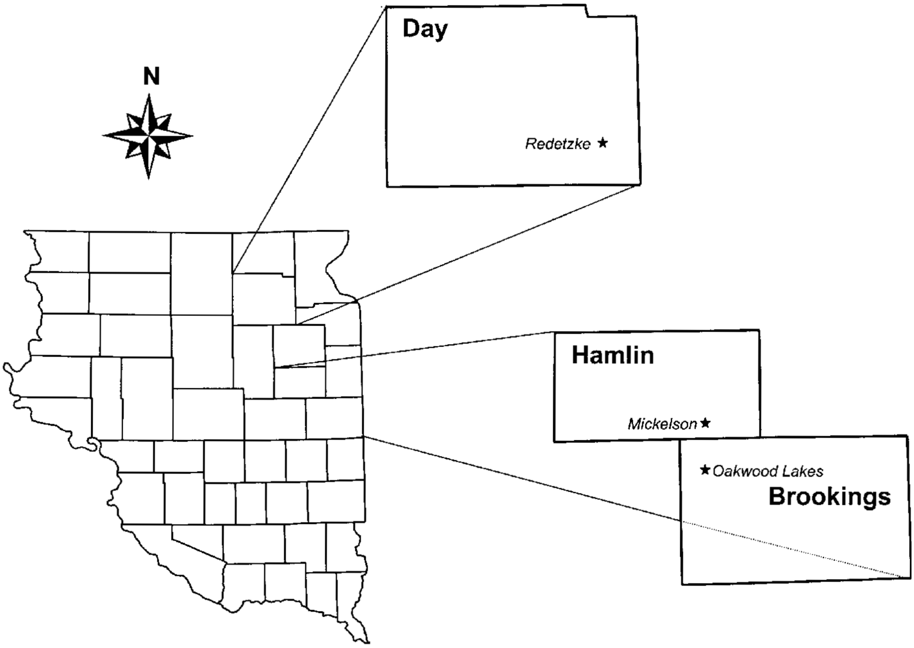

Figure 1. Study areas in eastern South Dakota.

Oakwood Lakes area for sampling. Mickelson Memorial Wetland, the second area, is a 400 ha restored hemi-marsh found in south central Hamlin County (T113N R51W S16-21). The Redetzke Game Production Area (GPA), located in southeast Day County (T121 R55W S27), was added in 1999. Redetzke contains 140 ha of uplands and a large palustrine emergent wetland. Six wetland sites were sampled for invertebrates in 1999: two wetlands in the Oakwood Lakes area (Moe and Moe Private), two sites in the Mickelson Memorial Wetland (Mickelson and Mickelson Burn), and two sites in Redetzke (Redetzke 1 and Redetzke 2).

METHODS

Wetlands were sampled for invertebrates in June and July of each year, during peak brood abundance (Duebbert and Frank 1984). Aquatic invertebrates were collected down to 14 cm below the water surface using funnel traps modeled after Riley and Bookhout (1990). Traps were set horizontally just below the water surface to maintain a consistent trap depth. In areas where traps were not completely submerged by water, they were placed directly on the wetland substrate. Floating sticky traps (King and Wrubleski 1998) were used to capture aerial invertebrates up to 25 cm above the water surface. These traps were placed vertically over a piece of rebar in the wetland substrate and sat directly on the water surface. Funnel and sticky traps were set in pairs, 1, 2, or 3 m from the wetland edge assigned from a random numbers table, but 1 m from each other to prevent any potential bias. In 1998, 10 pairs of traps were set per wetland site per collection, and in 1999, 5 pairs of traps were set per wetland site per collection; pairs of traps were set at 10 m apart Both traps were deployed in the morning and collected 24 hours later. In addition to invertebrate collection, habitat variables at each trap were also measured (Table 1). We selected wetland sites where duck broods were commonly observed, but no attempts were made to equally sample all shoreline areas of each wetland.

Aquatic invertebrates were sieved and rinsed with a rose bengal/alcohol solution (Mason and Yevich 1967) and stored in collection cups until identification. Transparencies from the sticky traps were rolled up and placed in plastic bags until identification. Invertebrates were removed by placing transparencies in a pan of ethyl alcohol to dissolve the sticky material (Murphy 1985). Aquatic invertebrates were identified to family using Pennak (1978), Merritt and Cummins (1984), and Thorp and Covich (1991). Aerial invertebrates were identified to family using a manual by Borror et al. (1989) in addition to the previously mentioned manuals.

Taxa and total abundance were estimated using methods similar to those outlined by Edmondson (1971). Taxa and total volume displacement (Swanson and Bartonek 1970, Edmondson 1971) in water were also estimated. If a family had negligible volume (<1 cc), it was recorded as a trace and not measured separately. Invertebrates less than 1 mm^3 were not included in any volume displacement. A reference collection containing one or more representatives of each family was kept for confirmation.

Abundance and volume data from 1998 and 1999 were tested for normality using a normal quantile-quantile plot (SAS Institute Inc. 1988). Only slight deviations at the beginning and end of the plots were apparent, therefore nor-

Table 1. List of wetland variables measured at each funnel and sticky trap site in 1998 and 1999. These parameters were used as independent variables in stepwise multiple regression models for aquatic invertebrate abundance and volume.

Water temperature
Water depth
Distance from peripheral vegetation[a]
Distance to nearest emergent vegetation[b]
Distance to submerged vegetation or substrate[c]
Percent cover of floating vegetation
Percent cover of submerged vegetation
Ambient high and low air temperatured
Wind Speed[d]

[a] Originally, funnel traps were placed 1, 2, or 3 m from the peripheral vegetation. During low water levels, traps were moved out for adequate submersion.
[b] This was only recorded if the emergent vegetation was closer to the trap than the peripheral vegetation and if it was deemed adequate for use as escape cover for ducklings.
[c] This was measured at funnel trap sites only.
[d] High and low air temperature and wind speed were obtained from the nearest weather station for the day of trap deployment.

mality was assumed, and no log transformations were made. Alphas for all statistical tests were set *a priori* at 0.1.

Simple linear regression analysis (SAS Institute Inc. 1988) was used to evaluate the possible association between the abundance and volume of invertebrates above and below the water surface. Pairs of observations were averaged at each wetland on each date, deriving mean aquatic and aerial invertebrate abundance and volume for use in the regression models. One abundance model and one volume model were developed for each year. In the models, the subsurface observations were the independent variable, while the aerial observations were the response variable because it was those trends we were trying to predict.

Analysis of variance (ANOVA) was used to test the differences in mean aquatic and aerial invertebrate abundance and volume between individual wetlands, while a least significant difference (LSD) means comparison test was run to detect where the differences occurred. During the analysis, statistical similarities in abundance and volume among wetlands were often encountered, and those wetlands were assumed to have comparable habitat variables. Therefore, wetlands were pooled into groups based on non-significance, and judgments on some groups were required. Stepwise multiple regression analysis (SAS Institute Inc. 1988) was performed on wetland groups to determine possible relationships between habitat variables and invertebrate abundance and volume. Only those habitat variables explaining 5% or greater of the variation in the multiple regression equations were reported.

RESULTS

Forty-three aquatic invertebrate taxa were collected from funnel traps in 1998 while 35 taxa were captured in 1999 (Table 2). During both years, cladocerans (water fleas), copepods, and ostracods (seed shrimps) were the most abundant taxa. In 1998 and 1999, 76 aerial invertebrate taxa were collected from floating sticky traps (Table 3). The most abundant aerial taxa encountered during 1998 and 1999 were collembolans (springtails), chironomids (midges), and ephydrids (shore flies).

Simple linear regression revealed no significant associations between invertebrate abundance and volume above or below the water surface in 1998 and 1999 (Table 4). In 1998, there was no apparent association between aquatic and aerial invertebrate abundance ($F_{1,78}$=1.691, r^2=0.022, P=0.197) or volume ($F_{1,78}$=0.201, r^2=0.003, P=0.655). Similar results were found for 1999 data regarding invertebrate abundance ($F_{1,58}$=0, r^2=0, P=0.995) and volume ($F_{1,58}$=0.036, r^2=0.001, P=0.850).

Stepwise multiple regression was performed on wetland groups obtained from ANOVA and LSD (Table 5). Before proceeding with stepwise regression, a strong association between maximum daily air temperature and water temperature in 1998 and 1999 was revealed ($F_{1,140}$=10987.940, r^2=0.988, P=0.001). Because air temperature is more variable and has some bearing on the temperature of the water, it was used in all abundance and volume models.

Table 2. Total abundance of aquatic invertebrate taxa collected from wetlands in 1998 and 1999. Diptera, Ephemeroptera, Lepidoptera (Pyralidae),and Odonata occurred in immature stages only. Coleoptera occurred in adult as well as immature stages and were combined. n=number of traps per year.

Taxa	1998 (n=80)	1999 (n=60)
Amphipoda		
Gammaridae	0	378
Hyallelidae	12,480	4414
Amopoda (Cladocera)	81,275	36,961
Araneae	9	2
Coleoptera		
Curculionidae	161	3
Dryopidae	1	0
Dytiscidae	353	189
Gyrinidae	1	0
Haliplidae	174	55
Hydrophilidae	125	41
Scirtidae	71	0
Staphylinidae	1	0
Collembola		
Isotomidae	5	5
Poduridae	4585	8
Sminthuridae	34	0
Copepoda		
Calanoida	160	34
Cyclopoida	55,126	73,088
Diptera		
Ceratopogonidae	523	12
Chaoboridae	10	4
Chironomidae	1198	329
Culicidae	17	32
Ephydridae	21	0
Stratiomyidae	9	4
Syrphidae	6	1
Tipulidae	1	0
Ephemeroptera		
Baetidae	9	3
Caenidae	188	14
Gastropoda		
Lymnaeidae	25	5
Physidae	95	65
Planorbidae	258	44
Hemiptera		
Belostomatidae	7	5
Corixidae	2190	5897
Mesoveliidae	315	17
Nepidae	2	1
Notonectidae	246	53
Pleidae	199	63
Hirudinea	614	250
Hydracarina	684	624
Lepidoptera		
Pyralidae	1	0
Odonata		
Aeshnidae	14	4
Coenagrionidae	0	5
Gomphidae	1	0
Lestidae	1	1
Podocopa	73,571	37,449
Total Abundance	*233,938*	*160,055*

Table 3. Total abundance of flying insect taxa collected from wetlands in 1998 and 1999. All occurred in the adult stage. n=number of traps per year.

Taxa	1998 (n=80)	1999 (n=60)
Araneae	255	170
Coleoptera		
Anthicidae	8	11
Chrysomelidae	3	5
Cicindelidae	0	2
Coccinellidae	3	1
Corylophidae	3	3
Cryptophagidae	1	1
Curculionidae	13	3
Dytiscidae	44	31
Heteroceridae	22	15
Hydraenidae	11	15
Hydrophilidae	15	3
Ptiliidae	19	9
Staphylinidae	126	128
Collembola		
Entomobryidae	14	0
Isotomidae	6148	1862
Poduridae	2942	1508
Sminthuridae	3146	861
Diptera		
Agromyzidae	890	228
Anthomyiidae	13	80
Asteeiidae	9	3
Bombyliidae	0	24
Calliphoridae	0	4
Cecidiomyiidae	33	23
Ceratopogonidae	170	44
Chaoboridae	442	0
Chironomidae	4126	7528
Chloropidae	27	19
Culicidae	14	2
Diopsidae	1	0
Dolichopodidae	289	144
Empididae	46	65
Ephydridae	2425	3052
Muscidae	57	31
Mycetophilidae	0	3
Otitidae	10	13
Phoridae	122	96
Psychodidae	169	13
Scathophagidae	8	1
Sciaridae	746	199
Sciomyzidae	37	4
Sepsidae	399	183
Simuliidae	21	27
Spaeroceridae	81	49
Stratiomyidae	16	7
Syrphidae	8	17
Tabanidae	4	3
Tipulidae	13	18

Table 3 continued.

Taxa	1998 (n=80)	1999 (n=60)
Ephemeroptera		
Baetidae	0	2
Caenidae	305	851
Hemiptera		
Corixidae	9	32
Gerridae	2	3
Hebridae	8	1
Lygaeidae	7	1
Mesoveliidae	30	17
Miridae	1	0
Notonectidae	1	0
Pleidae	1	1
Saldidae	65	45
Veliidae	1	19
Homoptera		
Aphididae	98	120
Cicadellidae	25	99
Delphacidae	5	30
Psyllidae	1	1
Hymenoptera		
Braconidae	23	28
Chalcididae	3	1
Diapriidae	0	6
Eucoilidae	5	3
Eulophidae	103	201
Ichneumonidae	13	9
Mymaridae	431	200
Pteromalidae	29	9
Scelionidae	307	110
Trichogrammatidae	350	334
Lepidoptera		
Cosmopterigidae	12	8
Noctuidae	2	0
Pyralidae	45	30
Neuroptera		
Coniopterygidae	0	3
Odonata		
Coenagrionidae	16	5
Lestidae	1	0
Orthoptera		
Acrididae	2	5
Th**ysanoptera**		
Phlaeothripidae	2	1
Thripidae	197	147
Total Abundance	*24,851*	*18,830*

Table 4. Simple linear regression values for comparison of trends in subsurface and aerial invertebrate abundance and volume in 1998 and 1999.

Year	Variable[a]	F-value	r^2	P	
1998[b]	abundance	1.69	0.02	0.20	NS
	volume	0.20	0.003	0.65	NS
1999[c]	abundance	0.00	0.00	0.99	NS
	volume	0.04	0.001	0.85	NS

[a] In the regression model, subsurface observations were considered the independent variable while surface observations were considered the response variable.
[b] In 1998, 40 funnel traps and 40 sticky traps were deployed for 24 hours during two sampling periods.
[c] In 1999, 30 funnel traps and 30 sticky traps were deployed for 24 hours during two sampling periods.

Table 5. Stepwise Multiple Regression values for associations between habitat variables and invertebrate abundance and volume in wetland groups obtained from ANOVA and LSD. Alpha =0.10

	Significant Wetland Groups	Habitat Variables	Statistics
Aquatic Abundance			
1998	Moe	air temp	r^2=0.756, P=0.001
	Mick, Oak A, Oak B	air temp	r^2=0.369, P=0.001
1999	Moe, Mick B	air temp	r^2=0.528, P=0.002
	Red 1, Red 2, Mick, Moe P	air temp	r^2=0.381, P=0.001
Aquatic Volume			
1998	Moe, Mick, Oak A, Oak B	dist. to em. veg, % float. veg, % sub. veg	r^2=0.433, P=0.001
1999	Moe	air temp	r^2=0.836, P=0.001
	Mick B, Mick, Moe P, Red 1, Red 2	air temp	r^2=0.544, P=0.001
Aerial Abundance			
1998	Moe	% sub. veg	r^2=0.649, P=0.001
	Mick, Oak A, Oak B	wind spd, % float. veg	r^2=0.790, P=0.001
1999	Mick, Red 1	air temp	r^2=0.949, P=0.001
	Mick B, Red 2, Moe, Moe P	air temp	r^2=0.796, P=0.001
Aerial Volume			
1998	Moe, Mick, Oak A, Oak B	wind spd	r^2=0.752, P=0.001
1999	Mick B, Red 2	wind spd	r^2=0.780, P=0.001
	Mick, Red 1, Moe, Moe P	dist. from edge	r^2=0.716, P=0.001

Maximum daily air temperature was the only significant habitat variable positively associated with aquatic invertebrate abundance in Moe ($F_{1,17}$=49.690, r^2=0.756, P=0.001) and the other three wetlands ($F_{1,60}$=34.430, r^2=0.369, P=0.001). Subsurface invertebrate volume in all four wetlands was positively associated with distance to nearest emergent vegetation, % cover of floating vegetation, and % cover of submerged vegetation ($F_{4,77}$ =18.830, R^2=0.433, P=0.001). Aerial invertebrate abundance in Moe was positively associated with a single habitat variable, % cover of submerged vegetation ($F_{1,20}$=35.080, r^2=0.649, P=0.001). In the other three wetlands, positive relationships with two habitat variables, wind speed (r^2=0.708) and % cover of floating vegetation (r^2=0.069), accounted for the majority of variation in aerial invertebrate abundance ($F_{4,60}$=71.58, R^2=0.790, P=0.001). In all four wetlands, the majority of variation in aerial invertebrate volume was positively associated with wind speed ($F_{2,80}$=118.280, r^2=0.752, P=0.001).

A positive relationship with maximum daily air temperature accounted for moderate variation in subsurface invertebrate abundance in Moe and Mickelson Burn ($F_{1,20}$=21.230, r^2=0.528, P=0.002), as well as the remaining four wetlands ($F_{1,39}$=23.360, r^2=0.381, P=0.001). The majority of the variation in aquatic invertebrate volume in Moe was due to a positive association with % cover of submerged vegetation ($F_{1,10}$=45.800, r^2=0.836, P=0.001). For the remaining five wetlands, an increase in subsurface volume of invertebrates was explained by an increase in maximum daily air temperature ($F_{1,49}$=57.170, r^2=0.544, P=0.001). A positive association with maximum daily air temperature accounted for much variation (r^2=0.926) in the aerial abundance model for Mickelson and Redetzke 1 ($F_{2,20}$=43.070, R^2=0.949, P=0.001). In the remaining four wetlands, a positive relationship with the same habitat variable, maximum daily air temperature, explained the majority of the variation (r^2=0.737) in the aerial abundance model ($F_{3,40}$=48.050, R^2=0.796, P=0.001). Wind speed was the only significant habitat variable positively influencing aerial invertebrate volume in Mickelson Burn and Redetzke 2 ($F_{1,20}$=67.160, r^2=0.780, P=0.001). Finally, an increase in aerial volume of invertebrates was attributed to an increase in the distance of the sticky trap from the wetland edge (r^2=0.678) in the remaining four wetlands ($F_{2,40}$=47.940, R^2=0.716, P=0.001).

DISCUSSION

Of the 43 aquatic invertebrate taxa collected during 1998, each of the four wetlands averaged 10-13 taxa per funnel trap. In 1999, aquatic invertebrate taxa captured ranged from 6 taxa in Moe to 14 taxa in Mickelson Burn. During both years, cladocerans were the most abundant invertebrate taxa, and made up 35% of the total in 1998 and 23% of the total in 1999. Cladocerans were also the most abundant taxon collected by Chura (1961) and constituted 55% of the total. The average number of aerial invertebrate taxa was much more variable between wetlands during both years. Mickelson averaged 19 taxon per sticky trap, while Oak A averaged 27 taxa per sticky trap in 1998. In 1999, Mickelson Burn had the highest average with 27 taxa per sticky trap and

Moe had the lowest with 10 aerial taxa per sticky trap. In a study by Chura (1961), the most abundant aerial taxon captured using sticky board traps was adult chironomids comprising 55% of the total. Likewise, in our study, adult chironomids were the most abundant and made up 16% of the total in 1998 and 40% in 1999.

Wetland productivity has previously been linked to the abundance, density, and diversity of aquatic invertebrates (Joyner 1980, Phillips and Wright 1993, Hanson and Riggs 1995, Cooper and Anderson 1996). Many aerial insects, such as midges (Chironomidae), mayflies (Ephemeroptera), and dragonflies/damselflies (Odonates) have aquatic life forms. Also, there are numerous aerial insects without aquatic life forms that are associated with wetlands for feeding or mating. Therefore, it is logical to assume wetland productivity could also be linked to indices of aerial insects. Significant associations between aquatic and aerial invertebrates were expected because wetland productivity should have been reflected in both mediums. However, the results did not support this hypothesis. Bias associated with the funnel traps may include avoidance of traps by nekton invertebrates, difficulty in collecting invertebrates making vertical migrations, or predators (fish or invertebrates) consuming prey while inside the trap. In addition, wind may have forced many flying insects into the sticky traps, while wave action could have released some insects from the trap. Thus, given the biases involved with our estimates, we cannot rule out a possible association between subsurface and surface invertebrate abundance or volume from our data.

Similar to most living organisms, invertebrates have a range of optimal temperatures in which they are most active. Extreme high and low temperatures, beyond the optimal range, can be detrimental to invertebrates (Clark 1978). Cox et al. (1998) have also speculated that low air temperature and thus lowered water temperature may suppress aquatic invertebrate activity. During both years in our study, aquatic invertebrate abundance increased with an increase in the surrounding air temperature.

During both 1998 and 1999, an increase in aquatic invertebrate volume was associated with an increase in submerged vegetation cover. The presence of submerged vegetation has been linked to the size of aquatic invertebrates (Armstrong and Nudds 1985). They observed larger invertebrates in shallow areas with an abundance of submerged vegetation. Furthermore, Voigts (1976) found that amphipods, one of the greatest contributors to volume in this study, were most abundant in beds of submerged vegetation.

There was also a positive relationship between aquatic invertebrate volume and distance from emergent vegetation, implying the farther from emergent vegetation, the greater the size of the invertebrates. Murkin et al. (1992) discovered maximum numbers of small nekton (i.e., cladocerans) within stands of cattail compared to low numbers of corixids. In contrast, Armstrong and Nudds (1985) found a positive relationship between aquatic inverterate size and density of emergent vegetation, suggesting a greater amount of emergent vegetation in an area yielded larger aquatic invertebrates.

Temperature and photoperiod are the most important seasonal regulators of insect emergence (Corbet 1964). Emergence is initiated as the surrounding air temperature increases, resulting in numerous aerial insects. Additional evidence suggests that adult midges (Chironomidae), the most numerous aerial insect in this research, emerge when conditions are warm and calm (Cox et al. 1998, King and Wrubleski 1998). Flying insect abundance, during both years, increased with an increase in the surrounding air temperature, thus supporting the above statements.

Flying insect abundance also increased in our study with an increase in the percent cover of submerged vegetation. In past studies, aquatic invertebrate abundance has been associated with submerged vegetation (Collias and Collias 1963, Krull 1970, Voigts 1976). It seems logical that aerial insect abundance could be associated with submerged vegetation since numerous aerial insects spend their immature stages in water. King and Brazner (1999) hypothesized that the suppression of submerged vegetation may result in decreased abundance and biomass of flying insects. This may indirectly relate to the suppression of aquatic forms of aerial insects while in the immature stages.

During both years, wind speed was the predominant variable associated with flying insect volume. As the wind speed increased, so did insect volume. This is opposite of what was expected. During times of high wind, aerial insects were mostly found in the shelter of emergent vegetation (King and Wrubleski 1998). Increased volume during times of higher wind was probably attributed to increased vulnerability of the insects to the sticky traps.

CONCLUSIONS

Duckling brood distribution has been correlated with areas having the greatest abundance of invertebrate foods that comprise the majority of the diet (Collias and Collias 1963). Further, Cox et al. (1998) discovered mallard duckling growth was positively influenced by invertebrate abundance and not biomass. Past research has associated aquatic invertebrate abundance with increased submerged vegetation (Collias and Collias 1963, Krull 1970, Voigts 1976). Aerial insect abundance, in this research, was positively associated with increased submerged vegetative cover. Therefore, in order to promote maximum numbers of aerial and aquatic invertebrates, wetlands should be managed for healthy communities of submerged vegetation.

The lack of association between aerial and aquatic invertebrates helps illustrate the importance of knowing both invertebrate communities before assessing the suitability of a wetland for brood rearing. Although a wetland may have a viable aquatic invertebrate community, aerial insects may be lacking or vice-versa. Both invertebrate types, whether found above or below the water surface, are critical to the growth and survival of young ducklings, and therefore deserve equal attention. The role of aerial insects as potential duckling food is important and should be considered in research and management of brood rearing wetlands.

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Abstracts of Senior Research Papers

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SMALL THEROPOD DINOSAUR ASSEMBLAGE, HELL CREEK FORMATION (LATE CRETACEOUS), NORTH DAKOTA

Julia T. Sankey
Museum of Geology
and
Department of Geology and Geological Engineering
South Dakota School of Mines and Technology
Rapid City, SD 57701

Dean Pearson
Pioneer Trails Regional Museum
Bowman, ND 58623

ABSTRACT

Outcrops of the Hell Creek Formation are exposed in the Little Missouri River Valley in southwestern North Dakota. The Hell Creek Formation in this area records the last two million years of the Cretaceous (latest Maastrichtian). A high-resolution stratigraphic and paleontologic framework of these fluvial deposits has been developed (Fastovsky, 1987; Hunter and Pearson, 1996; Johnson, 1992; Johnson et al., 2000; Pearson et al., 2001). This particular project reports on the small theropod dinosaur assemblage from these deposits, based on isolated teeth collected from microvertebrate sites. Theropod teeth were found by the second author by surface collecting (and screening one site) 20 microvertebrate sites at multiple stratigraphic levels from the Hell Creek Formation. All fossils are curated and reposited in the Pioneer Trails Regional Museum. The sampled sites span the entire section exposed in the area and all sites have been measured to the palynologically-defined Cretaceous/Tertiary boundary (Pearson et al., 2001).

A total of 144 small theropod teeth were identified from the 20 sites. The assemblage includes 65 (45%) *Richardoestesia isosceles* Sankey (2001), 45 (31%) dromaeosaurids and undetermined teeth, 17 (12%) *R.* cf. *R. gilmorei,* 13 (9%) *Paronychodon,* 5 (3%) bird, and 2 (1%) troodontids. The taxonomy of late Maastrichtian theropod teeth has received less attention (ie Estes, 1964) than those from the late Campanian (Currie et al., 1990; Baszio, 1997; Sankey and Brinkman, 2000), so better identifications, especially of the dromaeosaurids, is in progress. Tyrannosaurids and caenagnathids (toothless theropods) were not included in this study, but are present in the fauna. Also, because these are surface collections and not screened (with one exception), teeth from bird and small *R. gilmorei* and troodontids are under-sampled. However, several interesting patterns are apparent. 1) Baszio (1997) found that *Richardoestesia* sp. (= *R. isosceles*) is rare (less than 5%) in most Late Cretaceous (Campanian and Maastrichtian) theropod assemblages. However, he

also found that *R. isosceles* had 45% relative abundance in the Lance Formation of Wyoming (correlative to the Hell Creek). *R. isosceles* was probably a fish-eater (Baszio, 1997; Sankey, 2001), so its high abundance in near coastal deposits like the Hell Creek and Lance Formations is not surprising. 2) The relative abundances of the other theropods in this Hell Creek assemblage also match those from the Lance (Baszio, 1997), especially in abundance of *Paronychodon* and rarity of troodontids. However, further taxonomic work on late Maastrichtian small theropod teeth, especially the dromaeosaurids, is necessary before detailed paleoecological patterns can be documented. 3) Within the sampled section, the abundance of theropods in relation to other microvertebrates could be calculated from eight sites. From these sites, theropods were 5% or less of the total assemblage. Low theropod relative abundance in these sites is due to high abundance of other vertebrates, especially fish. 4) Sample sizes are too small to determine if theropod relative abundances change within the sampled section. However, we plan to screen-wash multiple sites through out the section in order to study this.

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FIMBRIAL ADHESIN AND ENTEROTOXIN GENES IN ESCHERICHIA COLI STRAINS ISOLATED FOR PIGS WITH DIARRHEA

Tyler Hanson, David Francis & Diane Baker
Veterinary Science Department
South Dakota State University
Brookings, SD 57007

ABSTRACT

The purpose of this study was to use multiplex polymerase chain reaction (PCR) to identify fimbrial and toxin genes in *Escherichia coli* isolates acquired from diarrheic pigs submitted to the South Dakota State University Animal Disease Research and Diagnostic Laboratory. The protocol and primers for this porcine multiplex PCR were developed in theory by Drs. Tom Casey and Brad Bosworth at the National Animal Disease Center (NADC) in Ames, Iowa, to identify the following fimbria: K88, K99, 987P, F41, and F18, and enterotoxins: heat labile toxin (LT), heat stable toxin a (STa), heat stable toxin b (STb), and Shiga toxin IIe (Stx2e).

E. coli samples from diarrheic pigs submitted for identification were streaked for isolation on Blood Agar plates, incubated at 37 degrees C for 24 hours, boiled in water at 95 degrees C for 8 minutes to expel and denature DNA, combined with multiplex PCR reagents, amplified using a thermocycler, and separated on a 4% agarose gel containing ethidium bromide to reveal the DNA fragments. *E. coli* strains containing all nine genes of interest were obtained from NADC and run as a positive control with each trial set of samples submitted for testing. The resulting DNA fragments representing fimbrial or toxin genes were illuminated and photographed under ultraviolet light. The fimbrial and toxin profiles were determined by comparing the DNA bands of the samples to the 9 DNA bands in the positive control lane and a standard DNA ladder.

Analysis of the PCR diagnostic test data allowed for the relative frequencies and combinations of fimbrial and toxin genes to be determined in *E. coli* samples submitted for analysis. It has been shown that *E. coli* strains containing K88+ and F18+ fimbrial genes are by far the most common strains submitted for characterization. Results from the past two years have shown that the fimbria 987P apparently no longer causes a disease problem in domestic porcine herds. Multiplex PCR using this set of primers has also detected a strain or strains of *E. coli* that do not exhibit any identifiable fimbrial genes, yet contain identifiable toxin genes. These may be strains that have lost fimbrial genes due to loss of a plasmid during subculturing or may represent a novel fimbrial type not currently characterized. Strains possessing fimbrial genes but no toxin genes have also been identified.

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

Edward Kraft and R. Neil Reese
South Dakota State University
Brookings, SD 57007

ABSTRACT

Psoralea esculenta Pursh is an herbaceous perennial legume, native to the Great Plains, that has a tuberous-thickened taproot. Native American populations have long used the roots of this plant as food source. The *Psoralea* root has a tough outer covering (bark) and a fleshy interior that 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, Toluidine Blue, IKI, and Aniline Blue were used to examine the tissue morphology. Digital pictures were made using a Leaf Microlumina 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. Alteration of protein and starch reserves was observed in mature roots, but absent in young roots. The vascular strands appeared to be randomly arranged in the secondary tissues of the root. Further analysis at different developmental stages will help to clarify the unique anatomical features observed in the root of *Psoralea esculenta.*

SPECIES RICHNESS AND NESTING SUCCESS OF NEOTROPICAL MIGRANTS IN NATURAL AND ANTHROPOGENIC WOODLANDS

Dale J. Gentry and David L. Swanson
Department of Biology
University of South Dakota
Vermillion, SD

ABSTRACT

Historic woodland nesting habitat for Neotropical migrant songbirds in the Northern Great Plains consists primarily of riparian habitat surrounding streams and rivers. These deciduous woodlands have become narrower as trees were cleared to make the land available for agriculture. Since then, new habitats for woodland nesting birds have arisen in the form of anthropogenic woodlots and shelterbelts. A decreased nesting success is associated with isolated and fragmented habitats due to increased rates of both nest predation by mammalian and avian predators, and brood parasitism by Brown-headed Cowbirds at forest edges. We compared nesting success in the two habitats to determine if Neotropical migrants are more successful nesting in reduced natural habitats or in anthropogenic woodlots. We also determined density and relative abundance of breeding birds with point counts four times during the summer. A total of 46 nests were found. Calculation of Mayfield nesting success on the nests in each habitat resulted in higher nesting success in the anthropogenic woodlands (0.543) than in the riparian areas (0.249) although we were not able to compare them statistically due to low sample size. Density and relative abundance were compared between habitats with an ANOVA and no significant differences were detected. These results represent only one field season, two more are planned before final results will be determined.

ADJUSTMENTS OF ORGAN MASSES AND MUSCLE FATTY ACID BINDING PROTEIN DURING WINTER ACCLIMATIZATION IN PASSERINE BIRDS

Eric T. Liknes and David L. Swanson
Department of Biology
University of South Dakota
Vermillion, SD

Christopher G. Guglielmo
Department of Zoology
University of British Columbia
Vancouver, BC

ABSTRACT

Winter acclimatization in small birds may involve adjustments at several levels of organization, but consistent seasonal changes include winter increases in whole-organism thermogenic capacity and the preferential use of fat as a metabolic fuel. In this study, we examine two components potentially contributing to these seasonal adjustments: 1) seasonal variation in organ masses important to provision and use of metabolic fuels, and 2) seasonal variation in muscle levels of fatty acid binding protein (H-FABP), an intracellular lipid transporter. We measured these parameters in summer (June-August) and winter (December-February) in three species of passerine birds wintering in cold climates, Black-capped Chickadees *(Poecile atricapillus),* White-breasted Nuthatches *(Sitta carolinensis),* and House Sparrows *(Passer domesticus)*. Organs were dissected on ice, blotted dry and weighed, then frozen in liquid nitrogen and stored at –80°C for later fat extraction (to determine organ lean dry mass) and H-FABP assays. Preliminary results on wet organ masses suggest that while body mass, liver mass, and supracoracoideus mass were seasonally constant in all species, heart and stomach masses increased in winter in all species. Sparrows and chickadees, but not nuthatches, showed winter hypertrophy of pectoralis muscles, the primary thermogenic organ. Nuthatches exhibited winter hypertrophy of the gizzard, but not of any skeletal muscles. Winter pectoralis muscle hypertrophy may contribute importantly to winter acclimatization in chickadees and sparrows. Pectoralis and supracoracoideus (SCC) muscle H-FABP was detected by SDS-PAGE and western blot analysis using antibodies developed against Western Sandpiper *(Calidris mauri)* H-FABP. Antibody cross reactivity ranged between approximately 32% and 59% in the three species, and H-FABP was quantified by ELISA. Pectoralis H-FABP was significantly elevated in winter in Black-capped Chickadees (P=0.025) and the winter elevation approached significance in White-breasted Nuthatches (P=0.062). House Sparrows showed no significant seasonal difference. SCC H-FABP tended to be elevated in winter in Black-capped Chickadees (P=0.159), but not in

House Sparrows or White-breasted Nuthatches. This study is the first to demonstrate that winter acclimatization can elevate H-FABP in thermogenically active tissues in some species and suggests that this may contribute to preferential catabolism of lipids in some winter acclimatized passerines. Further research investigating the potential for seasonal modulation of oxidative enzyme activities and utilization and mobilization of metabolic fuels in these three species is in progress.

STOPOVER HABITAT DISTRIBUTION OF AUTUMN LANDBIRD MIGRANTS IN SOUTHWESTERN IDAHO

Jay D. Carlisle
Idaho Bird Observatory
Boise, ID
and
Department of Biology
University of South Dakota
Vermillion, SD

David L. Swanson and Karen L. Olmstead
Department of Biology
University of South Dakota
Vermillion, SD

ABSTRACT

Migrating landbirds need suitable stopover sites for rest and re-fueling and it is important to identify which habitats are most important to migrants on a regional basis. While there is relatively little documentation of the habitat use patterns among autumn migrants in the western U.S., especially in the intermountain west, several recent studies have pointed to the importance of western riparian habitats as stopover sites. In 1997, studies were initiated in southwestern Idaho to identify and compare the migrant communities of different habitats in the Boise Foothills. Count surveys were conducted from August through October in the four major habitats at Lucky Peak (Ada Co., elevation 1845m): conifer forest (CF), mountain deciduous shrub (MS), shrub-steppe (SS), and willow riparian (WR). Bird densities among habitats and years were compared by ANOVA for individual species, migrant categories (Neotropical migrants, temperate migrants, and residents/irruptives), and all birds pooled. MS supported the highest densities of birds, particularly Neotropical migrants, and WR was of secondary importance for migrants, while CF was important to resident birds. Habitat distribution patterns varied somewhat among species but the highest densities for most species were in MS. Additionally, mist-netting was conducted in two of the habitats at Lucky Peak: MS (1997-2000) and WR (1998-99). Mist-netting was also conducted at a high-elevation riparian site in the nearby Owyhee Mountains (OWY) in autumn 1998. Relative abundance (corrected for effort) among sites in 1998 was similar for temperate migrants whereas MS and WR supported more Neotropical migrants than OWY. Community similarity was greatest between MS and WR and lowest between OWY and WR. These results highlight the importance of montane habitats to migrants in Idaho, especially deciduous shrub communities.

EXAMINATION OF APPEARANCE OF SYMPTOMS OF CORN SMUT *(USTILAGO MAYDIS)* ON FIELD CORN *(ZEA MAYS)* FROM SEEDLING TO MATURITY IN SOUTHEASTERN SOUTH DAKOTA

J. Fods and D. Hazelwood
Dakota State University
College of Natural Sciences
Madison, SD 57042

ABSTRACT

Ustilago maydis, the causal agent of common corn smut, is a warm temperature wound pathogen that infects corn *(Zea mays)* at all growth stages, but is reported to be most destructive to young, vigorously growing corn seedlings. Temperature requirements range from 17-35 C, with faster rates of growth reported at higher temperatures. During the last five years, we have observed incidence of corn smut in South Dakota fields at a low level, 1% to 5%. In contrast, during harvest 1999, we observed a field cropped to field corn in Minnehaha County that exhibited infection estimated at 75-90%, with a reduction in yield of approximately 50%. In 2000, this field and surrounding area was the site of our study designed to examine the appearance of symptoms of corn smut.

During growing season 2000, we examined field grown field corn from seedling to maturity for the appearance of corn smut caused by *U. maydis.* We set up four plots in fields subjected to a corn-soybean *(Glycine max)* rotation, two in fields cropped to field corn and two cropped to soybeans. Plot one was located in the field that had exhibited severe symptoms of corn smut in 1999, and was cropped to soybean in 2000. The second, in the adjacent field, was cropped to soybeans 1999 and to field corn 2000. Two other fields, one cropped to corn and the other to soybeans in 2000, were located nearby. In addition, we observed the field corn surrounding our plots and volunteer corn plants in the soybean fields. We examined corn plants each week from seedling stage in May until maturity in September. Because of the high infection rates and yield loss in 1999, our objective was to determine whether detection of early infection of seedlings would serve as a reliable indicator of subsequent infection of corn plants and especially infection of the ears.

In these fields, we observed that symptoms of corn smut appeared initially at anthesis. We were not able to correlate appearance of nonspecific symptoms such as yellowing or chlorosis that occurred before anthesis with subsequent infection. Instead, we observed that symptoms of corn smut continued to appear on corn plants from anthesis until maturity. Although we anticipated that a high innoculum level of *U. maydis* in the soil would lead to an increase in severity of corn smut, we observed, instead, that incidence was spot-

ty, and varied from a low level throughout most of the field, to a few areas of nearly 100% infection. The areas of highest incidence were consistently associated with driveway/turn around areas, plants with extensive mechanical damage at an early growth stage, the presence of tassel ears, or with factors of an unknown nature. We believe that the lower than anticipated incidence of corn smut in these fields in 2000 may be related in part to weather and most likely to other factors not yet understood. A follow-up study for growing season 2001 is under consideration.

ANTARCTIC SNOW AND ICE: A NATURAL ARCHIVE OF ATMOSPHERIC CHEMICAL COMPOSITION

Jihong Cole-Dai
Department of Chemistry & Biochemistry
South Dakota State University
Brookings, South Dakota

ABSTRACT

Continuous accumulation of snow at the polar regions of the world records and preserves constituents of the atmosphere. Chronological proxy records of atmospheric chemical composition can be obtained from chemical analysis of snow samples and ice cores collected at judiciously selected sites on the Antarctica and Greenland ice sheets. The history of atmospheric chemistry contains important information on the global climate system, chemical evolution of the atmosphere, major volcanic eruptions affecting the global atmosphere, anthropogenic impact, and biogeochemical cycles.

Ice cores and snow samples from a number of locations in Antarctica were analyzed for their chemical composition. The ice core records date back a few hundred to a few thousand years, with annual time resolution in some cases. Comparison of the chemical composition of recent (during the past 100 years) snow with that of older snow indicates that large scale air pollution in Southern Hemisphere is relatively insignificant, in contrast with findings from Greenland ice cores that show unequivocal evidence of anthropogenic pollution of the atmosphere in the Northern Hemisphere since the mid-Nineteenth Century onset of the industrial revolution. Variations of the sulfuric acid concentration in snow through the past 4000 years suggest that major volcanic eruptions occur frequently, and that frequent explosive eruptions in the past may have had a significant impact on the global climate. Long and detailed records of explosive volcanism were constructed using the sulfuric acid concentrations in Antarctic ice cores.

EFFECTS OF TILLAGE ON SOIL ARTHROPOD FAUNA IN CENTRAL SOUTH DAKOTA

Chris Noble, Paul J. Johnson and Tom Schumacher
South Dakota State University
Brookings, SD 57007

ABSTRACT

Tillage methods are management practices in central South Dakota field crops that directly influence soil properties and biotic components. Assessing the effect of differing tillage methods on the soil arthropod fauna is the primary objective of this project. Tillage methods were grouped into three treatments (long-term grass [control], no-till, and tilled). Nine sites of differing crops and soil types were selected for replication. At each site the soil fauna was sampled in three fields of the same soil type and which represented each management method. Four sub-samples from each field were pooled to make a field sample, each sub-sample included approximately one liter of soil from at and below the surface. Arthropods were extracted from soil samples by hand and using modified Tullgren-style funnels. Pitfall traps were used to sample surface-active arthropods. Five sampling trips 20-30 days apart were made during the season. A total of 89 specimens of *Parajapyx (Parajapyx) isabellae* (Grassi) (Insecta: Diplura) were collected from all sites and throughout the sampling season. When comparing treatments for this species 7 grass sites yielded 26 specimens, 8 no-till sites yielded 39 specimens, and 5 tillage sites yielded 24 specimens. Preliminary assessments suggest that increased vegetative cover (weed and crop), distance from unplowed areas, or localized field characteristics are important for maintaining dipluran presence and abundance.

BRAINWORM, *PARELAPHOSTRONGYLUS TENUIS,* IN WHITE-TAILED DEER *(ODOCOILEUS VIRGINIANUS)* OF EASTERN SOUTH DAKOTA: IMPLICATIONS FOR WESTERN SOUTH DAKOTA

Christopher N. Jacques and Jonathan A. Jenks
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007

ABSTRACT

Diseases and parasites are important mortality factors affecting cervid populations. Meningeal worm *(Parelaphostrongylus tenuis)* is a nematode parasite found in white-tailed deer *(Odocoileus virginianus)* populations throughout eastern North America. To determine the distribution of meningeal worm in South Dakota, heads of hunter harvested deer were examined for *P. tenuis* from 1997-1999. A total of 2,848 deer were examined for the parasite. Prevalence of *P. tenuis* infection was significantly higher in deer examined in eastern (n=2,271) than in western South Dakota (n=577) ($P < 0.0001$). One in four deer (25.1%) harvested east of the Missouri River were found to be infected with *P. tenuis* while only 1.4% of the deer examined in western South Dakota were infected. Furthermore, 570 of 578 (98.6%) infected deer were harvested in eastern South Dakota. Infected deer were present in 37 of 44 counties in eastern South Dakota and in 3 of 22 counties in western South Dakota. Distribution of *P. tenuis* also is dependent of the presence of suitable terrestrial gastropod intermediate hosts. To determine the distribution, abundance, species composition, and involvement of terrestrial gastropods in transmission of *P. tenuis* to deer populations, gastropods also were collected during the summers of 1999 and 2000. A total of 4,062 terrestrial gastropods representing 14 species, five of which are known intermediate hosts for *P. tenuis,* was collected throughout South Dakota during the summers of 1999 and 2000. Total number of gastropods collected was significantly higher in eastern (n=3,221) than in western South Dakota (n=841) ($P < 0.0001$). Furthermore, five known gastropod intermediate host species were collected in eastern South Dakota while only two known intermediate hosts were collected in western South Dakota. The scarcity of infected deer in western South Dakota might indicate that the Missouri River represents a physical barrier to the western movement of the parasite. Furthermore, the semi-arid climate associated with western South Dakota may not be suitable for survival of viable first stage *P. tenuis* larvae or may not be wet enough for a time period long enough to permit development to an infective third stage in terrestrial gastropods. The accidental introduction and the consequences for native mule deer *(O. hemionus)* and elk *(Cervus elaphus)* populations that currently occur in western South Dakota is

potentially disastrous. In fact, if *P. tenuis* became established in white-tailed deer populations in western South Dakota following an accidental introduction, it would be virtually impossible to eliminate. Thus, as game managers we must be conservative in our management practices to ensure that we not find out the hard way if *P. tenuis* could become established in western South Dakota if accidentally introduced.

STATISTICAL ANALYSIS OF SMALL THEROPOD TEETH FROM THE LATE CRETACEOUS (LATE CAMPANIAN) JUDITH RIVER GROUP, ALBERTA

Merrilee Guenther and Dr. Julia Sankey
South Dakota School of Mines and Technology
Museum of Geology
Department of Geology and Geological Engineering
Rapid City, SD 57701

ABSTRACT

Intensive collection of microvertebrate sites through both screen washing and surface collection from the Judith River Group (Campanian 79.5-74 Ma) during the past fifteen years by the Royal Tyrrell Museum of Paleontology has produced more than 1,700 theropod teeth. These teeth often represent the only theropod material available; therefore, determining their usefulness in taxonomic identification is key to understanding the true theropod diversity in the Judith River Group. To accomplish this, a statistical analysis of the morphological features of the teeth of several different taxa was done. The primary goal of this analysis was to attempt to distinguish the taxa based on tooth measurements and to create a framework that will aid other workers in identifying their own samples. The sample was studied in detail and large numbers of each taxon were measured. These measurements were then used to quantitatively assess the relationships between the various taxa using both bivariate and multivariate methods.

Some taxa, for example, *Troodon,* are morphologically very distinct. However, many of the taxa are difficult to differentiate solely based on general morphology. Measurements such as, curvature, denticles per millimeter, and fore aft basal length were used. The resulting analysis and graphical representations of the taxa indicate that definite boundaries between taxa are not always distinct, but that there are ranges and trends within the dimensions of the teeth that allow for better definition of the taxa. The goal of distinguishing *Richardoestesia* from *Saurornitholestes* and *Dromaeosaurus,* and in turn, further distinguishing *Saurornitholestes* from *Dromaeosaurus* was successful in recognizing standard ranges for each taxa. Further division of *Richardoestesia* into *R. gilmorei* and *R. isosceles* was less obvious statistically and suggests that a more conservative approach at the species level is required. In general, it appears that quantitative analysis can be useful in identifying theropod taxa based on teeth and therefore can play an important role in furthering our understanding of Judith River theropod diversity.

DEVELOPMENT OF THE SHORT WAVE AEROSTAT-MOUNTED IMAGER (SWAMI): A NOVEL INSTRUMENT FOR CONDUCTING SMALL- TO INTERMEDIATE-SCALE REMOTE SENSING MEASUREMENTS

Xuexia Chen, Lee Vierling, Matt Doering, Roar Engebretsen,
Gary Johnson, Kurtis Nelson, Dave Nuenke, Nathan Obr,
Aaron Pasala and Patrick Zimmerman
Institute of Atmospheric Sciences
South Dakota School of Mines and Technology
Rapid City, SD 57701

ABSTRACT

A casual hiker may gaze at the ground below and see a mosaic of fallen leaves, small sticks, and patches of dirt. At first glance, the ground appears static and unchanging. Upon crouching to take a closer look, however, the curious hiker discovers that in fact the ground below bustles with ecological activity: a caterpillar munches a leaf, translucent termites gnaw on a stick, and the patches of dirt actually serve as portals for countless ants to enter and exit the terrain. Although these miniature activities are undetectable by the upright hiker, they in fact play a critical role in cycling nutrients and maintaining the health of the entire forest.

Like the view of the upright hiker, images of the earth taken by satellite and aircraft-based remote sensing instruments offer an immensely valuable, yet limited perspective. While remote sensing technologies have revolutionized the study of the earth system by enabling large surface areas to be imaged quickly and frequently, various limitations can restrict the spatial resolution (i.e. pixel size) of remote sensing data to the point where observable surface detail is insufficient to study critical environmental processes. As a result, complex mathematical procedures are often necessary to derive "sub-pixel" fractions of various ground cover types such as trees, grasses, bare soil, and water. To complement and validate these mathematical procedures, novel remote sensing techniques are needed to bridge the gap between small-scale, ground-based observations and larger scale aircraft- and satellite-based measurements. The purpose of this project is to develop an instrument that can be attached to the tether line of a large, unmanned blimp and raised and lowered to view the earth across a range of intermediate perspectives.

An integrated research/education program at the South Dakota School of Mines and Technology (SDSM&T) is currently developing a lightweight, hyperspectral remote sensing instrument package for use on such a tethered balloon platform. Graduate students and faculty in the Institute of Atmospheric Sciences are teaming with undergraduate engineering students participating in

the SDSM&T Center of Excellence for Advanced Manufacturing and Production (CAMP) and Senior Design Courses to design, construct, and test the instrument. Instrument development will occur incrementally during each academic year from 2001-2005. Upon completion of each stage of instrument development, we will use the instrument to conduct several summer remote sensing experiments made possible by the balloon platform. For example, the balloon platform will be used to investigate how cover estimates of sub-pixel landscape components using various mathematical "spectral mixture analysis" techniques can be validated and improved. An operational version of the instrument will be completed in May, 2001, with the first field tests following in the Summer of 2001. The overarching goals of this work are 1) to foster collaboration between student scientists and engineers, 2) to conduct novel research and make advances in terrestrial remote sensing, and 3) to make this technology and research familiar to minority students and encourage them to pursue careers in science and technology.

SHORT- AND LONG-TERM STUDIES OF ECOSYSTEM-ATMOSPHERE CO_2 EXCHANGE IN SOUTH DAKOTA

Lee Vierling, Brad Baker, Denise Dykstra and Patrick Zimmerman
Institute of Atmospheric Sciences
South Dakota School of Mines and Technology
Rapid City, SD

David Clay
South Dakota State University
Brookings, SD

Cullen Robbins
Science and Applications Branch
EROS Data Center
Sioux Falls, SD

Tilden Meyers
National Oceanic and Atmospheric Administration
Oak Ridge, TN

ABSTRACT

Human emissions of carbon dioxide into the atmosphere affect the radiative balance of the earth as well as the photosynthetic functioning of natural and agroecosystems. At the global level, best estimates of the carbon budget suggest that not all of the anthropogenic CO_2 emissions can be accounted for by increased storage in the atmosphere, ocean, and terrestrial biosphere. At the local level, forest, cropland, and other land use management practices can influence diurnal to annual fluxes of CO_2. In order to assist in narrowing uncertainties relating to the global C budget, as well as to determine local carbon storage within managed systems in South Dakota, we have recently initiated short- and long-term measurements of ecosystem-atmosphere CO_2 exchange within the state. The two sites include a Moody County soybean field and a thinned Ponderosa Pine forest located in the Black Hills.

Measurements at the Black Hills were established during October of 2000 and are planned to operate continuously for at least 7 years as a part of a global network of micrometeorological flux towers. In contrast, measurements at the Moody County soybean site were performed for a period of three weeks during July and August of 2000. Both sites show a strong diurnal drawdown of CO_2 during the growing season, which extended into November of 2000 at the Black Hills Ponderosa Pine site. Representative fluxes and diurnal trends of the data along with their implications for assessing carbon storage with relation to land management in South Dakota will be discussed.

BROWN TROUT DIET VARIATION ALONG AN URBANIZED GRADIENT

Kerri T. Vierling and Peter R. Nelson
Dept. of Chemistry and Chemical Engineering
South Dakota School of Mines and Technology
Rapid City, SD

ABSTRACT

Brown trout *(Salmo trutta)* in Rapid Creek, South Dakota have been noted to be in poor condition, and this condition may be related to the physical structure of the creek, cumulative urban impacts (i.e. pollution), and/or factors affecting food availability. While it is well documented that macroinvertebrate communities in streams change along urbanized gradients, less work has addressed how changes in macroinvertebrate communities might affect the diet composition of the trout that feed on these macroinvertebrates. The objective of this study was to examine how brown trout diet varied along an urbanized section of Rapid Creek. Rapid Creek experiences relatively little disturbance from urban activities in upstream sites, but as it travels through Rapid City, it is subject to a variety of impacts (i.e. pollutants) that may negatively impact water quality and fishery habitat. Adult brown trout were collected in three 100m sites along Rapid Creek: one site was upstream of Rapid City, one site was in the middle of Rapid City, and one site was downstream of Rapid City. In October 2000, 60 fish from each site were captured using electrofishing techniques; their stomachs were pumped and stomach contents were preserved in 70% ethanol. Preliminary analysis of approximately 20 fish from each site indicate that the major insect orders consumed in all three sites included Diptera (midges and flies), Coleoptera (beetles), Trichoptera (caddisflies), and Ephemeroptera (mayflies). Consistent with our hypothesis, brown trout diet differed between upstream and downstream sites. For instance, chironomids (small midges) are characteristic of streams with low water quality. Chironomids were a relatively small component of diet in brown trout above Rapid Creek but comprised a major portion of the diet in sites in the middle and downstream portions of Rapid Creek. The results of this study suggest that trout diet can reflect predicted changes in macroinvertebrate communities along an urbanized gradient. Further, these data will provide information that will be helpful in analyzing the current poor condition of brown trout in Rapid Creek.

RECENT OBSERVATIONS OF THUNDERSTORM ELECTRIFICATION ON THE HIGH PLAINS

Andrew Detwiler, John Helsdon, Qixu Mo and Donna Kliche
Institute of Atmospheric Sciences
South Dakota School of Mines and Technology
Rapid City, SD 57701

ABSTRACT

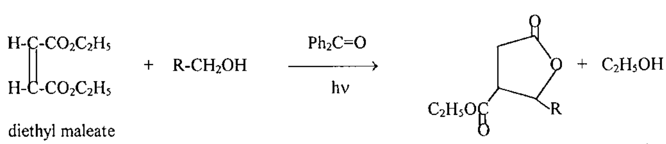
Coordinated observations from meteorological radars, lightning mapping systems, airborne and balloon-borne instruments, and a mobile meso-network of instrumented automobiles were obtained during the spring-summer of 2000 in the eastern Colorado/western Kansas High Plains during the Severe Thunderstorm Electrification and Precipitation Study (STEPS). Several severe storms, as well as many non-severe storms, were studied during the 8-week project. The focus of the project was to correlate electrical behavior with other storm characteristics, such as storm microphysics, updraft intensity, and size. Most thunderstorms produce predominantly cloud-to-ground lightning that lowers negative charge to ground, with only a small percentage of lightning events lowering positive charge. It has been observed that many severe storms in the study region produce anomalously high percentages of positive lightning. During our field study, we observed both severe and non-severe storms producing predominantly positive cloud-to-ground lightning, so it appears that predominant polarity may depend on other factors in addition to storm severity.

PRODUCT ANALYSIS FROM THE PHOTOCHEMICAL ADDITION OF 1-PROPANOL AND 1-PENTANOL TO DIETHYL MALEATE

Jesse J. Barondeau and M. Robert Stoner
Department of Chemistry
University of South Dakota
Vermillion, SD 57069

ABSTRACT

The irradiation of diethyl maleate and benzophenone in primary alcohols as solvent with ultraviolet light yields derivatives of ethyl tetrahydro-5-oxo-3-furancarboxylate in which the R group at the 2-position is dependent upon the structure of the alcohol. We have studied the lactone esters which are produced in the reaction when 1-propanol (R = CH_2CH_3) and 1-pentanol (R = $CH_2CH_2CH_2CH_3$) are used as solvents. The *cis* and *trans* isomers were separated and characterized by the use of IR and H-NMR spectroscopy. The relative amounts of *cis* and *trans* isomers produced have been determined by using gas chromatography. We have found that while the amount of the *trans* isomer produced is greater that the amount of the *cis* isomer in each case, the *trans/cis* ratio is not affected significantly by the length of the R group from one through four carbons. We have concluded that the differences in energies between the precursors leading to the *cis* and *trans* isomers does not change appreciably as the length of the carbon chain of the alkyl group R increases.



diethyl maleate

an ethyl 2-alkyltetrahydro-5-oxo-3-furancarboxylate
cis and *trans*

SYNTHESIS AND ANALYSIS OF TRI(C_8-C_{10}) METHYL AMMONIUM HYDROXIDE AND EXCHANGE WITH OTHER USEFUL ANIONS FOR THEIR ANTI-CORROSIVE PROPERTIES

Kari Lunder and Gary Earl
Chemistry Department
Augustana College
Sioux Falls, SD 57197

ABSTRACT

This project was intended to synthesize different anions for their anti-corrosive effects. This project consisted of the synthesis of a hydroxide quaternary compound. Acid-base reactions were examined to produce other anions from the hydroxide quat. The nitrate reaction was very successful because of the strong acid-weak base properties. The dichromate quat was also very successful because it is also a strong acid-weak base reaction. For the molybdate, there was no definite endpoint. It was important to make sure that the solution was very alkaline and that the mole ratio was 2:1. The anion that was obtained was $Mo_7O_{24}^{-6}$.

BIOFRIENDLY SURFACTANTS BASED ON GLUCOSAMINE

Chris Burke and Gary Earl
Chemistry Department
Augustana College
Sioux Falls, SD 57197

ABSTRACT

Traditional quaternary ammonium surfactants such as those used for fabric softening or hair care are not very biodegradable. This research further examines the use of D-glucosamine as a starting material in the search for more biofriendly surfactants. In this project benzaldehyde was examined as a reagent for protection of the amine group of the glucosamine. Then Fischer esterification and transesterification methods were examined as possible methods of adding lauric acid esters to the hydroxyl groups of the glucosamine to give the molecule hydrophilic-lipophilic character.

NOVEL SYNTHESES SILANIDE AND GERMANIDE DERIVATIVES

David Stone
Chemistry Department
Augustana College
Sioux Falls, SD

Weijie Teng and Karin Ruhlandt-Senge
Department of Chemistry
Syracuse University
Syracuse, NY

Abstract

Syntheses of rare alkaline earth metals in coordination with silicon and germanium compounds and the properties associated with these new molecules were explored. Limitations to synthesis of compounds were noted and synthetic routes were developed around limitations.

INTRODUCTION

Previous work by the Ruhlandt-Senge research group included syntheses of heavy alkaline-earth metal (Ca, Sr, Ba) silyl compounds using salt elimination and metallation synthetic routes. The product of the syntheses presents a rare metal coordination number between the metal (Ca, Sr, Ba) and a silyl group such as tris(trimethylsilyl)silane. These type of compounds are recognized as precursors in the development of semiconducting polymers containing Mg, Si, or Sn. Because of the limited availability of complexes of this type, structural and synthetic trends must be studied more thoroughly to better understand the properties of such compounds. By learning about specific chemical trends, information can be applied to other group IV compounds.

Synthetic strategies for the syntheses that lead up to the target compound are first, the synthesis and characterization of tetrakis(trimethylsilyl)-silane and -germane. Second, the synthesis and characterization of potassium tris(trimethylsilyl)-silanide and -germanide. And last the synthesis and characterization of alkaline earth metal silanides and germanides.

Serveral unexpected product were isolated including an intermediate of a reaction with potassium t-butoxide and tetrakis(trimethylsilyl)silane in coordination with THF.

Various conclusions were reached during the course of the summer. Several synthetic limitations were discovered involving the metallation of tetrakis(trimethylsilyl)silane and routes were developed for the formation of the desired product. Also, a synthetic pathway was established for tetrakis(trimethylsilyl)germane in the lab.

UNDERESTIMATION OF GASTROINTESTINAL NEMATODE BURDENS IN CATTLE HERDS WHEN ANALYZING SAMPLE POPULATIONS

K.J. Mertz, W.B. Epperson and M.B. Hildreth
Bio/Micro and Veterinary Science Departments
South Dakota State University
Brookings, SD 57007

ABSTRACT

Aggregation, over-dispersion, or clustering distributions has been described of parasite burdens in cattle herds. Aggregation within populations occurs when a majority of the pathogenic organisms inhabit a small part of the overall population. Statistically, variance to mean ratios (VMR) of aggregated distributions have a VMR greater than 1 as opposed to populations that have a Poisson distribution and have a VMR equal to one. When analyzing herds to determine levels of nematode infections, aggregation is often not taken into account. A sample population of 5 to 10 animals from within the herd population, is typically used to determine the level of nematode infections via fecal egg analysis, and may not represent true burdens for the herd. Our objective for this study was to determine the appropriate sample size population in order to accurately measure aggregated nematode burden levels in yearling grass cattle in the north central plains. Eight hundred yearling crossbred steers were grazed under production conditions from 28 APR 00 until 8 SEP 00 on nematode infested pastures. At the end of the grazing season, individual fecal samples were randomly obtained from 75 of the animals in the herd and fecal egg counts were performed. Arithmetic means were obtained for eggs per gram (EPG) of fecal material utilizing SAS 6.12 (1996). The arithmetic mean for EPG in the herd sample population was 28.45 EPG. The VMR for the study was 158.73 and represents a highly aggregated distribution of gastrointestinal nematodes in this cattle herd population. Considerations based on this data should be made as to sample population sizes when quantifying herd nematode infections. Several simulations were conducted to ascertain the appropriate estimator of the EPG measurements and also to determine the levels of confidence at different sample size population.

GELLAN PRODUCTION IN CONDENSED CORN SOLUBLES BY *SPHINGOMONAS PAUCIMOBILIS*

McKenzie Yackley and Dr. William Gibbons
Department of Biology/Microbiology
South Dakota State University
Brookings, SD 57007

ABSTRACT

Currently, a bonded fiber matrix (BFM), consisting of a binding agent (guar), mixed with organic fibers, is used in the landscaping industry to revegatate roadway ditches, mining spoils, and lawns. The BFM protects the site from erosion while allowing grass seed to germinate and grow through the matrix. Our primary hypothesis is that an inexpensive medium can be formulated, using corn processing byproducts, to support gellan production by *Sphingomonas paucimobilis* for use in place of the current binding agent, guar.

Our research consisted of two main objectives. First, to complete medium development efforts in the condensed corn solubles (CCS) medium, we needed to identify the optimum initial glucose concentration. Second, the literature indicated that it might be possible to boost gellan production by controlling nitrogen levels.

Shake flask fermentation trials were conducted in 500 ml flasks containing 200 ml of broth and 5% inoculum. The flasks were shaken for 96 hours at 270 rpm and at 27 degrees Celsius. HPLC samples, pH samples, and viable counts were taken every 24 hours and gellan samples every 48 hours. The gellan was then processed through a gellan recovery method to obtain a pellet for measurement.

For the first objective, we tested glucose levels of 8 to 35 g/1. Based on the fermentation efficiency and glucose levels over time, we determined the optimum level to be 20 g/1. To further test this finding, another trial was done at glucose levels of 8 to 20 g/l. This again showed the optimum level to be 20 g/1 based on fermentation efficiency and gellan levels.

Tentative conclusions are: CCS supports growth of *Sphingomonas paucimobilis*; less than or equal to 20 g/1 initial glucose resulted in 60% fermentation efficiency; based on prior studies, we anticipate in bioreactor fermentors that gellan production would boost from 5 g/1 to 8 to 10 g/1, productivity would increase from 0.09 g/1/h to 0.18 g/Vh and yield would increase from 0.25 g/g to 0.45 g/g. Upon completed replications of glucose trials, the effects of nitrogen supplementation will be conducted.

WATER QUALITY AND BENTHIC INVERTEBRATES WITHIN A PRAIRIE POTHOLE LAKE BASIN

Kelly Connelly and Nels H. Troelstrup, Jr.
Department of Biology & Microbiology
South Dakota State University
Brookings, SD 57007

ABSTRACT

Oak Lake (Brookings County, SD) is a small, semi-permanent prairie pothole lake basin on the eastern ridge of the Prairie Des Coteau. This lake is managed to support immersion contact recreation, marginal warmwater fish life propagation and livestock and wildlife watering. In addition, the western shoreline of this basin is bordered by the Oak Lake Field Station, a teaching and research facility managed by South Dakota State University.

Water quality and biotic integrity of Oak Lake have been monitored biweekly during the ice-free season over the period 1994-2000. Samples were collected from three mid-basin points using standard methods of water analysis. Water transparency (Secchi depth) averaged 33.6 cm (range of 0.4 to 180 cm) and water temperatures averaged 17.1°C (range of 2.5° to 30.0°C) during the growing season. Total dissolved solids averaged 299 mg/L (range of 135 to 505 mg/L) and conductance averaged 461 uS/cm (range 207 to 778 uS/cm). Water column pH values averaged 8.6 (range of 7.4 to 9.3) while dissolved oxygen averaged 6.9 mg/L (range of 5.6 to 15.0 mg/L).

Water column corrected chlorophyll a averaged 68.6 ug/L (range of 0.0 to 167.3 ug/L). Carlson Trophic State Index values generated from chlorophyll and Secchi data averaged 76 (range of 52 to 142). The fecal coliform values averaged 26.8 per 100 ml (range 5 to 470). The mid-basin benthic invertebrate community was found to be dominated by larvae of the midge genus *Chironomus* sp. (Chironomidae: Diptera). On average, this midge comprised 63% of total invertebrate abundance in Eckman dredge bottom samples. Other frequently occurring, but less abundant invertebrate taxa included *Procladius* sp. (Chironomidae: Diptera) at 30%, *Brundiniella* sp. (Chironomidae: Diptera) at 2.5%, *Chaoborus americanus* (Chaoboridae: Diptera) at 1.5%, *Tanypus* sp. (Chironomidae: Diptera), *Bezzia/Palpomyia* sp. (Ceratopogonidae: Diptera) at 1.5%, *Hexagenia limbata* (Ephemeridae: Ephemeroptera), *Rhinoncus* sp. (Curculionidae: Coleoptera) and *Palmacorixa buenoi* (Corixidae: Hemiptera) at 0.05%.

Oak Lake monitoring efforts provide data to evaluate compliance with water quality standards and support university instruction and research efforts. Existing data confirm that Oak Lake is a hypereutrophic basin. However, measured parameters did not fall outside established water quality standards. These data are available on-line (http://www.abs.sdstate.edu/bio/Oaklake/index.htm) for use by educational groups and research teams.

WOMEN'S CAREER EXPERIENCE IN THE LANDSCAPE INDUSTRY

Hala F. Nassar
South Dakota State University
Brookings, SD 57007

David J. Beattie and Dan T. Stearns
The Pennsylvania State University

ABSTRACT

Women entering male dominated professions had increased during the last two decades. Since not much research was available regarding women working in the landscape industry, the Landscape Contracting program at The Pennsylvania State University became interested in assessing the academic and professional experience of the women graduates. The study examined the academic performance of the graduates in the five courses specific to the major and the grade point average (GPA) at graduation. 319 male and female Bachelor degree recipients from the Landscape Contracting program were surveyed to determine their professional experience, with particular focus on their current occupational status. The study compared their job performance and satisfaction levels with various job aspects. Women graduates were surveyed to determine their perception of gender-related issues. The results of the study indicated that comparably trained female and male students have significantly different levels of academic performance, with female students consistently outperforming male students. Female students outperformed male students in all five courses specific to the Landscape Contracting major, in the overall performance of the five courses specific to the major, as well as, the cumulative GPA at graduation. Comparing men and women graduates regarding their professional experience, the results of the study indicated that women were represented in all job categories and performed similar type of work as their male peers. In addition, women did not differ significantly from men peers in regard to the job performance and satisfaction levels with achievement, praise, salary, as well as overall job satisfaction.

With respect to gender-related issues in the work place, roughly half of the women graduates perceived gender to have positive or no effect on career success, while the other half perceived gender to have negative effect. Over half the women graduates reported that they encounter gender-related problems, which seemed to disappear after professional respect is earned. In addition, women graduates indicated that "job demands" was the most important job aspect that women entering this industry needed to be aware of, especially long hours, seasonal demands, and physical effort. However, majority of the women graduates would still recommend this profession to other women.

In conclusion:

- Women were represented in all job categories, and perform same type of work as their male peers.
- Both men and women reported similar satisfaction levels in regard to job and praise satisfaction. However, women differed from men in satisfaction with salary.
- Majority of women graduates would recommend the profession to other women.
- For both men and women, the study indicated that the Landscape Contracting program provided realistic training and that their professional experience matched their career expectations.

AN INVERTEBRATE FAUNAL STUDY WITHIN THE PIERRE SHALE

Jamie Forish
South Dakota School of Mines and Technology
Rapid City, SD 57701

ABSTRACT

The Upper Cretaceous-age Pierre Shale was deposited in a shallow sea that covered the Western Interior of North America. This epicontinental sea was teeming with life. This is a report on some of the fossils collected from the Field's Ranch, approximately 5 miles north of Elm Springs, S.D, along Elm Springs Road. Here, the Upper Campanian Pierre Shale consists of gray to black marine shale with numerous calcareous and ironstone concretions that contain abundant molluscan fossils. Taxonomic identifications have yielded some interesting results. Three zones with distinctively different fauna have been identified. The lower zone has primarily *Inoceramus* and *Baculites* fossils, well preserved in brown iron-stone concretions. The middle zone has abundant *Placenticeras, Jeletzkytes*, and *Baculites,* including *B. compressus* and *B. cuneatus* fossils, which are not associated with concretions. The upper zone has well-preserved, very small bivalves and gastropods including *Inoceramus* and *Baculites compressus* preserved in dense calcareous concretions.

A HANDS-ON EDUCATIONAL TO INCREASE KNOWLEDGE AND CONSUMPTION OF MILK-CONTAINING FOODS

Trisha Bergjord and Kendra Kattelmann
Nutrition, Food Science, and Hospitality Department
South Dakota State University
Brookings, SD 57007

ABSTRACT

Children are not meeting the calcium Daily Reference Intake goal of 1300 mg/day during the critical growth period. A five year study conducted in Minnesota on student's eating patterns found that milk drinking dropped from an average of 2.5 times per day in third graders to 1.9 times per day. Calcium intake is one of the factors that effects bone density and a decreased intake may lead to an increased risk of developing osteoporosis later in life. The objective of this study is to determine in elementary (third through fifth grades) students if a hands-on educational lesson that includes food preparation techniques of a milk product will increase (1) knowledge of calcium containing foods and (2) consumption of milk containing foods. The hypothesis is that a hands-on educational lesson which includes food preparation techniques will increase knowledge and consumption of milk containing foods compared to an educational lesson alone. One hundred eight six students in eleven elementary school classes, third through fifth grade, were randomized by class to receive the educational program (control group) or an educational program with hands-on food preparation technique (experimental group). Consumption of milk was determined by measuring milk-waste in the school lunchroom before and approximately 6 weeks after the educational experience. Both experimental and control groups received information on how to get adequate calcium into the daily diet and the importance of calcium in the human body through an age-appropriate educational presentation. Students in the experimental group participated in the hands on lesson by learning to prepare a low-fat, dairy snack. The educational experience enhanced the students' knowledge on retention of knowledge about calcium containing foods and its importance in the body. However, milk consumption was not altered by the educational experience.

SCLEROGLUCAN PRODUCTION FROM *SCLEROTIUM GLUCANICUM* IN A CONDENSED CORN SOLUBLES BASED MEDIUM

Arlene Ceplecha and William Gibbons
South Dakota State University
Brookings, SD

ABSTRACT

Sclerotium glucanicum produces an exopolysaccharide called scleroglucan. A wide variety of uses have been demonstrated for scleroglucan, including: chemically enhanced oil recovery, a food and pharmaceutical binding agent, and the potential for use in a spray to prevent soil erosion of roadways and embankments. The problem with using scleroglucan for these applications are low yields and a resulting lack of cost effectiveness. The costs of producing scleroglucan can potentially be reduced with use of an inexpensive growth medium. The substrate investigated herein was condensed corn solubles (CCS), the terminal by-product of ethanol production from corn. The primary goal of this project was to maximize production of scleroglucan from *S. glucanicum* grown in a CCS medium.

The first step was to acclimate *S. glucanicum* to grow on the CCS medium instead of the standard medium, Wang's. By slowly increasing the concentration of CCS in a CCS/Wang hybrid medium through successive transfers, the organism was given time to adapt to the new medium. This adaptation was monitored by observing broth viscosity, which increased as cell biomass and scleroglucan accumulated. After approximately 15 transfers to broth of increasing CCS concentration, *S. glucanicum* had acclimated from the 100% Wang's to 100% CCS medium. The time from inoculation to maximum growth and media thickness in 100% CCS was equal to that observed for the Wang standard medium (approximately 120 h). The organism was also able to grow in the filtrate of the CCS medium.

A difficulty cited in the literature and found in experimentation was separating biomass from scleroglucan. While this is not a major concern for our intended use, as an erosion control matrix, it did create a challenge in the separate quantification of scleroglucan and biomass. My initial approach was to correlate mycelial dry weight with cell protein, in a medium not supporting scleroglucan production. The resulting equation had an R^2 value of 0.87. Subsequent testing of this procedure in Wang's medium showed a linear increase in protein with time (R^2 = 0.84). In the CCS medium however, protein levels remained basically constant over time (R^2 = 0.29). This was likely due to conversion of CCS protein into cell biomass, resulting in no net change in total protein levels over time.

As an alternate approach to quantifying biomass and scleroglucan, a fractional analysis using repeated centrifugation, washing and filtration was per-

formed. Results showed that the pellet contained approximately 100% of cell biomass and suspended CCS solids, with a small amount of scleroglucan. The supernatant contained 95% of recoverable scleroglucan. The remaining 5% of recoverable scleroglucan was released from the cell pellet following re-washing and re-centrifugation. The results thus far are encouraging but optimal glucose levels need to be determined, followed by a comparison of scleroglucan production in the CCS medium versus Wang's.

THE DIRECTIONAL TONE COLOR (DTC) LOUDSPEAKER APPLIED TO A SIX STRING ACOUSTIC GUITAR

Stephen E. Solberg and Christina Keller
Department of Physics
University of South Dakota
Vermillion, SD 57069

ABSTRACT

When the sound produced by a live guitar player is compared to the sound of a guitar produced by a traditional loudspeaker, a noticeable difference in the sound may be observed. When a guitar is played, the sound comes from vibrating components of the guitar like the strings and the body, vibrating in essentially three dimensions. Thus, the sound from a guitar seems to be coming from a number of different directions from all around the space in which the instrument is being played. This characteristic of a sound source is referred to as “presence”. When a traditional acoustic suspension loudspeaker reproduces the sound, the sound comes from a single rigid speaker cone, of essentially two dimensions, vibrating. This makes the sound seem to come from a hole in the wall; all of the sound is projected in a single direction and the three dimensionality of the instrument is lost. In an attempt to correct this difference, modifications may be made to commercially available speakers. The Directional Tone Color (DTC) Loudspeaker is such a modification. The DTC Loudspeaker is designed to represent more closely the “presence” of a stringed instrument being played live. Based on similar work with violins by Dr. Gabriel Weinreich, I have modified a commercially available acoustic suspension loudspeaker. The modifications to the commercial loudspeaker allow it to separate the guitar sound frequencies being reproduced and give it a more real feeling. I will present an acoustical analysis of the sound produced by a DTC Loudspeaker compared to that produced by a real guitar.

CONTROLLING SMOOTH BROME *(BROMUS INERMIS)* IN TALLGRASS PRAIRIE: EFFECTS OF COMPETING BIG BLUESTEM *(ANDROPOGON GERARDII)* AND SEASON OF CLIPPING

Gilbert W. Blankespoor
Department of Biology
Augustana College
Sioux Falls, SD

ABSTRACT

In the northern Great Plains, tallgrass prairie remnants are being threatened by alien plant species. Particularly troublesome in this regard is smooth bromegrass, *Bromus inermis.* The usual approach to controlling smooth brome in tallgrass prairie remnants is to clip or burn in the spring. In theory, burning or clipping in the spring significantly damages actively growing smooth brome while causing little harm to competing warm-season, native grasses which have not yet begun to grow. Although there have been some demonstrations of successful smooth brome control by spring burning or clipping, smooth brome continues to be a major threat to tallgrass prairie remnants.

Here I report on a field- and pot-based experiment that was designed to answer three questions. First, can it be demonstrated that warm-season grasses like big bluestem *(Andropogon gerardii)* compete directly with smooth brome? Second, does season of clipping influence the degree to which smooth brome is damaged? Third, is there an interaction between warm-season grass competition effects and season of clipping effects?

Two-way ANOVAs with smooth brome root biomass and smooth brome rhizome biomass as the dependent variables demonstrated that there were significant treatment effects related to the amount of below-ground competing big bluestem biomass and the season of clipping. As the amount of competing underground big bluestem biomass increased, smooth brome root and rhizome biomass decreased. Regarding clipping season, smooth brome clipped in early summer produced the least root and rhizome biomass. Interaction terms in the ANOVAs were not significant.

The results of this experiment suggest that the best smooth brome control is likely to be achieved when significant competing warm-season grass is present and when clipping occurs in early summer.

CARBON ISOTOPE DISCRIMINATION AS AN INDICATOR OF HEAT TOLERANCE IN WHEAT AND POTENTIAL FOR QUANTITATIVE TRAIT LOCUS MAPPING

Daniel D. Opheim, Kara J. Fuehrer, Steven R. Moeckly,
Michael E. Chapman and Michael K. Wanous
Department of Biology
Augustana College
Sioux Falls, SD 57197

Patrick F. Byrne
Department of Soil & Crop Sciences
Colorado State University
Ft. Collins, CO 80523

Keywords

carbon isotope discrimination, heat tolerance, water use efficiency, wheat

ABSTRACT

Carbon isotope discrimination expressed as $\delta^{13}C$ has previously been shown to be correlated with water use efficiency (WUE) in wheat (*Triticum aestivum* L.). In this study we evaluated $\delta^{13}C$ as an indicator for heat tolerance between heat tolerant and heat susceptible wheat cultivars. $\delta^{13}C$ measured from both grain and peduncle tissue samples discriminated between heat tolerant and heat susceptible cultivars under field heat stress conditions. WUE (as indicated by $\delta^{13}C$) was lower for the heat tolerant cultivars than the heat susceptible cultivars. This observation implies that high WUE under field heat-stress conditions is an indication of plants which have closed their stomata, resulting in less water loss, but also loss of photosynthetic carbon assimilation and productivity. Apparently, heat tolerant plants maintain water uptake, allowing transpirational water loss and sustained carbon assimilation through the stomata. This results in lower WUE, but higher productivity, compared to heat susceptible plants. We also investigated $\delta^{13}C$ as a tag for segregating heat tolerance genes in an $F_{2:3}$ population. We found that $\delta^{13}C$ values in this population made from a cross between the heat tolerant cultivar Kauz and the heat susceptible cultivar MTRWA116 had an approximately normal distribution, ranging between the two parents, with only two $F_{2:3}$ families outside the parent range. These results indicate that $\delta^{13}C$may be a useful marker for mapping quantitative trait loci (QTL) for heat tolerance in wheat.

OBESITY AND INFERTILITY IN THE LETHAL YELLOW MOUSE MODEL — DOES THE MUTANT GENE DIRECTLY AFFECT FERTILITY?

Maureen Diggins, Michelle Cederburg and Travis Dierke
Department of Biology
Augustana College
Sioux Falls, SD 57197

Nels H. Granholm
Department of Biology and Microbiology
South Dakota State University
Brookings, SD 57007

ABSTRACT

The lethal yellow mouse has a genetic mutation at the agouti locus on chromosome two. Mice homozygous for the lethal yellow gene (A^y/A^y) die during development. Heterozygous mice survive but exhibit a collection of characteristics known as the lethal yellow syndrome. Some of the characteristics of the syndrome are increasing obesity in adulthood, progressive infertility, and a yellow coat color. The working hypothesis was that dietary restriction in the lethal yellow mouse would reduce obesity and prolong fertility. Therefore, any effects of the mutation on fertility would result from increased adiposity.

Black mice (a/a) without the mutation were used as controls for the experiment. Mice were selected in their prime reproductive time and studied at three different ages (120, 150 and 180 days of age). Ten yellow females and ten black control females in each age category had been raised on a low fat (4%) diet. An equal number of mice in each age category had been raised on a high fat (10%) diet. Females in each group were mated with black males. Fertility was assessed by observation of first pregnancy. This was determined by observation of body weight, by assaying for progesterone with EIA (Enzyme ImmunoAssay) at five and twelve days after mating, and by the eventual observation of litters.

Dietary restriction appeared to diminish the degree of obesity and prolong fertility in the yellow mouse. In mice raised on low fat diets, day 5 progesterone levels were significantly lower in yellow mice compared to black mice at 150 and 180 days of age. Pregnancy in the yellow mice raised on low fat diets was delayed when compared to controls, but not prevented. In the mice raised on a high fat diet, pregnancy did not occur in 6 out of 10 yellow mice at 150 days of age. At 180 days of age, only 1 of 10 yellow mice raised on high fat became pregnant. Progesterone levels were significantly reduced in both groups. Therefore, the increased adiposity in the Ay mouse appears to cause decreased fertility. This does not, however, rule out other more direct effects of the gene on the reproductive system.

WHALE REMAINS FROM PUFFIN GROTTO, A RAISED SEA CAVE ON NOYES ISLAND, SOUTHEAST ALASKA

Timothy H. Heaton
Department of Earth Sciences/Physics
University of South Dakota
Vermillion, SD 57069

ABSTRACT

Puffin Grotto is a sea cave located on southern Noyes Island near Cape Addington, Southeast Alaska. The main entrance is 30 m wide and 15 m high, and several smaller entrances are connected by a series of archways. The cave is carved in marble and was formed primarily by wave action and secondarily by dissolution. The entrance is a spectacular site that can be seen by boat from several km away, and puffins frequently nest there.

Puffin Grotto extends back 75 m, and the back of the cave, called Jonah's Room, is 15 m above modern mean sea level (Allred 1994). The extent of driftwood indicates that modern waves only reach about half way back into the cave. The upper, back portion of the cave has been dry for millennia. Giant rounded cobbles of granite in Jonah's Room indicate that powerful waves once reached this area, but they are coated with calcite from years of quiet dripping action. Among these cobbles cavers discovered a whale vertebra that was also abraded by wave action. It is the atlas/axis complex of a great whale (baleen whale or sperm whale), and it was radiocarbon dated to 5,115±100 years B.P. (AA-21563). Since this bone would have been destroyed by long-term wave action, it must have been deposited during the final episode of waves reaching the back of Puffin Grotto.

Many sea caves in Southeast Alaska are inactive because they are above sea level out of the reach of modern waves. Sea level rose at the end of the Ice Age as glaciers melted, but most of coastal Alaska was depressed under the weight of the ice and took several thousand years to rebound once the ice was removed. Consequently sea level rose to at least 10 m above its modern level, peaking about 9,000 years B.P., then gradually fell to its present level. Some raised sea caves contain archaeological remains (Dixon et al. 1997). Puffin Grotto is the only cave in Southeast Alaska from which whale remains have been recovered (see Heaton and Grady 2002).

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ROCKS AROUND MT. FUJI

Keisuke Nozaki
University of South Dakota
Vermillion, SD

ABSTRACT

Mount Fuji, the highest mountain in Japan, is located 100 km southwest of central Tokyo, between the prefectures of Yamanashi and Shizuoka. The mountain is a typical strato-volcano with a history of violent volcanic eruptions dating back more than 5000 years.

Mt. Fuji is actually a group of superposed cones, and the structure of growth is hard to explain without the existence of Mt. Ashitaka, south of Mt. Fuji. Mt. Fuji consists of three different volcanoes: Komitake Volcano, Ko-Fuji Volcano, and Younger Fuji Volcano. The oldest part of the mountain probably started its activity in the middle of the Pleistocene Epoch. In the present millennium, Mt. Fuji has erupted at least thirteen times (AD 781-1707). The eruptions in 800, 864, and 1707 were more violent than the other eruptions.

Young Fuji was formed about 5000 years ago, and 20 major eruptions have been recorded. The tephra production rate is 0.14 km^3 / 100 years, and 0.3 km^3 tephra was produced by a major eruption. The tephra produced by Hoei Eruption was three times larger than the average volume of tephra by the others. The Hoei Eruption took place 840 years after the previous largest eruption. 293 years have passed after Hoei Eruption, and the next eruption is expected to produce 0.3-0.4 km^3 of tephra.

This study will determine the volcanic hazards of Mt. Fuji by studying the various rock types and looking at the history of eruptions at Mt. Fuji. Data will be used to predict future eruptions of the volcano and pinpoint likely target areas for volcanic fallout. This data will be used to construct a volcanic hazards map of Mt. Fuji for the surrounding communities.

A CROCODILIAN FOOTPRINT FROM THE FALL RIVER FORMATION (LOWER CRETACEOUS) OF SOUTH DAKOTA

Andrew A. Farke, Jennifer L. Cavin and Julia T. Sankey
South Dakota School of Mines and Technology
Museum of Geology
Department of Geology and Geological Engineering
Rapid City, SD 57701

ABSTRACT

Vertebrate fossils are extremely rare in the Lower Cretaceous Fall River Formation of the Black Hills. Consequently, the discovery of a crocodilian footprint represents an important step in understanding the paleontology of this formation. The natural cast of a footprint was collected near Hot Springs, South Dakota, at the type section of the Fall River Formation. The slab in which the cast is preserved had fallen from a cliff face and so it was not possible to determine the exact stratigraphic context of the specimen. The track cast is in an iron-rich mudstone and is overlain by fine-grained sandstone. Based on the environment of deposition of the Fall River Formation, it was likely made on a coastal mudflat at the time of a temporary marine regression. The print has four clawed toes. It is 17.5 cm in maximum width and 19.0 cm in maximum length. Based on the size and shape of the track, it is probably from the right rear foot of a large crocodilian. A possible second track, from the front foot of the same animal, may also be on the slab. The presence of this track indicates that more vertebrate ichnofossils may be preserved in the Fall River Formation. Prospecting for other tracks will continue to shed light on the paleoenvironment and paleoecology of western South Dakota during the Early Cretaceous.

CITY OF SIOUX CITY RIVERBANK FILTRATION STUDY

Jennifer Stanwick and Krisma DeWitt
Chemistry Department
Mount Marty College
Yankton, SD 57078

ABSTRACT

Revised Iowa Department of Natural Resources (IDNR) standards required validation of treatment processes and procedures for the water treatment facility at Sioux City. The project objective was to assess the filtering effect of the Missouri River alluvium in surface water migrating through sediments. Seven sites of differing depth and location on Sioux City water treatment channels were sampled twice daily and analyzed to determine whether current procedures would meet new IDNR standards.

Particulate analysis was done using a Met One WGS-267 grab sampler, in order to predict the possibility of bacterial contamination in the city's water supply and to validate current testing procedures. Counts were used to compare ground water samples to surface water samples. From the data set for each location, averages and log removals were calculated and graphed in order to determine if current testing procedures were sufficient. The log removals were determined based on influent and effluent flow at a particular point. In addition to particulate analysis counts, samples were tested for turbidity using a Hach turbidimeter. pH values were measured using two standards and each sample. Samples were randomly tested for chlorine content, calcium hardness, and specific alkalinity.

According to particulate analysis results, as the water passed through the sediments particles were removed. Because of these results, sampling frequency was reduced to once per day. In addition, only one lateral (a sampling location consisting fof depth variations) was needed for each sampling event. Initial results allowed verification of the lack of harmful bacteria in effluent water. Based on test results, current testing and treatment procedures were informally considered adequate to meet the new standards. Testing continues to ensure compliance is maintained through the treatment process.

TRANSGENE DETECTION IN SOYBEAN

C. Carter and S. Hansen
Plant Science Department
South Dakota State University
Brookings SD 57007

ABSTRACT

Soybean varieties that have been genetically modified to contain genes for herbicide resistance have been readily adopted by U.S. farmers. However, market forces may require the segregation and testing of transgenic and non-transgenic crops in the future. We are investigating methods to detect glyphosate-tolerant (Roundup Ready) transgenes and to measure potential levels of transgene dispersal in the field. Procedures were developed to reduce inadvertent contamination of samples and false positives, and DNA extraction methods were compared. The Roundup Ready transgene was detected by PCR amplification using primers for the CaMV-35S promoter and the NOS terminator region. The transgene was detected in 98.5% of positive control seeds using the NOS terminator primers, and in 97.5% of positive control seeds using the CaMV-35S primers. PCR amplification of the soybean actin gene concurrently with either the CaMV35S or NOS primers allowed determination of the presence and quality of the DNA sample simultaneously with detection of the transgene, thus eliminating a potential source of false negatives. We detected the transgene at concentrations as low as 0.01% using either the CaMV-35S primers or the NOS terminator primers, and in combination with actin primers. This is comparable to the best detection levels currently obtained commercially under similar conditions and is more sensitive than the 0.3% cut-off proposed by the USDA for certification of non-transgenic commodities.

SURVEY OF NATIVE BEES (HYMENOPTERA) IN THE PRAIRIE REGIONS OF SOUTH DAKOTA

Nicomas Dollar and Paul Johnson
Department of Plant Science, Entomology
South Dakota State University
Brookings, SD 570076

ABSTRACT

Probably the most significant activity of native bees in terms of benefits to humans is pollination of natural vegetation. Numerous species of small trees, bushes and herbaceous plants, require bee pollination to produce seed or fruit. Many cultivated plants and thus horticultural varieties depend upon bee pollination. Some plants are able to self-pollinate, but inbreeding depression is a frequent result, producing little or no seed and small or disfigured fruits.

Native bees are important pollinators that successfully replace feral populations of exotic honeybees lost to mites and diseases. In various crops, such as alfalfa, honeybees are poor pollinators compared to native bees. Native bees are commercially used due to their superior and "specialist" pollination capabilities throughout the world. Many states throughout the US including North Dakota (see O.A. Stevens, North Dakota Ag. Bulletins 1950s) have research bulletins covering identification, distribution, emergence and floral hosts of some native bee species in their state.

Presently no literature exists on native bees in South Dakota. Smithsonian Institute's Catalog of Hymenoptera in America North of Mexico (Krombein et al. 1979) lists only about 165 native bee species for the northern Great Plains region and only 51 species are listed in the State of South Dakota. Also there is little or no distribution, flower visitation, or pollen records listed on these species. Yet, more than 700 of the world's estimated 30,000 species (Michener, 2000) are likely to be found in South Dakota.

After realizing the lack of information about bees in South Dakota, our objective became to gather some of the missing basic bee information. We decided to begin producing the first database of native bees in South Dakota, along with information on their floral relationships with native plants.

Study sites were in Lyman, Stanley, Dewey, and Corson Counties, South Dakota in 1999. A study site in Brookings County, South Dakota was selected for the year 2000. Study season was from June through September in both years. Our hypothesis was that greater bee diversity would be found at the relatively lesser-disturbed, remote (as on some Indian reservation lands) areas. The identification of local bee species, emergence dates of species, floral preferences and habitat effects on diversity became the major objectives of our research.

The results of this study are new species of bees recorded for South Dakota, as well as new floral visitation and pollen records. It was found that native

bee species are more diverse on native flowering plants and in less disturbed habitats than on introduced and weedy plant patches in cultivated or pasture habitats. The few bee species occupying highly disturbed areas were higher in population than more diverse bee communities. This is likely because bee species in disturbed areas are mostly generalists in that they will use many different plant species to fulfill their needs. Low bee populations in less disturbed habitat may relate to bee requirements for fewer native species for which they specialize. Also plants themselves are sometimes low in number or more widely dispersed than weedy patches.

EXAMINATION OF THE ANTIOXIDANT ACTIVITY AND SAFETY OF *ECHINACEA ANGUSTIFOLIA*

Eric Huntimer and Fathi Halaweish
Department of Chemistry and Biochemistry
and
Neil Reese
Department of Biology and Microbiology
South Dakota State University
Brookings, SD 57007

ABSTRACT

For many years, Echinacea has shown a wide range of biological activities; its primary use for marketing purposes is as an immunostimulant. Its ability to treat many different ailments, ranging from minor to life-threatening, originates from its numerous methods of preparation. Analysis of Echinacea revealed several classes of compounds; these included caffeic acid derivatives, flavonoids, essential oil, polyacetylenes, alkylamides, alkaloids, and polysaccharides; inorganic components have been reported as well in trace amounts. Recently reports have shown that Echinacea works as a free-radical scavenger. However, it also has shown anti-inflammatory activity, in which it inhibits the enzyme hyaluronidase. Hyaluronidase is an enzyme responsible for producing inflammation to a given injury; it is also the enzyme responsible for allowing sperm to fertilize an egg, which may affect the mobility of sperm. Due to these findings, it seems necessary to examine the antioxidant activity and cytotoxicity of Echinacea. A total of twenty-two samples of *Echinacea angustifolia* were collected from North Dakota, South Dakota, Wyoming, Nebraska, and Kansas. The samples were tested individually for antioxidant activity by measuring the extinction of 2,2-diphenyl-1-picrylhydrazyl (DPPH). The samples were also tested for cytotoxic activity using a brine shrimp assay in an attempt to establish a correlation between cytotoxicity and antioxidant activity based on collection sites. The samples have shown a significant variance with relation to the collection site. The range of the antioxidant activities varies from 18% to 85%, in comparison with quercetin. The cytotoxicity of the individual samples varied significantly as well, ranging from 60 to 600 μg/mL.

POTENTIAL DEGRADATION OF LEAFY SPURGE TOXINS IN CATTLE RUMEN DIGESTA

M.B. Hubert and F.T. Halaweish
South Dakota State University
Brookings, SD 57007

S.L. Kronberg
USDA Research Station
Mandan, ND

ABSTRACT

Leafy spurge invasion of pastures in the northern Great Plains is a serious problem because cattle cannot tolerate toxins in spurge and therefore learn to avoid it. Prior data suggests that rumen microorganisms may be involved. We evaluated the toxicity of leafy spurge after *in vitro* fermentation with normal or modified cattle rumen digesta. Ruminal digesta was obtained from ruminally-canulated steers on an alfalfa/grass hay diet. Seventy-five ml of whole digesta was mixed with 300 ml of buffer solution and 26 g of ground (1 mm screen) leafy spurge or alfalfa (control), gassed with CO_2 and incubated at 39°. For one treatment, .5mg of neomycin sulfate antibiotic was added to the mixture in order to alter the population of microbes. Fermentations were stopped at 15 min, 6 h and 12 h by freezing the mixtures quickly in thin zip-loc bags. Fermentations were extracted with petroleum ether, and ether was evaporated from extracts before they were tested for toxicity using the Brine Shrimp Toxicity Assay. Three brine shrimp assays were conducted. In Assay 1, leafy spurge was more toxic than alfalfa ($P<.0001$), and less toxic at 15 min compared to 6 h ($P=.0004$) and 12 h ($P=.008$). For Assay 2, adding neomycin sulfate to the mixture did not affect the outcome ($P=.6503$), and spurge was less toxic at 15 min compared to 6 h for normal digesta ($P<.0001$) and modified digesta ($P=.0159$). In Assay 3, leafy spurge was more toxic than alfalfa ($P<.0001$) and the addition of a modifier did not increase or decrease the toxicity of leafy spurge compounds to brine shrimp. These results indicate that leafy spurge contains compounds that are toxic to shrimp, and these toxins are able to survive 6 and 12 h of exposure to rumen microbes.

A SURVEY OF MACROFUNGI OF THE BLACK HILLS OF SOUTH DAKOTA

E. Ebbert, A. Gabel and S. Sarver
Black Hills State University
Spearfish, SD 57799

ABSTRACT

A survey was initiated in 1998, to collect and identify macrofungi occurring in the Black Hills of South Dakota. Lichens and plasmodial slime molds were also collected. Specimens were collected four times throughout the summers of 1998, 1999 and 2000, from each of five permanent sites and less frequently from several additional sites. Data recorded included: site, date, taxon, substrate, primary and secondary vegetation at the site, land use, edibility, and collection number. Data were sent to the South Dakota Natural Heritage Program and exsiccatae were prepared for inclusion in the Black Hills State University Fungal Collection. A total of 1170 specimens representing 244 different species were collected during the study. Species in the Agaricales and Aphyllophorales were the most commonly collected. The most common species collected throughout the three-year study was *Gymnopus dryophilus.* The five permanent sites yielded a range of only 4-9% of species occurring all three years at each site. Eighty-eight different species were collected from a narrow, wet site dominated by *Picea glauca* and *Ostrya virginiana* compared to a total of 37 different species collected from a dry site dominated by *Pinus ponderosa* and *Juniperus virginiana*. August was the best collecting month for 1998 and 1999. July was the best collecting month for 2000. Soil was the substrate, which yielded the greatest numbers of specimens for all three summers.

DNA sequencing was performed to help resolve the identity of two very similar species identified as *Gymnopus dryophilus* and *G. acervatus* using characters listed in fungal field guides. DNA samples from both species were submitted to Genbank, which showed all samples were *G. dryophilus.*

INVERTEBRATE COMMUNITY RESPONSES TO PHYSICAL MANIPULATION OF LITTORAL ZONE HABITATS: EMPHASIS ON INITIAL RESPONSES BETWEEN SITE CLASSIFICATION

C.W. Braskamp and N.H. Troelstrup, Jr.
Department of Biology and Microbiology
South Dakota State University
Brookings, SD 57007

ABSTRACT

Recent efforts have demonstrated differences in littoral zone invertebrate communities between two level three ecoregions in eastern South Dakota and their relationships to littoral and shoreline conditions. The objective of this effort was to determine invertebrate response signatures to physical disturbance in littoral zones. Our study was conducted at Oak Lake, Brookings County, South Dakota, where overland drainage areas have been classified as "prone" or "not prone" to physical disturbance. We used three prone and three not prone sites, with three plots at each site (Control, Scour and Sedimentation). Littoral invertebrates, vegetative cover, water temperature, conductance, dissolved oxygen, and pH were collected at two-week intervals from May to September 1999 and 2000, with four pre-disturbance and eight post-disturbance sampling dates. Sites prone to physical disturbance had higher means for conductance (515 uS/cm), percent vegetative cover (43%) and vegetation stem density (57 stems/m^2), while not prone sites had higher mean dissolved oxygen (6.7 mg/L), pH (8.8) and water temperature (20.9°C). Mean fractional abundance of Annelida (0.52), Insecta (0.25), Mollusca (0.13) and Nematoda (0.01) were all found to be higher in not prone sites. Sites classified as not prone exhibited higher means for clean water metrics like ETSD, Ephemeroptera abundance, Ephemeroptera and Trichoptera richness and percent intolerant organisms. Not prone sites also had higher mean fractional abundance for climbers, gliders and swimmers (Habit guilds) as well as collector/gatherers and scrapers (functional feeding groups). Mean abundance and richness metrics (total abundance, percent dominant taxa and total taxa respectively) were found higher in prone sites. Prone sites also had higher means for tolerance metrics such as Hilsenhoff's Biotic Index (HBI) and percent tolerant organisms. Specific habit guilds (burrowers, clingers, crawlers and sprawlers) and functional feeding groups (collector/filterer, shredders, predators and parasites) were found in greater abundance in prone sites. Habit guilds (gliders and swimmers), functional feeding groups (collector/gatherers, predators and scrapers), richness measures (Gastropoda, Ephemeroptera, Oligochaeta and total taxa), total abundance and percent tolerant organisms increased initially after littoral manipulation. Habit guilds (gliders and swimmers),

functional feeding groups (collector/gatherers and scrapers), Gastropoda abundance and richness and percent intolerant organisms continued to increase two weeks later. Habit guilds (burrowers, climbers, clingers, crawlers and sprawlers), functional feeding groups (collector/filterer and shredders), fractional abundance measures (Chironomidae, Ephemeroptera and Oligochaeta), tolerance measures (HBI and percent tolerant organisms) and percent dominant taxa all decreased initially following treatment. Samples two weeks later showed fractional abundance of Ephemeroptera and sprawlers (habit guild) increased by 11% and 30% respectively over initial post manipulation scores. The HBI metric, which measures invertebrate tolerance to organic enrichment (lower scores indicate less tolerance) continued to degrease by 7% from initial findings. Our ability to detect shifts in community structure will facilitate development of response signatures along a time scale, aiding lake management efforts.

MOLECULAR ANALYSIS OF 35 RELATED ISOLATES OF METHICILLIN RESISTANT *STAPHYLOCOCCUS AUREUS*

Amy J. Stephenson and Patricia M. Tille
Mount Marty College
Yankton, SD

ABSTRACT

Contraction of an infectious disease in a long-term health care setting presents a difficult patient care issue. Often times, patient comfort becomes secondary to necessary aggressive containment strategies. Such containment strategies may include a total population surveillance, contact isolation, treatment for carriers, screening of new admits,and staff education. Costly containment strategies versus costs for health care to patients contracting nosocomial infections is a serious contemporary health care issue. Molecular epidemiological studies provide a means for monitoring appropriate containment strategies. However, often times, the health care facility lacks trained personnel and facilities to carryout such labor intensive analyses.

This study is a molecular analysis of 35 methicillin resistant *Staphylococcus aureus* clinical isolates. The molecular analysis is based on restriction endonuclease patterns of the organism's chromosome and plasmid content. Plasmid DNA was purified from clinical isolates using a modified alkaline lysis procedure. Restriction endonuclease patterns were examined by agarose gel electrophoresis. Analysis indicated the presence of reoccurring plasmid restriction endonuclease patterns. However, complete molecular analysis will be based on the culmination of the chromosomal and plasmid comparisons for each isolate.

POLYMORPHISM IN THE AGOUTI-RELATED PROTEIN (AGRP) GENE IN SWINE

Kent Donelan, Nels H. Granholm, and Carl A. Westby
Department of Biology & Microbiology
and
Donald M. Marshall
Department of Animal & Range Sciences
South Dakota State University
Brookings, SD 57007

ABSTRACT

The agouti-related protein (agrp) gene encodes a gene product that regulates components of energy homeostasis – appetite, food intake, body composition, physical activity, BMR, and others. The protein encoded by agrp binds to melanocortin receptors (MC4R) of hypothalamic neurons causing an increase in feeding behavior when it overwhelms or out-competes alpha-MSH, another naturally-occurring ligand of MC4R which acts to suppress appetite.

The purpose of this project was to isolate, clone, and sequence the porcine agrp from diverse breeds of pigs. Using the DNA nucleotide sequences of each breed-specific pig, we will conduct restriction fragment length polymorphism (RFLP) studies to determine if there are different alleles or variations among the various breeds of pigs. Porcine agrp sequences were amplified using previously designed primers and polymerase chain reaction (PCR). PCR products (agrp sequences) were ligated into a bacterial plasmid, grown in transformed E. coli, extracted using a mini-prep method, purified, and sequenced. Ten samples representing pure or various crossbreeds have been sequenced. The open reading frame (ORF) of porcine agrp consists of 978 nucleotides. Preliminary sequence data show a six to seven nucleotide difference between the samples. Whether these unique nucleotide differences qualify as polymorphisms remains to be seen. Information provided by this study may be valuable to pork producers. By optimizing the genetic regulation of weight gain, carcass quality and other aspects of energy balance, these data may help to produce healthier pigs with higher quality meats. This project was supported by funds from the SDSU Agricultural Experiment Station – Project numbers SD00186H and SD00060H.

ISOLATION AND CHARACTERIZATION OF THE BOVINE ATTRACTIN GENE

Ted W. Glad, Carl A. Westby, and Nels H. Granholm
Department of Biology and Microbiology
and
Donald M. Marshall
Department of Animal & Range Sciences
South Dakota State University
Brookings, SD 57007

ABSTRACT

The mouse lethal yellow gene (Ay) ubiquitously overexpresses agouti protein (AP) causing a number of abnormalities collectively known as the Lethal Yellow Syndrome (LYS). Age-onset obesity and diabetes, tumor susceptibility, yellow coats, infertility, and others characterize the LYS. Excess AP antagonizes two melanocortin receptors which regulate food consumption (MC4R in hypothalamic neurons) and pigmentation (MC1R in hair follicle melanocytes) by out-competing alpha-MSH, a naturally occurring ligand for both MC1R and MC4R. Ay/- mice exhibit aberrant patterns of energy homeostasis (appetite regulation, food intake, BMR, and exercise) that can be partially reversed by the attractin gene. Compound mutant mice (atrn/atrn Ay/a) are less yellow, less fat, exercise more, and show an elevated BMR when compared to control Ay/- mice (+/+ Ay/a). Since atrn exhibits striking energy homeostasis effects in mice, we want to determine the role that homologous atrn genes may play in livestock energy homeostasis.

The purpose of this work was to amplify the bovine atrn gene that has previously been characterized in humans and mice. We used a technique called RT-PCR (Reverse Transciptase PCR) to amplify a bovine DNA fragment that consists of a 487 bp sequence. We isolated, cloned, and sequenced transcripts from brain, liver, and lung of a number of different cattle. Using GenBank's BLAST, we determined that our bovine atrn sequence is highly homologous to human and mouse atrn genes. Tissue-specific differences in nucleotide sequences of bovine atrn may suggest that cattle possess two or more alleles of attractin. Since fat content, feed efficiency, carcass quality, and other aspects of energy homeostasis are important to cattle producers, the characterization of favorable atrn alleles in cattle should be of value. This project was supported by funds from the SDSU Agricultural Experiment Station – Project numbers SD00186-H and SD00060-H and the Eagles Ehrmann Cancer Fund.

THE EFFECTS OF CHANGING CO_2 CONCENTRATIONS ON GENTAMICIN MIC TESTING IN HYPERBARIC CONDITIONS

Sarah O. Hammar, Brandon J. McCall, Jenny M. Volkert,
Contessa E. Creager, Spring J. Mayer, Nicholas L. Strasser,
Julie M. Altmann, Julie A. Groen, Casey J. Schlenker and William J. Soeffing
Natural Science Area
University of Sioux Falls
Sioux Falls, SD 57105

Keywords

Carbon dioxide, Gentamicin sulfate, Hyperbaric, MIC Testing, *Pseudomonas aeruginosa*

ABSTRACT

Contingent to preliminary investigations regarding the chemotherapy and characterization of otitis induced by exposures to hyperbaric environments, comparative data analyses suggest that clinical testing methods and standards established on normobaric conditions may not be appropriate for diagnostic use in extreme environments where carbon dioxide concentrations exceed normobaric levels. This study examined the effects that changing carbon dioxide concentrations have on the results of the minimum inhibitory concentration testing (MIC) of gentamicin sulfate on *Pseudomonas aeruginosa* in a 162 kPa compressed air hyperbaric environment.

Standardized MIC testing was conducted on *P. aeruginosa* under normobaric and hyperbaric incubation conditions using a concentration gradient of gentamicin sulfate that ranged from 0.23 µg/ml to 2.0 µg/ml by two fold concentration intervals. Bacteria cultures were grown in 96 well culture plates where the final volumes of bacteria, antibiotic and culture medium in each well did not exceed 105 µl. Culture plates were incubated at 37 °C in humidified normobaric (101 kPa) and hyperbaric (162 kPa) air microenvironments, where the atmospheric concentrations of carbon dioxide varied from 400 ppm to 5000 ppm. Positive, negative and contamination controls were conducted in parallel with each sample.

Results obtained through experimentation were reproducible and significantly different ($p < 0.01$) among the four experimental conditions. The minimum inhibitory concentration of gentamicin in normobaric testing conditions was 0.45 µg/ml, while the typical minimum inhibitory concentration in hyperbaric testing conditions was 1.0 µg/ml. Variation in MIC values among the hyperbaric testing conditions (manned undersea habitat, ambient pressure chamber and hyperbaric chamber) portray the minimum inhibitory concentration of

gentamicin as directly related to the atmospheric concentration of carbon dioxide in the incubation microenvironment. MIC values in hyperbaric conditions were most similar in the experiments conducted in the hyperbaric chamber and most variable in the manned undersea habitat. Carbon dioxide levels in the hyperbaric chamber remained relatively constant (~640 ppm) while carbon dioxide concentrations oscillated between 1800 ppm and 5000 ppm in the manned undersea habitat. The oscillating carbon dioxide concentration levels in the undersea habitat are directly correlated to the activity levels of the habitat's occupants. MIC values intermediate in variation were derived from the ambient pressure chamber that may be best described as a slowly declining carbon dioxide concentration gradient (5000 ppm to 690 ppm).

The sensitivity of standard MIC testing methods to elevated carbon dioxide concentrations found in hyperbaric microenvironments suggests that attention must be given to the interpretation of results derived from extreme environment research, where the atmosphere control system retains a higher than normobaric concentration of carbon dioxide. The aforementioned consideration is immediately applicable to closed system environments found in submarines, space crafts, undersea habitats and space stations.

FRUITBATS OF MONTSERRAT: SUB-LETHAL PATHOLOGY ASSOCIATED WITH THE INGESTION OF VOLCANIC ASH

Scott C. Pedersen
South Dakota State University
Brookings, SD

ABSTRACT

Since 1995, we have observed a dramatic increase in sub-lethal pathologies among fruitbat populations on the small Caribbean island of Montserrat coincident with renewed pyroclastic activity from the Soufriere Hills volcano. Indeed, apart from the minor inconvenience of being incinerated by the occasional pyroclastic flow (500 C), the fruitbats of Montserrat have contended with acid rain, the deposition of volcanic ash on fruits/flowers (and its subsequent ingestion), and the accumulation of ash on the animals pelage whilst foraging. Life in this world dusted by volcanic ash has had serious consequences for the health of Montserrats' fruitbat populations. We observed, in all species of fruitbat on the island, that the occlusal surfaces of the teeth exhibit abnormal wear, advanced dramatically by the incidental ingestion of volcanic ash while feeding and grooming. Before 1995, idiopathic hair-loss (alopecia) had been observed only once in 638 captures, whereas alopecia has been recorded frequently (30-60%) for *Brachyphylla, Artibeus,* and *Ardops* in each of our last three surveys ('97, '98, '00). The incidence of alopecia is more difficult to pin-down, however, it is most likely due to mineral deficiencies associated with the ingestion of ash, and to abnormal amounts of roost-parasitism. The adjacent island of Antigua has served as an excellent biological control for the natural history of Montserrat's fruitbats; these islands share similar habitats and faunal diversity. However, without the threat of living beneath a volcano, Antiguan bats have not been affected by the volcanic ash, exhibiting neither abnormal tooth-wear, nor alopecia.

A HURRICANE PLUS A VOLCANO, RECIPE FOR DISASTER FOR BAT SPECIES ON THE ISLAND OF MONTSERRAT, WI

Vicki J. Swier, Scott C. Pedersen, Jon Appino
South Dakota State
University, Brookings, SD

ABSTRACT

Hurricanes and volcanic eruptions have had significant impacts upon the bat populations of the British Crown Colony of Montserrat, as underlined by the
loss of three of its ten species: *Chiroderma, Sturnira,* and *Noctilio*. The declines were first observed in 1989 after Hurricane Hugo caused near total defoliation of the island which lead to a 10-fold decrease in the bat population. Then in 1995, the Soufriere Hills volcano erupted, causing destruction of major roost sites (caves) and foraging habitat which has depressed the populations even further. Seven surveys have been conducted (78, 84, 94, 95, 97, 98, 00), the last four during the recent volcanic activity. In the last two years (1999-2000), volcanic activity has declined and is reflected in a slight rebound in the fruitbat population, as estimated by bat captures per net per night (BNN). In 1995, 1.6 bats were captured per net per night, and 1.1 during the 1997 to 1998 surveys. Capture data from the recent survey (2000) resulted in a slight increase to 1.3 BNN. Two species, *Ardops* and *Artibeus,* have experienced interesting population shifts within the frugivore guild. These tree roosting bats differ in that *Artibeus* is the larger of the two species (46 grams) and tends to consume larger fruit than *Ardops* (28 grams). Of these two species, *Artibeus* has remained numerically dominant in all seven surveys (range 64 - 94% of *Ardops* + *Artibeus* captures), however, during the 95, 97, and 98 surveys, the *Ardops* population increased at the relative expense of *Artibeus* (*Ardops* 36% of *Ardops* + *Artibeus* captures). During our recent survey, 2000, the trend has reversed and *Artibeus* are making a comeback. Volcanic activity may have affected each species differently. Several hypotheses will be explored to explain these shifts in the population balance.

WATER COORDINATION NUMBERS FOR EU^{3+} IONS IN AQUEOUS SOLUTION

Jian Sun and Mary T. Berry
Department of Chemistry
University of South Dakota
Vermillion, SD

ABSTRACT

New spectroscopic evidence for an equilibrium between eight and nine-coordinate Eu^{3+}*(aq)* ions in dilute solutions of $EuCl_3$ resolves the longstanding issue of water coordination number for Eu^{3+}. A comparison of emission and excitation spectra for aqueous $EuCl_3$ with the spectra of the crystalline, nine-coordinate, europium ethylsulfate and eight-coordinate, europium vanadate makes it clear that the crystal-field splitting of the Russell-Saunders levels for the aqueous species is not well represented by the crystal-field splitting of either the tri-capped trigonnal structure in europium ethyl sulfate or by the approximately square-antiprism structure of europium vanadate. However, a sum of the spectra of the two crystalline species reproduces the aqueous emission and excitation spectra very closely, suggesting that the aqueous ions exist with both eight and nine-coordinate structures.

REPRODUCTIVE BIOLOGY AND AGRONOMIC POTENTIAL OF CUP PLANT *(SILPHIUM PERFOLIATUM)*

Paula Loewe and Arvid Boe
South Dakota State University
Brookings, SD

ABSTRACT

Cup plant is a tall, vigorous native forb (Asteraceae) found in moist ground from northeastern North Dakota to Kansas in the eastern Great Plains. The plant can be identified by its leaves, which are joined around the thick, resinous, angular stem. Cup plant has been studied in Europe and Asia for several decades as an alternative fodder and nectariferous crop. Our objectives are: (1) determine the breeding system of cup plant, and (2) determine the genetic variation of cup plant for agronomic and conservation traits in the Northern Great Plains. The germplasm came from Illinois and Minnesota. Forty-one half-sib families were transplanted to spaced-plant nurseries at two locations in eastern South Dakota. In the second year of growth (2000), plants were harvested to determine biomass yield, seed yield, and self-pollinated and open-pollinated seed weights. Averaged across locations, biomass yield mean was 2.1 kg plant^{-1} with a high of 5.7 kg plant^{-1} and a low of 0.1 kg plant^{-1} and a standard deviation of 1.1. Seed yields averaged 11.3 g plant^{-1} with a standard deviation of 11.1. High and low yields were 64.8 g plant^{-1} and 0.2 g plant , respectively. Preliminary analysis of controlled pollination seeds indicated that open- and self-pollinated seed weights varied among individual plants. Upon completion of the evaluation of these half-sib families at the two locations, superior plants will be selected for cultivar development. In addition to its already recognized potential as a forage crop, we feel that cup plant also has outstanding potential as a buffer-strip crop for nitrogen management and soil stabilization in prairie wetlands that receive runoff from cropland and pasture areas.

OBSERVATIONS ON THE ROLE OF INSECTS IN THE REPRODUCTIVE ECOLOGY OF SOME NATIVE LEGUMES

Arvid Boe and Paul Johnson
South Dakota State University
Brookings, SD

ABSTRACT

Native legumes are integral components of grassland ecosystems in the northern Great Plains. They are significant community species that are critical to the support of diverse and complex animal guilds, particularly plant feeders, and parasites and parasitoids. Some species provide high quality forage for native and non-native grazing animals, food and shelter for birds and other small vertebrates, and are essential hosts and substrates for hundreds of species of arthropods. Seed of native legumes is in high demand for revegetation of roadsides, rangelands, and mine spoils, and for beautification and diversification of parks and ruderal areas.

Our objectives were to develop a baseline inventory of the phytophagous and parasitoid insects affecting development of the seed crop under natural conditions, and to determine the impact of seed predators on viable seed production in several species of native legumes. Here, we report on seed rearing studies. Work was conducted at the Oak Lake Field Station near Astoria, SD. During 1999 and 2000, we collected pods from eight species of native legume that were in various stages of development. Insects were reared in the laboratory from the pods collected in the field.

A diverse insect fauna was reared from species representing the genera *Amorpha, Astragalus,* and *Dalea.* The primary seed predators collected were beetles that belonged to the Curculionidae and Chrysomelidae: Bruchinae, and midges that belonged to the Cecidomyiidae. Parasitic Hymenoptera that were collected belonged to the chalcidoid families Eulophidae, Pteromalidae, Eupelmidae, and the ichneumonoid family Braconidae. Estimates of pod predation ranged from 0% for *Astragalus adsurgens* to greater than 80% for *Dalea purpurea.* For several of the legumes, individual seed predators served as hosts for at least four parasitoids each. Data collected from this research provides essential insight into the diversity of the phytophagous and parasitic insects associated with seeds of native legumes and estimates of seed production and natural species survivability for native legumes in grassland of eastern South Dakota.

FLUORESCENT COLORED SIGNS DON'T "GRAB" ATTENTION, THEY "GUIDE" IT!

Paul Schieber
Department of Psychology
Heimstra Human Factors Laboratories
University of South Dakota
Vermillion, SD

ABSTRACT

Several recent studies have demonstrated the enhanced daytime conspicuity afforded by highway signs constructed using fluorescent colored materials. A conference session on the topic of fluorescent highway signs was recently held at the 2001 Meeting of the Transportation Research Board (TRB). All four papers presented at the TRB session stated that fluorescent colors were superior because that they "grabbed the attention" of the driver. Yet, none of these papers (nor any previous studies) have explicitly demonstrated that the superior daytime performance associated with the use of fluorescent colors is due to their enhanced *attentional conspicuity* (i.e., their ability to automatically recruit the focus of visual attention on the basis of *bottom-up* mechanisms). A novel visual search protocol was used: (1) to demonstrate that fluorescent colored signs could be localized more efficiently than their non-fluorescent counterparts and (2) to isolate the *bottom-up* (attentional conspicuity) versus *top-down* (search conspicuity) mechanisms that were the basis of this improved search efficiency for fluorescent colored signs. Experimental participants were presented with an array of multicolored signs on each trial. A full-spectrum daylight simulator with a programmable electrochromic aperture screen were used to present the stimuli with rapid and precise onset times. The participants searched through the array for a target sign containing a single "up arrow". When this target appeared upon an **unexpected** fluorescent colored "singleton" no improvement in search time was observed. However, when the target appeared on an **expected** fluorescent colored singleton remarkable reductions in search time were observed. This pattern of results strongly suggests that fluorescent colored highway signs improve visual efficiency via top-down rather than bottom-up mechanisms as previously assumed. That is: fluorescent colored highway signs do not appear to "grab" visual attention. Instead, they "guide" the locus of attention in a top-down manner. This pattern of results is consistent with recent findings in cognitive psychology and have important implications for roadway design and implementation.

AGE DIFFERENCES IN THE VISUAL INFORMATION PROCESSING DEMANDS OF HIGH-LOAD VEHICLE INSTRUMENT PANEL INTERFACES

Paul Schieber
Department of Psychology
Heimstra Human Factors Laboratories
University of South Dakota
Vermillion, SD

ABSTRACT

The emergence of the Intelligent Transportation System (ITS) has been accompanied by rapid development and deployment of sophisticated in-vehicle displays and related technology (e.g., route guidance systems, in-vehicle signing, real-time internet sevices). As a result, instrument panels of everyday automobiles are becoming increasingly complex. Increased visual information processing demands imposed by vehicle instrument panel interfaces may consume attentional resources better dedicated to the task of safely maneuvering the automobile. The potential for such processing overload problems appears to be particularly acute for the broad class of older drivers who already display reduced attentional capacity during the performance of driving-related tasks (Schieber & Harms, 1998). In response to this problem, ergonomists have attempted to develop techniques to quantify the information processing demands imposed by in-vehicle displays and related interfaces. Wierwille (1990) demonstrated that age differences in the visual processing demands of instrument panel controls could be quantified on the basis of eye movement data. Schieber, et al. (1997) demonstrated that such eye fixation data could be reliably measured using low-cost video monitoring techniques. The current project extends these converging lines of research. The instrument panel of a STISIM v. 8.0 driving simulator was augmented with a "head down" video text console (used to emulate Internet client services). Video cameras were mounted on the instrument panel so that driver eye gaze location could be classified (off-line) as either "on the road", "on the video text console" or "other". The eye gaze fixation patterns of 16 young (ages 18-30) and 16 older (ages 70-80) participants were monitored as they attempted to simultaneously drive and read video text messages of variable length (1,2,3,4,6 and 8 lines of 24-point text). Driving performance (lane position variance; crashes) declined significantly as the length of the text message being read was increased - especially in the case of the older participants. Nonlinear increases in the number of glances and total glance time also accompanied increases in text message length. As expected, older drivers exhibited a greater number of glances as well as an increase in total glance time for messages longer than two lines in length. Unexpectedly, older drivers also demonstrated longer "eyes on the road" intervals between successive glances to the instrument panel. This find-

ing suggests that older drivers take longer to re-establish visual contact with the road (i.e., an attention switching deficit).

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MODELING THE APPEARANCE OF FLUORESCENT COLORED MATERIALS

Paul Schieber
Department of Psychology
Heimstra Human Factors Laboratories
University of South Dakota
Vermillion, SD

ABSTRACT

Many interesting theoretical questions have accompanied the increased deployment of durable fluorescent colored materials in traffic safety applications (e.g., highway signs, safety vests). One of the more theoretically "vexing" issues will be presented here: namely, specifying the psychophysical relationship between the photometric properties of fluorescent materials and their psychological appearance. A primitive but potentially powerful model is proposed to account for both the fluorescent color appearence threshold (G_0 as proposed by Evans, 1974) as well as provide a wavelength-dependent scale for expressing the magnitude of fluorescent color appearance (i.e., "fluorence"). This model can be expressed as

$$F = Y/Y_m,$$

where,
F = magnitude of fluorescent appearance (i.e., fluorence)
Y = relative reflectance of a colored surface (Y=100 for reference "white")
Y_m = MacAdam Limit for the "optimal color" at a given chromaticity

A psychological scale of fluorescent color appearance based the use of the MacAdam Limit as a normalization function was first proposed by Schultze (1953). Unfortunately, he was unable to provide data to support this elegant hypothesis. The current study identifies two data sets that are now available to test the model. Curve fits to these data sets revealed that the model accounted for between 85-95 per cent of the scaled appearance data (using *magnitude estimation* as well as *Thurstonian scaling* techniques). This model has important implications for the specification and study of the efficacy of traffic control devices.

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