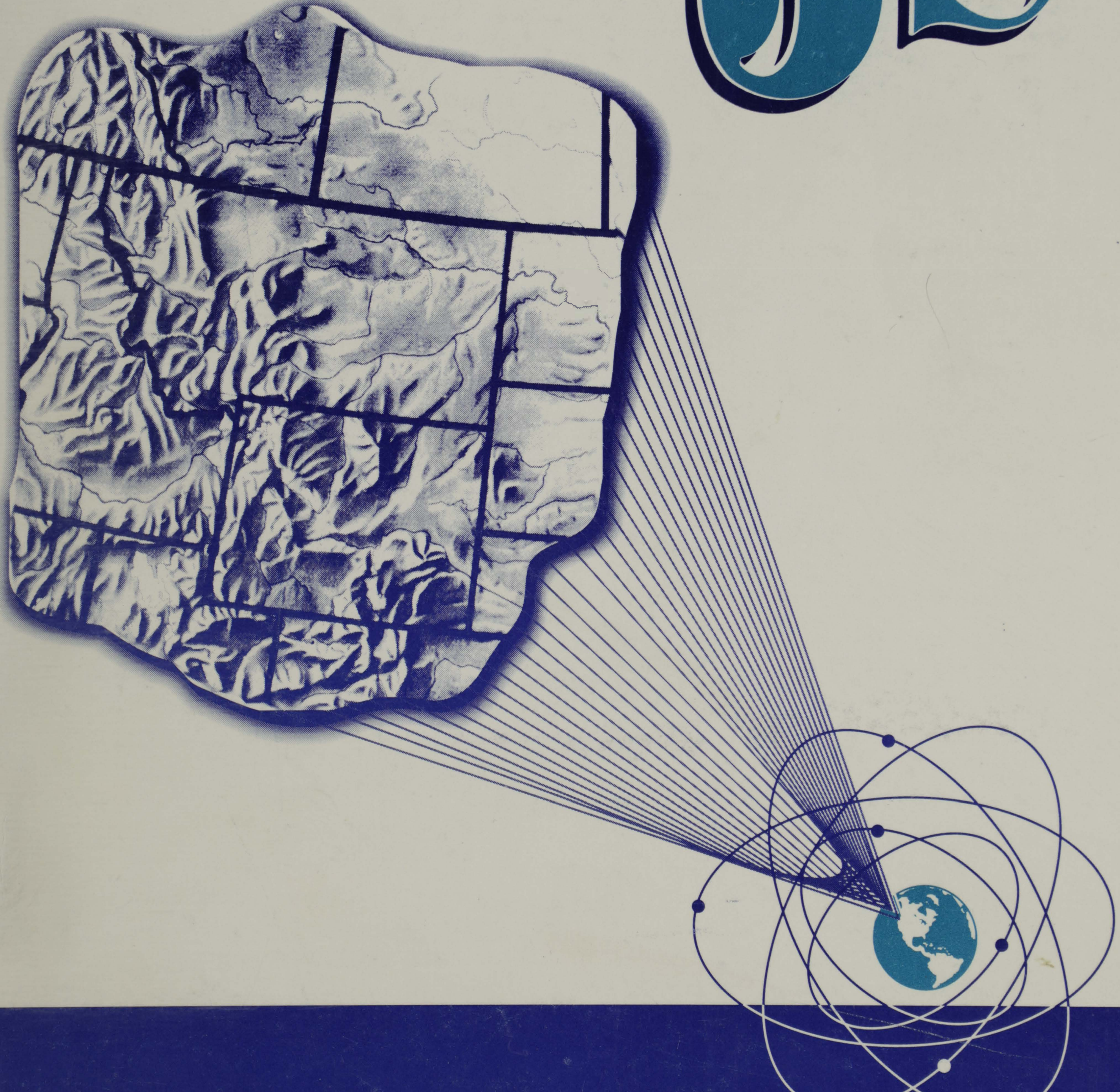
ntermountain Journal of Sciences

(ISSN 1081-3519)
IJS

Vol. 4, No. 1/2 - 1998



INTERMOUNTAIN JOURNAL OF SCIENCES

The Intermountain Journal of Sciences is a regional peer-reviewed journal that encourages scientists, educators and students to submit their research, management applications or viewpoints concerning the sciences applicable to the intermountain region. Original manuscripts dealing with biological, environmental engineering, mathematical, molecular-cellular, pharmaceutical, physical and social sciences are welcome.

Co-sponsors/publishers include the Montana Academy of Sciences, the Montana Chapter of The Wildlife Society, and the Montana Chapter of The American Fisheries Society. This journal offers peer review and an opportunity to publish papers presented at annual meetings of the co-sponsor organizations. It is the intent of the governing bodies of the co-sponsor organizations that this journal replace printed proceedings of the respective annual meetings. Therefore, it is the policy of the editorial board that presenters at annual meetings of the co-sponsors be given priority in allocation of space and time of publication, although submission of other manuscripts for review and publication without regard to membership is encouraged.

Initial funding was provided by the co-sponsor organizations. Long-term funding will be derived from page charges assessed authors, sponsoring organizations or agencies at $35 per printed page upon acceptance of each manuscript and from annual subscriptions: student $6; regular member $15; patron member $25; library $25; life member $150; and, sustaining subscriber $2,500.

The intent of the co-sponsors and editorial board is that *The Intermountain Journal of Sciences* be expanded to a quarterly journal. Achieving that objective depends upon numbers of acceptable manuscripts received and available funding. It also is the intent of the editorial board that contributing authors be assured of publication within 12 months of acceptance of their manuscript by the managing editor.

The organizational staff is voluntary and consists of an editorial board, an editor-in-chief, a managing editor, associate editors, a business manager and a panel of referees. The editorial board is responsible for establishing policy and the chair of the editorial board serves as liaison to the sponsoring organizations. The editor-in-chief is responsible for determining acceptability and level of revision of manuscripts based on referees' comments and recommendation of an associate editor. The managing editor serves as liaison for layout and printing. Associate editors include but are not limited to the section vice presidents of The Montana Academy of Sciences. Referees are selected on the basis of their field and specific area of knowledge and expertise.

Referees and associate editors judge submitted manuscripts on originality, technical accuracy, interpretation and contribution to the scientific literature. Format and style generally follow the *Guidelines for Manuscripts Submitted to the Intermountain Journal of Sciences, Dusek 1995*. Organization may vary to accommodate the content of the article, although the text is expected to elucidate application of results.

Send all manuscripts to: Editor-in-Chief, P.O. Box 3014, Bozeman, MT 59772-3014

ISSN #1081-3519

INTERMOUNTAIN JOURNAL OF SCIENCES

EDITOR-IN-CHIEF

Mary J. Nickum, Bozeman, MT

MANAGING EDITOR

Terry N. Lonner, Montana Fish, Wildlife and Parks, Retired - Bozeman, MT

ASSOCIATE EDITORS

BIOLOGICAL SCIENCES

Carl L. Wambolt - Botany
Animal and Range Sciences Dept.
Montana State University
Bozeman, MT 59717

Al Zale - Fisheries
Montana Cooperative
Fishery Research Unit
Department of Biology
Montana State University
Bozeman, MT 59717

Gary L. Dusek - Wildlife
Montana Fish, Wildlife and Parks
P. O. Box 173220
Bozeman, MT 59717

ENVIRONMENTAL SCIENCES AND ENGINEERING

Holly G. Peterson
Environmental Engineering Dept.
Montana Tech
Butte, MT 59701

HUMANITIES AND SOCIAL SCIENCES

Mary J. Nickum
33 Hofer Lane
Bozeman, MT 59718

MATHEMATICS, STATISTICS AND COMPUTER SCIENCE

George F. Votruba
Dept. of Mathematical Sciences
University of Montana
Missoula, MT 59812

MOLECULAR CELLULAR BIOLOGY AND NEUROSCIENCES

Richard Bridges
School of Pharmacy
University of Montana
Missoula, MT 59812

PHARMACOLOGY AND TOXICOLOGY

Charles Eyer
School of Pharmacy
University of Montana
Missoula, MT 59812

PHYSICAL SCIENCES

Richard Smith
Physics Department
Montana State University
Bozeman, MT 59717

EDITORIAL BOARD

Richard J. Douglass	Chair, Montana Tech - Butte
Joe Ball	USDI Wildlife Coop Unit, U of M - Missoula
Gary L. Dusek	Montana Fish, Wildlife and Parks - Bozeman
Sharon Eversman	Montana State University - Bozeman
Craig A. Johnston	University of Montana - Missoula
Lynn Kaeding	USDI Fish and Wildlife Mgmt Assistance Office - Bozeman
Brad Shepard	Montana State University - Bozeman
John P. Weigand	Montana Fish, Wildlife and Parks, Retired - Bozeman
Al Zale	USDI Fisheries Coop Unit, MSU - Bozeman

BUSINESS MANAGER

Kenneth L. Hamlin	Montana Fish, Wildlife and Parks - Bozeman

EDITORIAL REVIEW POLICY

The *Intermountain Journal of Sciences* (IJS) is a fully refereed journal.

Manuscripts are submitted to the Editor-in-Chief (EIC) for initial consideration for publication in the IJS. This review shall include, but not be limited to, appropriateness for publication in this journal, correct formatting, and inclusion of a letter of submittal by the author with information about the manuscript as stated in the "Guidelines for manuscripts submitted to the *Intermountain Journal of Sciences*" (Dusek 1995). This cover letter must also include a statement by the author that this paper has not been submitted for publication or published elsewhere. The EIC notes the date of receipt of the manuscript and assigns it a reference number, IJS-xxxx. The EIC forwards a letter of manuscript receipt and the reference number to the corresponding author. The corresponding author is the author who signed the submittal letter.

Three hard copies of the submitted manuscript, with copies of the "Guidelines and checklist for IJS referees" attached are forwarded to the appropri-ate Associate Editor. The Associate Editor retains one coy of the manuscript and guidelines for his/her review,and submits a similar package to each of two other reviewers. A minimum of two reviewers, including the Associate Editor, is required for each manuscript. The two other reviewers are instructed to return the manuscript and their comments to the Associate Editor, who completes and returns to the EIC a blue "Cover Form" and all manuscripts and reviewer comments plus a recommendation for publication, with or without revisions, or rejection of the manuscript. This initial review process is limited to 30 days.

The EIC reviews the recommendation and all comments. The EIC then notifies the corresponding author of the results of the review and the publication decision.

ACCEPTANCE

For accepted manuscripts, each copy of the manuscript containing comments thereon and other comments are returned to the corresponding author. Revised manuscripts are to be returned to the EIC in hard copy, four copies if further review is required, or one hard copy plus the computer disk if only minor revision or formatting is necessary. The revised manuscript shall be returned to the EIC within 14 days of the notification. Review of the revised manuscript by the Associate Editor and reviewers shall be completed and returned to the EIC within 14 days. An accepted manuscript will then be forwarded to the Managing Editor (ME) for final processing.

REJECTION

Each manuscript that is rejected for publication is returned by the EIC to the corresponding author along with the reasons for rejection. The author is also advised that the manuscript may be resubmitted, provided all major criticisms and comments have been addressed in the new manuscript. The new manuscript may be returned to the initial review process if deemed appropriate by the EIC. If the manuscript is rejected a second time by either the EIC or the Associate Editor and reviewers, no further consideration will be given for publication of the manuscript in IJS. The corresponding author will be notified of this decision.

REVIEWER ANONYMITY

The identity of all reviewers shall remain anonymous to the authors, called a blind review process. All criticisms or comments by authors shall be directed to the EIC; they may be referred to the ME or the Editorial Board by the EIC for resolution.

MANUSCRIPTS SUBMITTED BY EDITORS

Each manuscript submitted by an Associate Editor shall be reviewed by the EIC and a minimum of two other reviewers with expertise in the subject being addressed. Each manuscript submitted by the EIC shall be forwarded with the necessary review materials to the Chairman of the Editorial Board of IJS, who will serve as the EIC for that manuscript.

ABSTRACTS

Only abstracts from the annual meetings of the sponsoring organizations will be published in IJS. Other submissions of abstracts shall be considered on a case-by-case basis by the Editorial Board. Sponsoring organizations shall collect abstracts, review them for subject accuracy, key or scan them onto a 3.5" diskette, and submit the diskette and hard copy of each abstract to the EIC on or before November 1. Each abstract shall be reviewed by the EIC to assure proper grammar, compliance with IJS "Guidelines for Abstracts Only" and for assignment to the appropriate discipline section. All abstracts will be published in the December issue only.

COMMENTARY

Submissions concerning management applications or viewpoints concerning current scientific or social issues of interest to the Intermountain region will be considered for publication in the "Commentary" Section. This section will feature concise, well-written manuscripts limited to 1,500 words. Commentaries will be limited to one per issue.

Submissions will be peer reviewed and page charges will be calculated at the same rate as for regular articles.

LITERATURE CITED

Dusek, Gary L. 1995. Guidelines for manuscripts submitted to the *Intermountain Journal of Sciences*. Int. J. Sci. 1(1):61-70.

TABLE OF CONTENTS

ARTICLES

BIOLOGICAL SCIENCES

PHYSICAL SCIENCES

DESIGN AND LAYOUT ~ MEDIA WORKS, BOZEMAN, MONTANA
PRINTING ~ KWIK KOPY PRINTING, BOZEMAN, MONTANA

Thomas O. Lemke
John A. Mack
Douglas B. Houston

WINTER RANGE EXPANSION BY THE NORTHERN YELLOWSTONE ELK HERD

ABSTRACT

*We examine and describe changes in northern Yellowstone elk (*Cervus elaphus*) winter distribution, population size and harvests from 1975-1997. Since the late 1970s, northern Yellowstone elk have expanded their winter range by 41 percent to about 152,663 ha. During this period, elk winter range north of Yellowstone National Park (YNP) has more than doubled from 22,179 ha to 53,262 ha. Since 1988-89 the number of elk wintering north of YNP has averaged 5,460 elk/year (1,533-8,626) with 2,000-4,500 elk wintering north of Dome Mountain where few Yellowstone elk wintered prior to 1988-89. Minimum fall elk population estimates increased from 11,149-12,941 animals in the late 1970s to a mean of 17,409 ± 1,377 (SD) elk based on nine annual counts conducted between 1981-82 and 1994-95. Minimum winter (post-hunting) numbers averaged 15,520 ± 2,324 (SD) elk for the same period. With more elk migrating out of YNP, late season elk harvests increased 64 percent from 892 ± 506 (SD) elk/year from 1979-80 to 1987-88 to 1,459 ± 815 (SD) elk/year from 1988-89 to 1996-97. Winter range expansion, elk migration behavior, and increased winter harvests dispelled earlier concerns that winter hunts would prevent elk from using all available winter range. Challenges facing the management of Yellowstone elk north of YNP include harvesting enough elk to maintain the long-term diversity and productivity of winter range vegetation, resolving land use conflicts with elk expanding into Paradise Valley, and addressing growing concerns about the possible transmission of the disease brucellosis from elk to domestic livestock.*

Key words: *Cervus elaphus*, elk, northern Yellowstone elk herd, population trends, winter range, Yellowstone National Park.

INTRODUCTION

The northern Yellowstone elk herd is the largest ungulate population in the Yellowstone National Park (YNP), greatly exceeding the combined populations of bison (*Bison bison*), mule deer (*Odocoileus hemionus*), antelope (*Antilocapra americana*), moose (*Alces alces*), bighorn sheep (*Ovis canadensis*), and mountain goat (*Oreamnos americanus*). Elk population management and the effects of large numbers of elk on vegetation are controversial issues (Pengelly 1963, Erickson 1981, Chase 1986, Lemke and Singer 1989, Wagner *et al.* 1995, Yellowstone National Park 1997).

Hunting of migrant Yellowstone elk immediately north of YNP during December-February resumed in 1976 after an 8-year moratorium, prompting concerns that winter hunting would inhibit the natural movement of elk out of YNP and prevent elk from reaching the northernmost available winter range (Houston 1979). Conversely, large elk migrations north of YNP may result in decreasing plant diversity and productivity, reduced ability of winter

Thomas O. Lemke, Montana Fish, Wildlife and Parks, SC 85 Box 4126, Livingston, MT 59047
John A. Mack, National Park Service, P.O. Box 168, Yellowstone National Park, WY 82190
Douglas B. Houston, Biological Resources Division, U.S. Geological Survey (retired), 600 E. Park Avenue, Port Angeles, WA 98362

hunts to control elk numbers, and a decline in private landowner tolerance for elk. Since the 1970s, significant changes in winter elk distribution and migration have gone unreported.

Here, we present elk population estimates and annual harvests from 1975-1997, and document changes in the boundaries of occupied winter range. In reviewing elk survey and harvest information for this paper, we discovered minor errors in the numbers reported for some elk surveys and harvests since 1975. We used original survey and harvest data to make appropriate corrections.

STUDY AREA

Many elk in the northern Yellowstone population are migratory. During summer, elk occupy up to 470,000 ha in YNP and 100,000 ha on adjacent lands to the north and east (Houston 1982). From movements of radio-collared elk, Vore (1990) documented migrations of up to 150 km between summer and winter ranges. During winter (mid-November to April) elk occupy a much smaller area known as the "northern Yellowstone winter range," at lower elevations from 1,500-2,500 m along the Yellowstone, Lamar, and Gardiner rivers (Fig. 1). Elk migrate northerly in the winter and southerly in the spring along an extensive system of obvious trails that parallel the rivers.

In winter, elk congregate inside YNP in lower Soda Butte Creek, Slough Creek, Lamar Valley, Specimen Ridge, Hellroaring/Little Buffalo Creek face, Crevice Creek, Blacktail Plateau, Mount Everts, Gardiner Canyon, Stevens Creek, and Reese Creek. North of YNP, elk occupy Deckard Flats, Eagle Creek, Little Trail Creek, Bassett Creek, Cedar Creek, Slip and Slide Creek, Dome Mountain, Dailey Lake, Beattie Gulch, Cinnabar Mountain, and the Cinnabar Basin divide. During winter, elk forage primarily in steppe and steppe shrub habitat types (Despain 1990) where they are readily observed.

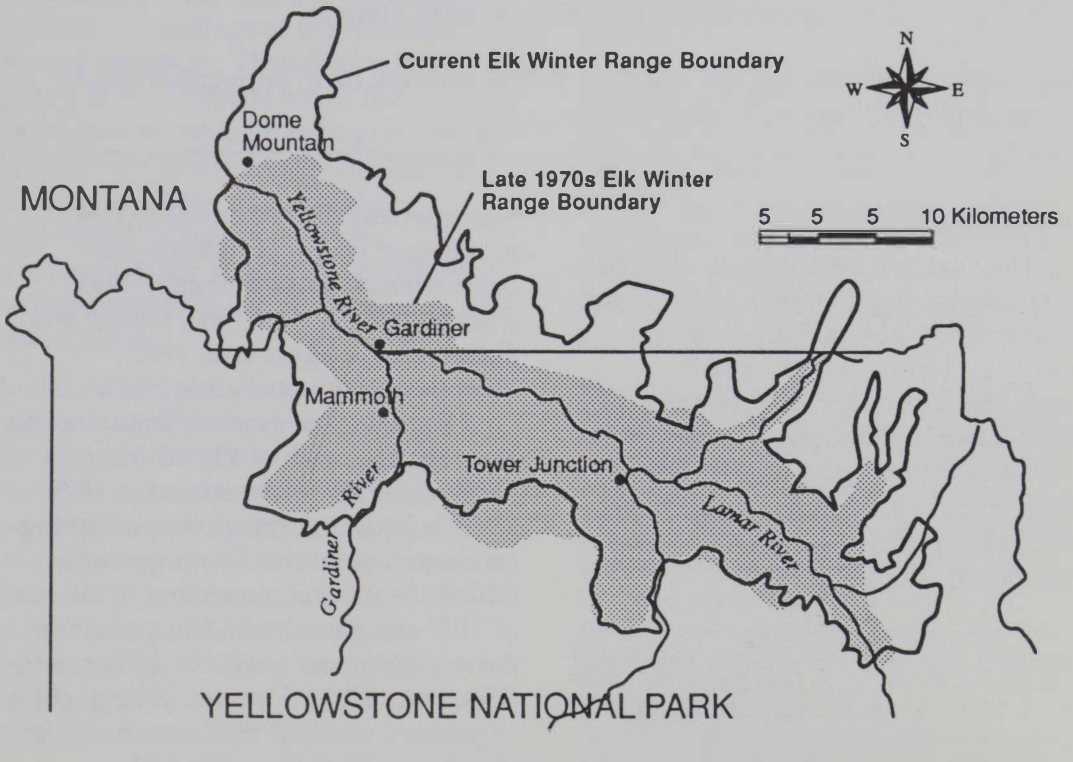


Figure 1. *Location and boundaries of current versus late 1970s northern Yellowstone elk winter range.*

METHODS

We determined winter range boundaries and elk distribution from counts of elk obtained with use of a Piper Super Cub aircraft. The presence of elk or elk sign in snow, such as trailing and feeding craters determined the size and location of winter range use. We attempted complete censuses of elk, recognizing that counts invariably fall below actual numbers present (Houston 1982). Four to six winter counts were conducted annually during the 1970s. Two days were required to complete the counts using one aircraft. The highest counts were obtained during December-January when large concentrations of elk first occupied snow covered steppe shrub communities and elk made minimal use of forested habitat.

Montana Fish, Wildlife, and Parks (FWP) and YNP personnel changed survey procedures during the 1980s and 1990s to adjust for increasing elk numbers and the size of the occupied winter range. By 1982, two aircraft typically were used simultaneously. Since 1985, four aircraft have been employed, and five of the last 10 censuses were completed in a single day. Since 1994, the northern Yellowstone winter range has been divided into 68 count units with 50 units primarily inside YNP, 18 units primarily north of YNP, and six units overlapping the YNP boundary. In years when fresh elk tracks were absent, some upper elevation units were not surveyed completely. The areas within the 1970s and the current elk winter range boundaries were measured using Geographic Information System (GIS) technology.

We relied on elk counts described above and elk harvest information for the general big game hunting season and the late Gardiner elk hunt (winter harvest) to estimate minimum elk population numbers and trends. Fall elk harvests from 1976-1981 were estimated using mail survey questionnaires. Since 1982, elk harvest estimates were based on telephone harvest surveys for Montana resident license holders and mail surveys for nonresidents (Cada 1985). Annual surveys since 1982 have sampled 42-44 percent of elk licence holders.

The fall harvest for northern Yellowstone elk includes harvest estimates for elk taken in Montana Hunting Districts 313 and 316, located north of YNP. Late season elk removals, legal harvest plus known illegal kills and wounding losses, were determined at FWP check stations. All hunters were required to check in and out of the hunting area at the check stations. Stations were not operated in 1978-79 or 1979-80; harvest estimates were derived from warden field checks in 1978-79 and a mail survey in 1979-80.

A review of harvest records revealed minor discrepancies between field data and what appeared in annual FWP reports (unpublished Pittman-Robertson Survey and Inventory Job Progress Reports 1976-1986). Discrepancies in elk survey data also were found in Singer *et al.* (1989), Mack and Singer (1993), Singer and Mack (1993), and Coughenour and Singer (1996). To reconcile these errors we examined original flight data and elk harvest cards and made the appropriate corrections (Table 1). Houston (1982) derived estimates for minimum fall elk populations by adding fall harvest estimates to the maximum census count. We estimated minimum winter populations by subtracting winter harvest removals from the maximum elk counts for the winters of 1976, 1978 and 1979. These calculations were reported in Houston (1982); however, the minimum winter population estimates were not distinguished from survey counts in his Table 3.1 (Houston 1982).

Since 1990, the beginning of the winter elk season was moved from mid-

Table 1. *Population counts, harvests, and minimum seasonal fall and winter population estimates for the northern Yellowstone elk herd, 1975-1997.*

Winter Period	Maximum Number of Elk Counted	Date of Count	Number of Elk Removed			Minimum Fall Population[c]	Minimun Winter Population[d]
			Fall Hunt[a]	Late Hunt[b]	Total		
1975-76	12,014	12/17-18	340	1,189	1,529	12,354	10,825
1976-77	8,980[e]	1/23-24	219	No hunt	219	9,199	9,199
1977-78	12,680	12/20-21	261	802	1,063	12,941	11,878
1978-79	10,838	12/29-30	311	31	342	11,149	10,807
1979-80	No count		194	467	661		
1980-81	No count		243	133	367		
1981-82	16,019	1/6-7	344	1,015	1,359	16,473	15,114
1982-83	No count		447	1,434	1,881		
1983-84	No count		404	1,657	2,061		
1984-85	No count		360	1,211	1,571		
1985-86	16,286	12/19-20	456	1,042	1,498	16,885	15,387
1986-87	17,007	12/10	894	845	1,739	17,901	15,268
1987-88	18,913	1/19	359	220	579	19,316	18,737
1988-89	10,265[e]	1/26 & 2/9	487	2,409	2,896	12,328	9,488
1989-90	14,829	1/18-19	815	484	1,299	15,805	14,506
1990-91	9,456[e]	2/6	308	697	1,005	10,287	9,282
1991-92	12,859	12/16	2,728	1,787	4,515	15,587	11,072
1992-93	17,585	11/21 & 12/3	481	1,574	2,055	18,066	16,011
1993-94	19,045	1/20-24	254	273	527	19,359	18,832
1994-95	16,791	12/21	499	2,039	2,538	17,290	14,752
1995-96	No Count		306	1,400	1,706		
1996-97	No Count		855	2,465	3,320		

[a] Combined mid-point elk harvest estimate for Hunting Districts 313 and 316 from FWP Statewide Harvest Survey.

[b] Check station count of late hunt elk harvest plus known illegal kills and wounding loss for all years except 1978-79, 1979-80, and 1981-82. Known annual illegal and wounding loss ranged from 6-106 elk/year ($\bar{x}$ = 45 elk).

[c] Minimum fall population estimate = maximum survey count + estimated fall harvest + late hunt removals that occurred prior to survey date, if any.

[d] Minimum winter population estimate = maximum survey count - late hunt removals that occurred after survey date, if any.

[e] Survey conditions were exceptionally poor resulting in inaccurate counts.

December to early January to reduce the incidental harvest of nonmigratory elk north of YNP. Elk counts since the 1980s often occurred after the start of winter hunts due to mild weather or aircraft scheduling problems. The timing of winter hunt removals relative to survey flights affect minimum winter and fall population estimates. Thus, we adjusted the minimum fall and winter population estimates for all years based on date of harvest information.

RESULTS AND DISCUSSION

The size of the northern Yellowstone elk winter range has increased by 41 percent over the last 20 years. In the late 1970s, the estimated elk winter range included about 100,000 ha (Houston 1982). As determined more recently from GIS technology on Houston's boundaries, elk occupied a winter range of 108,553 ha in the 1970s. Based on current winter elk distribution, elk occupy a winter range of 152,663 ha, which extends from the upper Lamar River northwest to Sixmile Creek 32 km north of YNP (Fig. 1).

From the 1970s to the present time, the size of the elk winter range outside YNP more than doubled from 22,179 ha to 53,262 ha. In 1997, 35 percent of the total winter range was located north of YNP compared to 17 percent in the 1970s. Winter elk distribution now includes 9,200 ha between Dome Mountain and Sixmile Creek north of YNP. Since 1988-89, 2,000-4,500 elk have wintered in an area previously occupied by few elk (Fig. 2). In the harsh winters of 1991-92 and 1996-97, elk that migrated from YNP moved further north into Paradise Valley beyond Sixmile Creek. In 1996-97, an estimated 500-1,000 elk moved as far as 10 km beyond Sixmile Creek, the typical northern boundary of their winter range.

Once beyond Sixmile Creek, migratory Yellowstone elk were largely on private agricultural lands and were in direct conflict with agricultural interests. Elk may compete with livestock for standing forage, pose a threat to stored hay crops, damage fences, and mingle with cattle, which raises concerns among livestock producers about transmission of the brucellosis disease bacteria (*Brucella abortus*) from elk to livestock (Thorne *et al.* 1997). Human tolerance for increasing numbers of migrant elk north of Sixmile Creek is low. If migratory elk continue to expand their winter range into Paradise Valley, conflicts between wildlife and livestock producers will increase.

Absent or partial snow cover during 1976-77, 1988-89, and 1990-91 resulted in unrealistically low elk counts. These mild conditions allowed elk to winter at higher elevations in forested habitats,

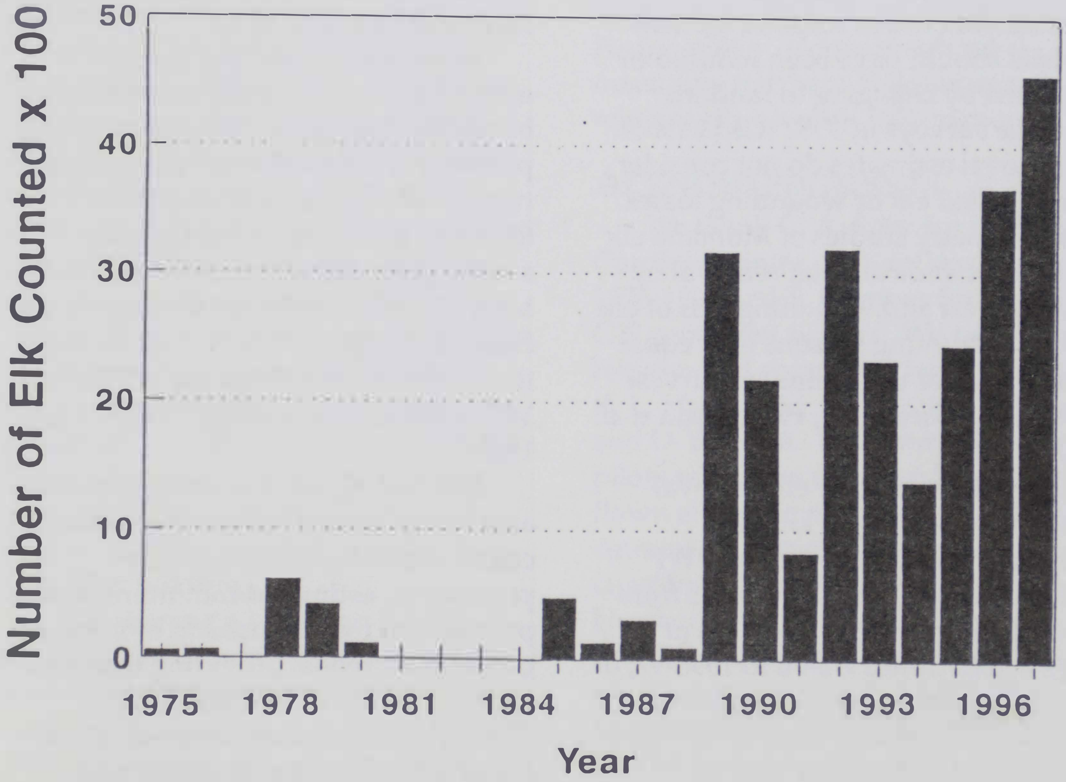


Figure 2. *Number of elk counted during winter north of Dome Mountain, at the northern end of the Yellowstone elk winter range.*

which reduced their observability. Minimum fall populations averaged 17,409 ± 1,377 (SD) elk for nine annual counts conducted from 1981-82 through 1994-95, excluding poor counts of 1988-89 and 1990-91. No total elk counts were conducted in 1995-96 and 1996-97. Annual removals were variable and averaged 1,823 ± 1,022 (SD) elk over the 14 years, including 1,192 ± 661(SD) elk removed annually during the winter hunts. Minimum winter populations averaged 15,520 ± 2,324 (SD) elk for nine annual counts from 1981-82 through 1994-95, excluding 1988-89 and 1990-91. The mean observed rate of increase (r) for minimum winter populations was -0.0012 for the 14-year period and did not differ significantly from zero (regression of l_n elk numbers on time, $r =$ b, P > 0.08 (Caughley 1977).

The calculated minimum fall population depended on estimates of fall elk harvests that may have been biased upward from 1976-81. Successful hunters were more likely than unsuccessful ones to respond by mail. This bias should have been reduced or eliminated by changing to random telephone surveys in 1982 (Cada 1985). Fall removal estimates do not consider illegally killed elk or wounding losses. Radio telemetry studies of Montana elk populations indicate that removal by illegal harvest and wounding loss of elk during fall hunting seasons may equal 10-18 percent of the estimated harvest (Hamlin and Ross 1991, Henderson *et al.* 1993).

Estimates of winter elk removal included known illegal kills and wounded animals retrieved by FWP wardens (Table 1). Known losses from these sources averaged 45 elk/year (range 6-106) from 1975-76 to 1996-97, or about 2-7 percent of the legal harvest. Additional illegal and wounding losses surely occurred, but they may be relatively low because of the high density of hunters and wardens in the hunting areas. Wounded animals were quickly killed by other hunters. Winter removals have generally increased since 1988-89, paralleling the increase in elk migrating out of YNP. Winter hunt removals in the last nine years (1988-89 to 1996-97) averaged 1,459 ± 815 (SD) elk/year compared to 892 ± 506 (SD) elk/year removed during the nine years from 1979-80 to 1987-88, a 64 percent increase.

The calculated minimum winter populations assumed that each elk removed during the winter hunts would have been counted in the earlier survey, which is unlikely. The rationale for using the estimated minimum winter population to monitor trends is that this value represents the density of animals subjected to the full rigors of the Yellowstone environment when resources are most limited. Such estimates also are in keeping with a tradition begun in the 1930s, that is, conducting counts after elk removals were completed by the National Park Service within YNP and hunting seasons had closed outside YNP.

Minimum winter population estimates may be subsequently affected by natural late-winter mortality, which probably would influence population trends. Winter elk mortality that followed the counts varied greatly among years (Houston 1982) and has been difficult to monitor accurately. An estimated 3,021-5,757 elk died during the winter of 1988-89 on the northern Yellowstone winter range (Singer *et al.* 1989).

Depending on objectives, any of the alternative annual values (maximum elk count, estimated minimum fall population, estimated minimum winter population) may be used to monitor elk population trends, providing that the chosen value is used consistently. Mixing survey counts with minimum fall or winter estimates would bias population growth projections.

The number of northern Yellowstone elk currently exceeds the equilibrium of 12,000 elk predicted in the 1970s (Houston 1982). Current elk numbers equal or slightly exceed the ecological carrying capacity originally estimated at 15,000-17,000 elk (Houston 1982). At current elk population levels, two significant changes have occurred: (1) elk winter distribution has expanded both inside and outside YNP, and (2) larger numbers of elk have consistently migrated to areas north of YNP despite increased winter harvests.

Expanding elk distribution across the winter range may have resulted from a series of exceptionally mild winters during the 1980s that allowed elk to exploit new areas, and/or a simple consequence of higher elk numbers. Other ungulate populations in the greater Yellowstone area also increased during the 1980s, an apparent response to mild winters (Singer 1991, Mack and Singer 1993).

Increased elk use of winter range north of YNP began in the harsh winter of 1988-89 with a migration of over 7,000 elk (Lemke 1997) following wildfires that burned 321,283 ha inside YNP (Despain *et al.* 1989). From 1988-89 to 1996-97, the number of elk wintering north of YNP averaged 5,460 elk/year (1,533-8,626). Large numbers of elk wintering north of Dome Mountain (Fig. 2) have established an important new migratory pattern (Lemke 1997). From 1989 to 1993, a cooperative winter range acquisition project placed 3,500 ha of key privately owned winter range into public ownership (Rocky Mountain Elk Foundation 1993). Livestock grazing was discontinued on this purchased land to increase winter forage for elk and other wildlife.

Maintaining a large annual elk migration with animals distributed to the northern extremes of their winter range while harvesting 1,459 ± 815 (SD) elk/year during winter hunts since 1988-89 dispelled earlier concerns that harvesting large numbers of elk would inhibit migrations north of YNP (Houston 1979). Hunting regulations, which delay the winter hunting season, open hunting areas based on migrant elk distribution, assign hunters to specific 2 or 4-day hunt periods, allow for 3-day rest periods between hunts, and direct the majority of the harvest to antlerless elk, all helped FWP protect and provide high quality winter habitat, reduced game damage conflicts, and provided sustainable public recreation (Lemke 1995a, 1995b).

The greatest issues currently facing management of migratory Yellowstone elk are sustaining a large enough elk harvest to maintain long-term plant diversity and productivity outside YNP, minimizing conflicts between elk and other land uses if elk expand their winter range beyond Sixmile Creek, and addressing concerns about the transmission of brucellosis from elk to domestic livestock. We recommend that consistent monitoring of northern Yellowstone elk be continued to document changes in population size, elk harvests, and winter distribution. Future policy decisions related to managing northern Yellowstone elk will rely heavily on such information.

ACKNOWLEDGMENTS

We thank C. A. Sime for reviewing Gardiner winter elk hunt records from 1976-1993 and E. Compas for creating GIS generated figures. We appreciate reviews and comments by P. J. P. Gogan, K. L. Hamlin, M. Meagher, F. J. Singer, and D. B. Tyers. We thank all of the pilots who have safely and skillfully flown elk surveys over the last 20 years. Annual elk surveys have been coordinated and funded by the Northern Yellowstone Cooperative Wildlife Working Group since 1985. Working group members include Montana FWP, YNP, U.S. Forest Service (Gallatin National Forest), and U.S. Geological Survey (Biological Resource Division). YNP provided GIS assistance.

LITERATURE CITED

Cada, J. D. 1985. Evaluations of the telephone and mail survey methods of obtaining harvest data from licensed sportsmen in Montana. Pp. 117-128 *in* S. L. Beasom and S. F. Robertson, eds. Game harvest management. Caesar Kleberg Wildl. Res. Inst., Kingsville, TX. 374 pp.

Caughley, G. 1977. Analysis of vertebrate populations. John Wiley and Sons, New York, NY. 234 pp.

Chase, A. 1986. Playing God in Yellowstone: the destruction of America's first national park. Atlantic Monthly Press, Boston, MA. 446 pp.

Coughenour, M. B., and F. J. Singer. 1996. Elk population processes in Yellowstone National Park under the policy of natural regulation. Ecol. Applications 6:573-593.

Despain, D. 1990. Yellowstone vegetation, consequences of environment and history in a natural setting. Robert Rinehart, Inc., Boulder, C0. 239 pp.

Despain, D., A. Rodman, P. Schullery, and H. Shovic. 1989. Burned area survey of Yellowstone National Park: the fires of 1988. Yellowstone National Park, Mammoth Hot Springs, WY. 14 pp.

Erickson, G. L. 1981. The northern Yellowstone elk herd — a conflict of policies. Proc. Ann. Conf. West. Assoc. Fish and Wildl. Agencies. 62:92-108.

Hamlin, K. L., and M. S. Ross. 1991. Varying definitions of the legal bull — the effects on hunters, hunting, and elk populations. Pp. 247-254 *in* A. G. Christensen, L. J. Lyon, and T. N. Lonner, comps. Proc. Elk Vulnerability Symp., Montana State Univ., Bozeman. 330 pp.

Henderson, R. E., B. A. Sterling, and T. O. Lemke. 1993. The lower Clark Fork elk study: final report 1985-1990. Montana Fish, Wildlife & Parks, Unpubl. Rept., Helena, MT. 141 pp.

Houston, D. B. 1979. The northern Yellowstone elk — winter distribution and management. Pp. 263-273 *in* M. S. Boyce and L. D. Hayden-Wing, eds., North American elk: ecology, behavior, and management. Univ. of Wyoming, Laramie. 294 pp.

Houston, D. B. 1982. The northern Yellowstone elk: ecology and management. Macmillan Publishing Co., New York, NY. 474 pp.

Lemke, T. O. 1995a. A Montana tradition. Montana Outdoors 26(2):1-9 .

Lemke, T. O. 1995b. Yellowstone Park elk management review, Gardiner late hunt. Montana Fish, Wildlife and Parks, Bozeman, MT. 8 pp.

Lemke, T. O. 1997. Late winter 1996-97 northern Yellowstone elk survey; trends in Yellowstone elk migrations and distribution; bison counts and brucellosis monitoring update. Montana Fish, Wildlife and Parks, Bozeman, MT. 6 pp.

Lemke, T. O., and F. J. Singer. 1989. Northern Yellowstone elk: the big herd, a management challenge. Rocky Mtn. Elk Foundation, Bugle 6:113-121.

Mack, J. A., and F. J. Singer. 1993. Population models for elk, mule deer, and moose on Yellowstone's northern winter range. Pp. 270-305 *in* R. S. Cook, ed., Ecological issues on reintroducing wolves into Yellowstone National Park. Natl. Park Ser. Scientific Monog. 93:22. 328 pp.

Pengelly, W. L. 1963. Thunder on the Yellowstone. Naturalist 14:18-25.

Rocky Mountain Elk Foundation. 1993. Preserving a legacy through partnerships—northern Yellowstone elk herd project. Missoula, MT. 12 pp.

Singer, F. J. 1991. Ungulate prey base for wolves in Yellowstone National Park. Pp. 323-348 *in* R. B. Keiter, and M. S. Boyce, eds. The greater Yellowstone ecosystem: redefining America's wilderness heritage. Yale Univ. Press, New Haven, CT. 428 pp.

Singer, F. J., and J. A. Mack. 1993. Potential ungulate prey for gray wolves. Pp. 75-117 *in* R. S. Cook, ed., Ecological issues on reintroducing wolves into Yellowstone National Park. Natl. Park Ser. Scientific Monogr. 93:22. 328 pp.

Singer, F. J., W. Schreier, J. Oppeheim, and E. O. Garton. 1989. Drought, fires, and large mammals. BioScience 39:716-722.

Thorne, E. T., S. G. Smith, K. Aune, D. Hunter, and T. J. Roffe. 1997. Brucellosis: the disease in elk. Pp. 33-44 *in* E. T. Thorne, M. S. Boyce, P. Nicoletti, and T. J. Kreeger, eds., Brucellosis, bison, elk, and cattle in the greater Yellowstone area: defining the problems, exploring solutions. Wyoming Game and Fish Dept., and Greater Yellowstone Interagency Brucellosis Committee, Cheyenne, WY. 219 pp.

Vore, J. M. 1990. Movements and distribution of some northern Yellowstone elk. Unpubl. M.S. Thesis, Montana State Univ., Bozeman. 80 pp.

Wagner, F. H., R. Foresta, R. B. Gill, D. R. McCullough, M. R. Pelton, W. F. Porter, and H. Salwasser. 1995. Wildlife policies in the U.S. National Parks. Island Press, Washington, DC. 242 pp.

Yellowstone National Park. 1997. Yellowstone's northern range: complexity and change in a wildland ecosystem. National Park Service, Mammoth Hot Springs, WY. 148 pp.

Charles C. Schrader-Patton
Robert D. Pfister
Lloyd P. Queen

ESTIMATION OF FOREST STAND STRUCTURE ATTRIBUTES FROM AERIAL PHOTOGRAPHS

ABSTRACT

Awareness of potential inaccuracies in stand structure data derived from remotely sensed imagery is important in landscape-level analyses. Attributes of forest stand structure were estimated from aerial photographs using standardized photointerpretation procedures and accuracy assessments were conducted using error matrices by comparing the estimates to plot data. Over 500 stands were photo-interpreted by a single interpreter (1:15,840 nominal scale, normal color) for six forest structure attributes (canopy cover, stand height, DBH, cover type, crown diameter, and canopy layers). Percentage accuracy adjusted for chance agreement ranged from 29 percent to 59 percent; percentage accuracy varied according to the techniques used to evaluate individual attributes. Potential means for correcting biases and rating landscape analyses are discussed.

Keywords: aerial photo interpretation, remote sensing, accuracy assessment, forest stand structure, landscape analysis.

INTRODUCTION

Defining relatively homogeneous patches (stands) across forested landscapes is crucial in assessing wildlife habitat, fire risk, forest health, and resource outputs for project planning. Ground-based survey methods for defining forest stand structure are prohibitive in time and cost for large landscapes. Efficient and accurate patch characterization from remotely sensed images is critical to landscape-level studies. Of equal importance is the accuracy of data collected from these images.

Our primary objectives in this study were: 1) to determine the accuracy of obtaining forest stand structure attributes from 1:15,840 nominal scale color aerial photographs, and 2) to compare two measures of accuracy used for data derived from remotely sensed images.

Photointerpreted data have been used in wildlife habitat models (Short 1988), old growth surveys (Rutledge and Hejl, 1990), and large-scale landscape assessments (Kalkhan *et al.* 1995; Allen 1994, Gonzales 1994; Lehmkuhl *et al.* 1994, Green *et al.* 1993, Deegan and Befort 1990). In these types of studies it is necessary to be aware of the potential inaccuracy of photointerpreted data and the effect this inaccuracy may have upon the results. Deegan and Befort (1990) showed that inaccurate photointerpretation can have a substantial effect on forest cover type acreage estimations. Some researchers have used aerial photo data as "ground truth" reference data for maps constructed from satellite digital images (Green *et al.* 1993, Hudson 1987). However, errors in the reference data

Charles C. Schrader-Patton, Redcastle Resources, in residence of USDA Forest Service, Remote Sensing Applications Center, Salt Lake City, Utah 84119
Robert D. Pfister, School of Forestry, University of Montana, Missoula, Montana 59801
Lloyd P. Queen, School of Forestry, University of Montana, Missoula, Montana 59801

may affect quality of digital image classifications as well as efforts to assess their accuracy (Congalton, 1991).

Data obtained from aerial photographs continue to be important in natural resource management because of widespread accessibility, cost effectiveness, and relative ease in developing interpretation skills. Like all remotely-sensed data, however, the accuracy of the data should be assessed and incorporated appropriately into the analysis.

Previous investigations into the accuracy of estimating stand structure attributes from aerial photographs have been conducted at the plot or single tree level (Spurr 1960, Worley and Meyer 1955, Worley and Landis 1954); few studies have examined this issue at the stand or landscape scale (Deegan and Befort 1990). Our study explores accuracy at the landscape scale using structure attributes interpreted at the stand level.

METHODS

Study area

The Finley Creek management area is located on the Flathead Indian Reservation, north of Missoula, Montana. The area ranges in elevation from 3,800 ft to 6,000 ft (1,158 m to 1,829 m) and is generally west-facing. A wide range of cover types are present in the 11,200 acre (4,532 ha) management area; the drier, lower elevation slopes contain ponderosa pine (*Pinus ponderosa*)/ Douglas-fir (*Pseudotsuga menziesii*) forest cover types, whereas the highest portions of the area are dominated by whitebark pine (*Pinus albicaulis*) and subalpine fir (*Abies lasiocarpa*) cover types.

The lower elevation western part of the Finley Creek area has been extensively managed using both even- and uneven-aged silvicultural methods, while the eastern portion of the area has no history of silvicultural activity with the exception of fire suppression activities. The eastern part of the management area is characterized by steep, rocky slopes, high-elevation lakes and meadows.

Photo interpretation

Confederated Salish/Kootenai Tribal Forestry personnel provided stand boundaries in the form of an ARC/INFO file. We transcribed these boundaries on acetate sheets overlaying the aerial photos using even-aged cutting units, roads, lakes and talus slopes to reference the maps provided by the Tribe. Stand structure attributes were photo-interpreted in July 1995, using techniques described in Lillesand and Keifer (1994) and in Paine (1981). Photointerpreted stand structure attributes included DBH (diameter 4.5 ft above ground), crown diameter, height of the dominant and co-dominant trees, canopy layers, canopy cover, and cover type. A single investigator conducted the photointerpretation and field work to eliminate any bias between observers.

The aerial photographs (1:15,840 nominal scale, 9" x 9", normal color, date of exposure 8/90) were scaled and effective areas delineated. We measured height, canopy cover, and crown diameter with standard photointerpretation tools such as estimation templates (transparencies), parallax bar, a Bausch and Lomb zoom stereoscope (6-10 X power), and 10-power hand lens.

Cover type and stand canopy layers were estimated based on the texture, tone, and pattern visible on the image. We identified four cover-type classes based on the majority overstory species: DF (Douglas-fir), WL (western larch [*Larix occidentalis*]), LP (lodgepole pine [*Pinus contorta*]), and PP (ponderosa pine). We interpreted each stand as having one, two, or three layers; stands lacking distinct layers were assigned to class four. Canopy layers were required to have at least 20% canopy cover. We determined stand cover type and canopy layers by visually estimating the conditions seen throughout the stand; no formal photo interpretation plots were measured within each stand. The DBH was visually estimated to the nearest inch from the aerial photos.

Sampling design

Following photointerpretation, we selected 51 stands randomly, approximately a 10 percent sample intensity, for field inventory. Simple random sampling was selected as the sampling scheme because the Kappa analysis technique (see below) assumes a multinomial sampling model (Congalton 1991).

We systematically located five 1/5 acre (0.05 ha) plots in each of the 51 sample stands on maps plotted from the ARC/INFO files.

Field methods

Within each plot, we selected three representative dominant or co-dominant trees that best represented the stand conditions within the plot. We then recorded the DBH, height, crown diameter, and species of each tree. Tree measurements were taken using standard forest mensuration tools (diameter tape, logger's tape, clinometer). For each plot we estimated the number of canopy layers; each layer was required to have at least 20% canopy cover. Canopy cover within each plot was estimated considering only tree vegetation ten feet in height or greater because trees smaller than ten feet could not be distinguished from brush on the aerial photographs.

Data compilation and analysis

We calculated the mean plot value for DBH, height, crown diameter, and canopy cover; the mean of these values for all five field plots located within each stand was calculated to produce the stand value for each attribute. We determined stand cover type and canopy layers by using the majority of the five plots. For example, if a stand had 3 plots with a cover type of Douglas fir, then the stand would be recorded as Douglas fir. In cases where a majority could not be determined, we selected a cover type and/or canopy layer class based on observations made while traveling between plots within the stand.

The two data sets (field and photo) were compared to develop an accuracy assessment for the photo interpretation work. The five-plot data set will hereafter be referred to as reference (ground) data.

We used two different methods, error matrices and a Chi-square test, to assess accuracy in the analysis of the data. When conducting these assessments, we assumed for all attributes that the 'true' values are the field inventory values from the reference data set.

Error matrix tables (Story and Congalton 1986). — Two-way error-matrix tables were constructed for all attributes. In addition to estimating errors of commission, errors of omission, and overall accuracy, the error matrix tables displayed classes that were misinterpreted and for the interval attributes, which were inaccurately estimated.

Of the two types of accuracy that can be determined from error matrices, we determined that errors of commission, or user's accuracies, were of greater importance in this study. The user's accuracy is the number of stands correctly classified divided by the total number of stands placed into that class (row total). User's accuracy is considered a measure of reliability of a map in depicting ground conditions; it is the probability that what is shown on the map is actually representative of what is on the ground (Story and Congalton 1986). Errors of omission, or producer's accuracies, are described as the probability that a particular stand is correctly represented on the map and may be useful in some circumstances. However, they do not represent the accuracy of the map in depicting ground conditions, which is a concern in applied use of maps and images by land managers. The producer's accuracy is calculated by taking the number of stands correctly classified and dividing by the total number of stands in that class in the reference data (column total). Interval attributes including DBH, height, crown diameter, and canopy cover, were collapsed into error matrix classes (Table 1).

Using the error matrix table comparing the photo-interpreted estimates of stand DBH to ground values (Table 2), we show how the tables were analyzed. Stands were placed in cells in the table based on the estimated value of the attribute (row) and the ground value of the attribute (column). The shaded cells indicate the number of stands that were correctly classified (Table 2). The sum of the stands in the major diagonal divided by the total number of sample stands is the overall accuracy.

Stands in cells to the right of the major diagonal were placed in a class lower than the reference data; these stands were underestimated. Likewise, stands in cells to the left of the major diagonal were overestimated. If the number of underestimated stands equals the number of overestimated stands, then the photo-interpreted estimate is not biased.

Analysis of producer's accuracy provides information on classes where stands were consistently omitted from the correct class. User's accuracies can be explored in a similar way by examining the rows of the table and identifying those stands that were placed in the wrong class by the estimating technique.

Three accuracy coefficients, Kappa (K), Tau (T_e), and overall accuracy (P_o), were calculated from the error matrices using methods described in Ma and Redmond (1995). The Kappa and Tau coefficients represent adjustments to overall accuracy to account for chance agreement.

To simplify the analysis, we focused on just one of the error matrix coefficients. We selected the Tau coefficient because of its ability to compensate for chance agreement. P_o does not account for the chance placement of a stand into the correct cell in the matrix and therefore tends to overestimate accuracy (Ma and Redmond 1995, Congalton and Mead 1983). Foody (1992) demonstrated that the Kappa (K) coefficient overcompensates for chance agreement and thus under-represents classification accuracy. When the three coefficients are calculated from the same matrix, K tends to be the highest value, P_o the lowest, and T_e falling somewhere in between (Ma and Redmond 1995). T_e is an improvement over K because it compensates for random chance agreement and for actual correct classification (Foody 1992, Ma and Redmond 1995).

<u>Chi-square test of a hypothesized variance (Freese 1960).</u> — This test compares the estimates of an interval attribute to the true values so that the accuracy of an estimating technique can be determined. We used the chi-square test to calculate the probability, P(Z), that the estimate is within the user-specified allowable error of the ground value (Table 3) and to determine if there is any consistent difference between the estimated values and the true values. An example of a source of bias would be an improperly calibrated instrument used in the estimating technique or perhaps using an incorrect constant in a formula. The chi-square test allows for the detection of bias and subsequent calculation of P(Z) assuming the source of bias was eliminated. We removed bias if it resulted in an increase of 0.05 or greater in the P(Z) value. The allowable error values (Table 3) are consistent

Table 1. *Classes for error matrix tables. The interval attributes were collapsed into these classes for the error matrix analysis.*

DBH (inches)	Height (ft)	Canopy closure	Crown diameter (ft)
1. < 5 (12.7 cm)	1. < 20 (6.1 m)	1. < 25%	1. < 5 (1.3 dm)
2. 5 - 8.9 (22.8 cm)	2. 20 - 39 (11.9 m)	2. 26 - 59%	2. 5 - 8.9 (2.3 dm)
3. 9 - 14.9 (38.1 cm)	3. 40 - 59 (17.9 m)	3. > 60%	3. 9 - 14.9 (3.8 dm)
4. 15 - 20.9 (53.3 cm)	4. 60 - 70 (21.3 m)		4. 15 - 20.9 (5.3 dm)
5. > 21 (53.3 cm)	5. 71 - 99 (30.2 m)		5. > 21 (5.3 dm)
	6. > 99 (30.2 m)		

Table 2. *Error matrix table of the aerial photo estimates of stand DBH. Shaded cells indicate stands that were correctly classified. Accuracy values for the table are overall accuracy (P_0) = 0.53, Tau (T_e) = 0.41, and Kappa (K) = 0.27.*

		Reference (ground) data						
	Class	1	2	3	4	5	User's Accuracy (%)	Row total
Photo-interpreted data	1			1			-	1
	2	1	2	2	1		33	6
	3		1	14	5	1	67	21
	4			8	10	2	50	20
	5				2	1	33	3
	Producer's Accuracy (%)	-	67	56	56	25		
	Column total	1	3	25	18	4		51

Table 3. *Allowable error for chi-square test. These values were used in the chi-square test of a hypothesized variance (Freese, 1960) for the interval attributes.*

Attribute	Allowable error
DBH	+/- 3" (7.62 cm)
Height	+/- 10' (3.05 m)
Crown diameter	+/- 4' (1.2 m)
Canopy closure	+/- 10%

with errors reported for images of this scale in the literature (Worley and Landis 1954, Worley and Meyer 1955, Spurr 1960). We rearranged the basic equations presented by Freese (1960) algebraically so the probability the estimate is within the allowable error of the ground value could be easily determined. The chi-square technique assumes a normal distribution of the data. Normal probability plots were examined to test this assumption.

The Tau coefficient (T_e) and the Z probability corresponding to the chi-square test of a hypothesized variance were the accuracy measures used to evaluate the estimation techniques.

RESULTS

Photointerpretation error matrices

Table 4 summarizes the stands that were accurately interpreted and those that were mis-estimated for the interval attributes.

DBH. — The User's accuracy figures indicate we were best able to interpret DBH in classes 3 and 4. Over 80% of the stands were in these two classes (Table 2).

Height. — Estimates of stand height from the photos were generally underestimated, such that stands were frequently placed in lower classes by the photo-interpreter (Table 4). The User's accuracies for stand height classes 3 and 4 were greater than 50 percent, and 86 percent of the stands were in these two classes.

Crown diameter. — Photo estimates of average crown diameter tended to be low. Thirteen stands were underestimated while 7 were overestimated (Table 4). Like the estimates of DBH and height, the User's accuracies were high in the classes that contained the majority of the stands (classes 3 and 4).

Canopy cover. — Estimates of canopy cover did not appear to be biased (Table 4). All of the stands were either in class 2 or 3. Most of the underestimated stands were in class 3, whereas all of the overestimated stands were in class 2; thus interpreters were unable to distinguish classes 2 and 3. Accuracy is low considering that there were just three classes.

Canopy layers. — Most of the sample stands were single-layered (class 1) and there was substantial misclassification between one-and-two layered stands. Fifteen stands were classified as one-layered when they were actually two-layered, indicating that it was difficult to detect the second layer of stand canopy.

Cover type. — Over half of the sample stands were of the Douglas-fir cover type (27 out of 51); User's accuracy for Douglas-fir was high (74 percent). User's accuracy for subalpine fir was also high (75 percent). Five stands were incorrectly classified as Douglas-fir; conversely six Douglas-fir stands were erroneously classified as other cover types.

Error matrix coefficients calculated for each attribute show a similar trend as reported by Ma and Redmond (1995), with K coefficient values being the lowest, T_e values in the middle, and P_o values the highest (Table 5).

Chi-square test of a hypothesized variance

The P(Z) values were substantially higher than the corresponding Tau coefficient values (Table 6) for each attribute. The chi-square analysis was not applicable to the nominal attributes (canopy layers, cover type). Bias was detected in DBH, height, and crown diameter attributes; the P(Z) values (Table 6) were calculated with bias removed.

Table 4. *Summary of error matrix results for ordinal attributes. Each cell represents the number of stands.*

Attribute	Underestimated by > 1 class	Underestimated by 1 class	Accurately classified	Overestimated by 1 class	Overestimated by > 1 class	Sample size (stands)
DBH	3	9	27	12		51
Height	4	13	25	8		51
Crown Diameter	5	8	31	7		51
Canopy Cover		13	27	11		51
Canopy Layers		15	33		3	51

Table 5. *Error matrix accuracy coefficient values. The same error matrix for each attribute was used to calculate each coefficient.*

Variable	Kappa	Tau	
DBH	0.27	0.41	0.53
Height	0.14	0.29	0.49
Crown diameter	0.42	0.51	0.65
Canopy cover	0.13	0.29	0.53
Canopy layers	0.18	0.50	0.63
Cover type	0.47	0.59	0.64

Table 6. *Summary table of the Tau and P(Z) accuracy measures for each attribute.*

Variable	Tau	P(Z)
DBH	0.41	0.69
Height	0.29	0.55
Crown diameter	0.51	0.84
Canopy cover	0.29	0.52
Canopy layers	0.50	N/A
Cover type	0.59	N/A

DISCUSSION

Spurr (1960) reported on the tendency to underestimate crown diameter which agreed with our findings. He stated that thin branches cannot be resolved on the photos causing an underestimation of crown diameter. This may be one factor explaining the significant bias detected in the chi-square equation for this attribute. However, the quality of film and lenses has increased tremendously since the 1960s and low resolution may not be the cause of this underestimation.

The steep topography in parts of the study area resulted in shadows and changes in resolution that may have resulted in the overestimation of canopy cover. The detected error in our comparison might result from the tendency to underestimate canopy cover from the ground (Spurr, 1960). Estimates of canopy cover from aerial photographs may be more accurate than estimations from the ground. We found that the percentage of ground obscured by overstory canopy for the entire stand was easier to visualize from an aerial perspective than from a series of ground plots. This discrepancy may be partially responsible for the low reported accuracy for this attribute.

Estimating canopy layers from the photos was difficult and we often depended more on the site characteristics, topography, elevation, and aspect of the stand rather than the texture, tone or patterns seen on the photograph (Paine 1981, Spurr 1960). Site characteristics were obtained from topographic stand maps. Our knowledge of the plant ecological relationships to physical site characteristics played an important role in the interpretation. The reported accuracy (T_e = 0.50) was fairly high considering the difficulties described above. Perhaps greater familiarity with the vegetation conditions and how they relate to the physical characteristics of the stands would have resulted in an increase in accuracy for this attribute.

Over half of the stands were in the Douglas-fir cover type; the remaining six cover types had six or fewer stands in each cover type class. The high reported User's accuracy for subalpine fir may be because this species tends to have a distinctly pointed crown compared to the other species and therefore was easier to distinguish on the photos. We chose single species cover types because of the large variety of species mixes that occur in the study area. We felt that it would be easier to identify the major species on the photos rather than try to define species mixes by canopy cover composition. Like the stand layers attribute, the site characteristics of the stand were often critical in making cover type judgments from the photos. Accuracy (T_e = 0.59) is high when the difficulty of determining the dominant cover type species from the many mixed species stands is considered; the accuracy reported for cover type is not significantly different from that reported by Deegan and Befort (1990), who analyzed data from 1:15,840 scale black and white infrared photos and ground plots in northern Minnesota ($T_e = 0.54$).

We detected significant bias in the chi-square calculations for DBH, height, and crown diameter; this may be partially due to the growth of the trees since the time the photos were taken. The photos were taken in August 1990 and the field inventory was conducted in August - September 1995, which would have allowed growth to occur.

For all of the attributes, the majority of stands were classified into one or two classes, with a few stands scattered among the remaining classes. In many of the under-represented classes, small sample sizes allowed for greater errors. For example, the DBH class 2 producer's accuracy would be reduced from 67 percent to 33 percent if just one of the correctly classified stands had been misclassified (Table 2). A larger number of sample stands would presumably add stands to the under-represented classes and increase reliability of the producer's and user's accuracy figures. The User's accuracies for the classes where most of the stands were placed by the reference data were relatively high for most of the attributes, suggesting that our photo-estimating techniques may be more accurate than the error matrix coefficients indicated.

Congalton (1991) points out that traditional statistical methods for determining sample size are not appropriate for error matrix tables and that a minimum of 50 samples per error matrix category is recommended. Adhering to this recommendation would mean field sampling 250 stands (half the stands in the study area) to populate an error matrix with five categories. We sampled 51 stands for practical reasons (field time, expense). We intended to sample 50 stands, one extra stand was accidentally sampled.

Selection of class breaks and the number of classes can have a significant effect on error matrix accuracy coefficients. We selected these error matrix classes based upon their utility to Salish/Kootenai forestry personnel and because the class boundaries seemed logical for this region. The same data aggregated into a different number of classes may result in different accuracy coefficient values (Openshaw 1987). It is interesting to speculate on whether collecting data in an ordinal form would have any effect on error matrix accuracy. Biging *et al.* (1991) interpreted stands into broad classes using methods and imagery similar to this study; reported accuracies are somewhat higher. This may be because their classes were much broader than ours. Placing stands directly into categories seems to be popular (Lehmkuhl *et al.* 1994), probably because of the relative ease and speed with which stands are interpreted. In short, manipulating the number and width of classes and the class breaks can have a significant impact on accuracy and should be considered prior to data collection or aggregation into classes.

The observed tendency for the P(Z) values to be higher than the corresponding Tau values is because the two methods measure accuracy in different ways. The P(Z) value is the probability that the estimate is within the allowable error of the ground estimate. Thus, with a reported P(Z) value of 0.68, in 68 out of 100 stands we would expect the estimate to be within the allowable error of the ground value. Error matrix values (T_e) indicate the percent chance that a stand is in the correct class. They can also be interpreted as the percent improvement over a random placement of stands into cells in the error matrix table. It seems that the two measures should be closer than the results (Table 6) indicate; the higher P(Z) values reported may be because this technique considers the difference between each attribute pair (estimated - observed) whereas the error matrix technique lumps the interval attribute pairs into categories. In directly comparing the predicted versus estimated values, the effects of gross estimation errors in any one stand may be smoothed over by other, more accurately interpreted stands.

The obvious difference between the two measures is that one measures interval scale data (chi-square) and the other measures categorical data. Collecting interval scale data allowed us to collapse the data using many different classifications. Thus, if a particular model or analysis requires different class breaks, we could collapse the interval data into the appropriate categories. This freedom is lost if the data were collected in categories.

Although direct comparison of the two accuracy assessment techniques is not possible, the success of the estimating techniques in predicting the ground values of the interval attributes may be higher than the Tau coefficients indicate because of the problem of low sample sizes in many of the classes. The sample sizes recommended by Congalton (1991) are certainly reasonable for satellite images where the population consists of thousands pixels, but they are impractical when the experimental unit is the stand, not the pixel. We recommend using the chi-square test when few ground plots are available.

A question that a land manager must ask when faced with the need for landscape-level data is whether the increased accuracy of a ground-based inventory method justifies the extra expense. Photointerpretation is a cost-efficient method of obtaining data, especially if imagery does not have to be purchased. Project objectives are critical to this discussion of efficiency versus accuracy. Resource managers may accept a higher level of error when the goal is estimation of the areal extent and arrangement of various structure and cover types in broad classes across a large landscape. When a smaller landscape is being assessed for management planning, the level of acceptable error may be lower, perhaps to the point of justifying a ground survey of all stands. The objectives may involve collapsing attribute data into a stand type classification based on two or more of the attributes. In this case, the accuracies of each of the attributes used in the classification would be multiplied for the estimated accuracy of the stand classification. For example, if a stand type classification is based on diameter class and cover type and the Tau coefficients for these two attributes are 0.75 and 0.80, then the accuracy coefficient of the classification would be (0.75)(0.80) = 0.60.

A reasonable approach to landscape assessment would be to combine remotely-sensed data, existing ground data (stand exams), and field survey data into the landscape assessment, as in Morrison (1994). Ground data could be used to conduct an assessment of the photo-interpreted stands provided that the inventory methods were compatible, or to train photo-interpreters before data collection from the photos.

CONCLUSIONS

As more is learned about landscape-level processes, there will be a greater need for efficient methods of collecting data across landscapes. Satellite image technology is progressing, but accurate classification of some forest structure attributes has not been attained (Spies 1994, Cohen 1994). When compared to digital image processing, photointerpretation is a relatively low cost method that is within the means of most land management agencies. A multi-stage approach is probably best; satellite images may be used for data collection in broad classes across large areas, and aerial photographs for more specific data on mid-scale landscapes. For detailed, site-specific data field inventory will be necessary.

In this study, we used photointerpretation methods similar to those used by most land management agencies. Other methods of collecting information from aerial photographs (Martin and Gerlach 1981, Teuber 1983) are certainly valid, but the methods used in this study seem to be commonly used in operational landscape assessments (Lehmkuhl *et al*. 1994).

Accuracy assessments should be conducted on all projects where data from remotely sensed images are used. The accuracy assessment methods we describe could easily be implemented on most data sets. The number of field plots or sample stands may be restricted by expense, but as few as 50 plots (stands) provide insight into errors and misclassifications. Existing stand inventory data may be used in assessing the accuracy of remotely sensed or modeled data; this would minimize the amount of new field data needed. Knowledge of the accuracy of remotely sensed data will give increased confidence in decisions based upon the data and also provide feedback to improve future interpretation and classification projects.

Forest structure attributes frequently are the defining characteristics for landscape elements such as the patch, matrix and corridor (Forman 1995). Landscape models have been developed to meet the challenge of implementing ecosystem management; some examples include SIMPPLE (Chew 1995), FIRE-BGC (Keane *et al.* 1996), and FRAGSTATS (McGarigal and Marks 1995) These models frequently utilize remotely sensed data of these forest landscape elements. The accuracy of these input data and the effect of errors on model output are frequently overlooked (Hess 1994). The application of some models may be pointless and misleading if the input data are not accurate to a certain extent. Land cover weighting schemes, which are often used in wildlife habitat models, can be adjusted based on observed classification error (Prisley and Smith 1987). Further research into the effect of errors in spatial data on landscape models, and methods to adjust models based on these errors, is needed.

Often land managers have data from several different sources at their disposal when making resource decisions. They need a method to weight these different data sets; an accuracy assessment provides a good basis for weighing the value of remotely sensed data (McCloy 1995). Resource professionals will continue to look to remote sensing technology as a cost-effective way to obtain data as they assess forest resource patterns and processes across larger landscapes. Awareness of the limitations of this technology and of potential inaccuracies in these data are critical factors to consider when decisions are to be made based on a landscape-scale analysis.

ACKNOWLEDGMENTS

The authors would like to extend their thanks to the Confederated Salish-Kootenai Tribes for their support of this research. Support was also received through a McIntire-Stennis grant to the Montana Forest and Conservation Experiment Station at the University of Montana School of Forestry. Thanks also to the USDA Forest Service Region 1 Forest Insect and Disease Lab for the use of their stereoscope and to the many reviewers whose comments greatly improved this paper.

LITERATURE CITED

Allen, C.D. 1994. Ecological perspective: Linking ecology, GIS, and remote sensing to ecosystem management. In: Remote Sensing and GIS in Ecosystem Management. V. A. Sample, ed. Island Press, Washington, DC. 369 pp.

Biging, G. S., R. G. Congalton, and E. C. Murphy. 1991. A comparison of photo-interpretation and ground measurements of forest structure. [pp 6 - 15.] In: Technical Papers, Vol. 3, ACSM-ASPRS 57th Annual Convention, Baltimore, MD.

Chew, J. D. 1995. Development of a system for simulating vegetative patterns and processes at landscape scales. Ph.D. dissertation, University of Montana, Missoula, MT. 181 pp.

Cohen, W. B. 1994. GIS applications perspective: Current research on remote sensing of forest structure. In: Remote Sensing and GIS in Ecosystem Management. V.A. Sample, ed. Island Press, Washington, DC. 369 pp.

Congalton, R. G. and R. A. Mead. 1983. A quantitative method to test for consistency and correctness in photo-interpretation. Photogrammetric Engineering and Remote Sensing, 49(1): 69-74.

Congalton, R. G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens. Environ. 37: 35-46.

Deegan, G., and W. A. Befort. 1990. Photointerpretation accuracy across two decades of forest inventory. In: State of the art methodology of forest inventory: A symposium. V. LauBau and T. Cunia, eds. USDA Forest Service, PNW Research Station. PNW-GTR-263.

Foody, G. M. 1992. On the compensation for chance agreement in image classification accuracy assessment. Photogrammetric Engineering and Remote Sensing, 58(10): 1459-1560.

Forman, R. T. 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, New York. 632 pp.

Freese, F. 1960. Testing accuracy. Forest Science 6(2):139-145.

Gonzales, J. 1994. GIS applications perspective: Using remote sensing and GIS for modeling old-growth forests. In: Remote Sensing and GIS in Ecosystem Management. V.A. Sample, ed. Island Press, Washington, DC. 369 pp.

Green, K., S. Bernath, L. Lackey, M. Brunengo, and S. Smith. 1993. Analyzing the cumulative effects of forest practices: Where do we start? Geo. Info. Systems 3(2): 37-29.

Hess, G. 1994. Pattern and error in landscape ecology: A commentary. Landscape Ecology 9(1):3-5.

Hudson, W. D. 1987. Evaluating LANDSAT classification accuracy from forest cover-type maps. Canadian Journal of Remote Sensing 13(1): 39-42.

Kalkhan, M. A., T. J. Stohlgren, and M. B. Coughenour. 1995. An investigation of biodiversity and landscape-scale gap patterns using double sampling: A GIS approach. In: Proceedings of the Ninth Annual Symposium on Geographic Information Systems, Vancouver, BC March 27-30, 1995.

Keane, R. E., P. Morgan, and S. Running. 1996. FIRE-BGC — A mechanistic ecological process model for simulating fire succession on coniferous forest landscapes of the northern Rocky Mountains. USDA Forest Service INT-RP-484.

Lillesand, T. M. and R. W. Keifer. 1994. Remote Sensing and Image Interpretation. John Wiley and Sons, Inc. New York, NY. 723 pp.

Lehmkuhl, J. F., P. F. Hessburg, R. L. Everett, M. H. Huff and R. D. Ottmar. 1994. Historical and current forest landscapes of eastern Oregon and Washington. Part I: Vegetation pattern and insect and disease hazards. USDA Forest Service, PNW-GTR-328. Eastside forest ecosystem health assessment, Volume III.

Ma, Zhenkui and R. L. Redmond. 1995. Tau coefficients for accuracy assessment of classification of remote sensing data. Photogrammetric Engineering and Remote Sensing, 61(4): 435-439.

McGarigal, K. and B. J. Marks. 1995. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. USDA Forest Service PNW-GTR-351.

Martin, F. C. and Gerlach, F. L. 1981. Forest stand mapping and evaluation on state and private lands in Montana. Bulletin 46, Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Missoula, Montana 59812.

McCloy, K. R. 1995. Resource Management Information Systems. Taylor and Francis, London. 415 pp.

Morrison, P. H. 1994. GIS applications perspective: Development and analysis of a chronosequence of late-successional forest ecosystem data layers. *In*: Remote Sensing and GIS in Ecosystem Management. V.A. Sample, ed. Island Press, Washington, DC.

Openshaw, S. 1987. Learning to live with errors in spatial databases. In: Accuracy of spatial databases, M. Goodchild and S. Gopal, eds. Taylor and Francis, New York. 290 pp.

Paine, D. P. 1981. Aerial Photography And Image Interpretation For Resource Management. John Wiley and Sons, New York.

Prisley, S. P. and J. L. Smith. 1987. Using classification error matrices to improve the accuracy of weighted land-cover models. Photogrammetric Engineering and Remote Sensing, 53(9): 1259-1263.

Rutledge, L. T. and Hejl, S. J. 1990. Inventorying old-growth by aerial photograph analysis and ground surveys: An initial assessment. The Northwest Environmental Journal. 6(2):397-398.

Short, H. L. 1988. A habitat structure model for natural resource management. Journal of Env. Management, (27) 289-305.

Spies, T. A. 1994. Ecological perspective: The nature of mature and old-growth forest ecosystems. *In*: Remote Sensing and GIS in Ecosystem Management. V.A. Sample, ed. Island Press, Washington, DC. 369 pp.

Spurr, S. H. 1960. Photogrammetry and Photo Interpretation. The Ronald Press, New York. 472 pp.

Story, M. and R. G. Congalton. 1986. Accuracy assessment: A user's perspective. Photogrammetric Engineering and Remote Sensing 52(3):397-399.

Teuber, K. B. 1983. Aerial photographic interpretation of forest stands on Lubrecht experimental forest, Montana. Mastersí Thesis, University of Montana, Missoula, MT. 157 pp.

Worley, D. P., and Landis, G. H. 1954. The accuracy of height measurements with parallax instruments on 1:12,000 scale photographs. Photogrammetric Engineering 20(5): 823-829.

Worley, D. P., and Meyer, H. A. 1955. Measurement of crown diameter and crown cover and their accuracy on 1:12,000 scale photographs. Photogrammetric Engineering, 21(3): 372-375.

N. Tursich
T. Weaver

PLANT GROWTH IN SOILS FROM SNOWDRIFT VS. ADJACENT DRIFTLESS MEADOW SITES

ABSTRACT

Soils from snowdrift sites may be leached of nutrients and thus support less plant production than soils from otherwise similar sites. In greenhouse experiments designed to test this hypothesis, biomasses of plants grown in soils from drift sites were 3-5 percent less than plants grown in soils from adjacent normal-pack sites. While the differences were statistically significant, it is unlikely that the large differences in vegetation between drift and driftless sites seen in the field are caused by leaching.

Keywords: Leaching, fertility, snow drift, mountain meadows, *Festuca idahoensis*.

INTRODUCTION

Snow deposits in mountain meadows of the Bangtail Range (Bozeman, MT) range from slight on windswept sites to considerable under large drifts. Vegetation differs relatively little between windswept (<0.5m of snow) and normal (<1m) sites. But vegetation of heavily drifted sites (>2m) is distinct (Weaver 1974): species composition is almost completely different and production is less. Comparable snow effects are reported from Colorado (Webber et al. 1976), Utah (Harper 1981) and Wyoming (Knight 1975).

We consider four factors as possible reasons for snow effects on vegetation. 1) Soil water. While water deposited on drift sites is five or more times greater than on normal sites (Weaver 1974), we expect little difference in community water relations. Water availability on drift sites does not exceed that of driftless sites with similar soils, however, because water storage is determined by the water holding capacity of the profile and excesses run through or off (Buchanan 1972, Weaver and Collins 1977). Differences in flooding are also unlikely, because the soils are loamy and well-drained (Buchanan 1972). 2) Compaction. Soils of drift sites are more compact than those of non-drift sites (Weaver 1974 and Weaver and Collins 1977). Plant growth in compacted soils is significantly reduced, but the effect of compaction is too small to explain the large differences in vegetation observed (McNeal and Weaver 1982). 3) Leaching. Presumably, large flows of melt-water through soils of drift sites are responsible for lowered nutrient levels on long-affected sites (Table 1) (Weaver 1974) and, even, on sites affected for as few as five years (Weaver and Collins 1977). Plant growth in soils of these sites should be contrasted to determine if nutrient reductions are sufficient to account for vegetation differences. 4) Seasonality. Relative to plants on a drift site, plants on a driftless site a) initiate growth earlier and under cooler shorter-day conditions, b) cease growth earlier due to earlier exhaustion of water, and c) have a longer growing season because their water is used under cooler less

N. Tursich, Biology Department, Montana State University, Bozeman, MT 59717
T. Weaver, Biology Department, Montana State University, Bozeman, MT 59717

Table 1. *Snowdrift effects on soil density (gm/cc), soil chemistry (ppm) and the nutrient supplying capacity of soils (gm plant/kg soil). Means are given with their standard errors. Depth (Weaver 1974), density (McNeal and Weaver 1982), and chemistry (Weaver 1974 and Weaver and Collins 1977) are summarized from earlier work. The phytometer analysis (gm/kg) is new.*

		Control	Drift
Snow depth (dm)		<2	>24
Soil density (gm/cc)		0.9 ± 0.2	1.27 ± 0.2
Soil chemistry/physics			
pH	natural drift	5.8	5.3
	snowfence	6.2 ± 0.1	6.0 ± 0.0
Conductivity (mmhos)	natural drift	0.6 ± 0.1	0.5 ± 0.1
	snowfence	0.4 ± 0.1	0.2 ± 0.0
Mg (ppm)	natural drift	878 ± 69	617 ± 43
	snowfence	461 ± 20	434 ± 8
K (ppm)	natural drift	875 ± 94	892 ± 30
	snowfence	553 ± 20	435 ± 9
Na (ppm)	natural drift	100 ± 7	98 ± 9
	snowfence	76 ± 4	64 ± 4
NO_3 (ppm)	natural drift	0.7 ± 1	0.5 ± 1
	snowfence	1.7 ± 0.2	2.1 ± 0.1
NH_4 (ppm)	snowfence	29 ± 25	26 ± 7
OM (%)	natural drift	4.8 ± 0.2	4.7 ± 0.0
	snowfence	6.0 ± 0.2	5.7 ± 0.1
P (ppm)	natural drift	54 ± 7	84 ± 7
	snowfence	16 ± 1	21 ± 2
Resource supplying capacity			
Wheat (gm/kg[1])	natural drift	50 ± 2	47 ± 0
	snowfence	52 ± 2	51 ± 1
Corn (gm/kg[1])	natural drift	52 ± 2	51 ± 1
	snowfence	53 ± 2	50 ± 1

[1] Gm plant/kg soil. The actual measurement, based on 489 gm soil, was multiplied by 2.045 to give gm/kg.

evaporative conditions (Weaver and Collins 1977). Such differences could select for different species on drift and non-drift sites.

The following experiments were designed to determine whether differences in soils of driftless and drift sites might be responsible for the differences in vegetation observed on them. While we hypothesize effects due to leaching of nutrients, it is not our object to distinguish leaching effects from other snow induced developmental changes, such as clay movement leading to changes in texture and classification.

METHODS

We conducted two experiments designed to determine if differences in soil qualities might account for differences in plant production that might, in turn, explain differences in vegetation between snow drift and driftless sites. Our general strategy, elaborated below, was to collect soils from drift and driftless sites, grow plants in them, and compare yields (gm plant/kg soil). Soil qualities were tested with plants, phytometers, (Weaver and Clements 1938) because plants integrate influences across nutrients better than previously made chemical analyses and may incorporate influences not measured in standard soil tests. The test plants were wheat (*Triticum aestivum* var pondera) and corn (*Zea mays* var Pioneer hybrid 3540). They were chosen because they were easily available, grow rapidly, are well adapted to greenhouse conditions, and, as grasses, may represent the dominants of the meadow flora.

The meadow sites studied were both located near the Bangtail Station, Bangtail Range, Bozeman, Montana (T1S, R6E,Sec 6). The first experiment focused on a line of trees that created a natural snowfence (Billings 1969) approximately 2 km south of the station. Drifting and leaching differences have occurred upwind and downwind from the tree line for over 100 years and, thus soil conditions may be approaching equilibrium. Along this natural snow fence site, six pairs of samples were collected with one unit taken in the drift and one upwind of it. Each sample consisted of dozens of rectangular cores, approximately 3 cm x 15 cm x 15 cm deep, taken at 1 m intervals on lines parallel to the fence. The total volume of each sample exceeded 20 liters.

The second experiment was started in 1969, when five snowfences (30 m x 2.5 m) were installed parallel to each other and perpendicular to the prevailing wind to create a 30 x 30 m drift (Weaver and Collins 1977). In comparison with the natural drift (Experiment I), the soil development (leaching) period in Experiment II was shorter (27 years). Thus, soil differences were less (Table 1) (Weaver 1974, McNeal and Weaver 1982), and conditions were likely non-equilibrium. Soils under the 30 m drift were collected on lines parallel to and between fences. Soils that were comparable, but not influenced by the drift, were collected on lateral extensions of the transects in locations to the side of the drifted area.

Soils from the natural drift, 'equilibrium', site were used to compare soils from long established drift and driftless areas. Details of the analysis follow: 1) Soils from the first site (Expt Ia) were dried and sieved immediately after collection. 2) Thirty-six 10 cm pots were filled with soil, half (6 samples x 3 pseudo-replications) from the drifted area and half from the driftless area. Because nutrient supply is proportional to soil weight, a uniform quantity (489 gm) of soil was put in each pot. 3) Wheat was planted in each pot. A template with 3 cm prongs created four identical holes in moistened soils. Two seeds were planted in each hole and, on germination, the weaker seedling was cut. 4) Pots were arranged in a 12 x 3 matrix on the bench. The first row contained alternating samples from drift and driftless subsites, starting with a driftless sample. The third row was identically arranged, the second row differed in starting with a drift sample. 5) Plants were grown under warm well-watered greenhouse conditions to eliminate differences in environmental conditions other than those due to soil. 6) They were harvested after flowering, fruiting, and partial drying. The wheat grew 130 days (18 Jan-8 May 1997). They were then pressed, dried, and weighed. Each of the 12 samples included twelve plants: four per pot over three replicate pots. The first pooling guaranteed that nutrient extraction from each pot was maximized and that use was averaged among plants. The second maximized uniformity of environment while avoiding pseudo-replication.

7) Treatments were contrasted with a t-test on the advice of the MSU Statistician, W Quimby.

The first experiment was repeated with a second species, field corn (Expt 1b, 2 treatments x 6 reps x 3 pseudo-reps). This experiment was identical except for species, location of pots on the bench, and the growth period. The growth period was 95 days (13 Feb-18 May 1997). Because of these differences, we compared performance in the two soils with a second t-test.

Soils from the non-equilibrium snowfence site (Expt 2) were used to compare soils from drift and driftless areas established for only 27 years. In this analysis (Expt 2a), wheat phytometers were used to contrast the soils with procedures very similar to those described above. A different field site was sampled. Four, rather than six, samples were taken in each treatment area, 2 treatments x 4 reps x 3 pseudo-reps. A different bench site was used. The same time period of 130 days was used (18 Jan-8May 1997). Processing and analysis were identical.

The preceding experiment was repeated with a second species, corn (Expt 2b). Thus, it was identical to experiment 2a (2 treatments x 4 reps x 3 pseudo-reps), except for species, bench location, and duration of growth, 95 days, (13 Feb-18 May 1997).

Chemical analyses of these soils were made by the MSU Soil Testing Lab and published earlier (Weaver 1974, Weaver and Collins 1977). The data are repeated in Table 1 to provide a context for our evaluation of the differences measured with phytometers (Weaver and Clements 1938).

Results and Discussion

Soils from drift sites have lower nutrient concentrations than those from sites with normal packs (Table 1), presumably due to leaching. This is true whether the drift is ancient (Weaver 1974) or only five years old (Weaver and Collins 1977). Integrative indicators (pH and conductivity) and most individual ions (Mg, K, Na, NH_4) decline with the presumptive leaching and decline more on sites leached for more years. That the transport is not entirely simple is shown by phosphorous: instead of falling, its concentration rises on drift sites, probably because phosphorus is imported on blowing clays or organic matter.

We hypothesized correctly that plants grown in soils from 'low nutrient' drift sites will produce less than those grown in soils from driftless, unleached, sites. On the 'equilibrium' site, wheat plants growing on the leached portion weighed 4.5 percent less than those growing on the driftless portion ($p<5$ percent) And corn plants growing on the leached portion were 1.8 percent lighter ($p<5$ percent). A similar pattern was observed on the 'artificial' site snowfenced for 27 years. Wheat plants growing on the leached portion were 3.3 percent lighter than those growing on the normal portion ($p> 5$ percent). And corn plants growing on the leached portion were 5.4 percent lighter ($p< 5$ percent).

Our test was made with wheat and corn rather than the native grasses which decline (*Festuca idahoensis* and *Danthonia intermedia*) or increase (*Bromus ciliatus* and *Agropyron caninum*) on drift sites (Weaver 1974, Weaver and Collins 1977). While the natives might have been more appropriate subjects, we used exotics because we expected them to give a more rapid, certain, and robust response. The responses of grasses were parallel, wheat produced 6.2 percent less than corn on drift sites ($p<5$ percent) and 5.4 percent less than corn on driftless sites ($p<5$ percent). The fact that these very different grasses behaved similarly suggests that the responses of native grasses to nutrient differences would also be similar.

Despite the phytometer response, it seems unlikely that the large differences in vegetation on normal and drift sites (Weaver 1974) are due to lack of nutrients on drift sites. There are consistent differences in nutrient availability, estimated by chemical tests, but these differences are small (Table 1) (Weaver 1974, Weaver and Collins 1977). Plant responses correlated with such nutrient differences are statistically significant, but small. Thus, leaching cannot be the primary cause because the yield deficiency of drift site soils, as observed in experiments isolating the fertility factor, is small (Table 1), compared with yield deficiencies observed on natural drift sites greater than 60 percent (Weaver 1974).

Interaction of nutrient differences and another edaphic factor with small significant effects (compaction, McNeal and Weaver 1982), doesn't explain the observed yield differences, but it may contribute to differences in community composition on drift and non-drift sites. Consider two models. First, if roots of a grass penetrate compacted soils poorly (McNeal and Weaver 1982), compaction is expected to reduce access to nutrients and reduce yields. Second, if roots of another species penetrate compacted and uncompacted soils to equal depths, compaction by 20 percent (McNeal and Weaver 1982) will provide access to 20 percent more nutrients and 20 percent more production. Thus, compaction might increase or decrease yields, but in neither case to the extent seen on natural sites, >60 percent, (Weaver 1974). On the other hand, differences in vegetation composition on drift and driftless sites not described here (Weaver 1974, Weaver and Collins 1977) may be determined partially by compaction influenced competition for nutrients.

LITERATURE CITED

Billings, W. 1969. Vegetational pattern near alpine timberline as affected by fire-snowdrift interactions. Vegetatio 19:192-207

Buchanan, B. 1972. Ecological effects of weather modification, Bridger Range MT: relationships of soil, vegetation, and microclimate. PhD dissertation, Montana State University, Bozeman, MT. 136 pp.

Harper, K. ed. 1981. Potential ecological impacts of snowpack augmentation in the Uinta Mountains, Utah. Dept. of Botany and Range Science, Brigham Young Univ, Provo, UT. 291 pp.

Knight, D. ed. 1975. Potential sensitivity of various ecosystem components to winter precipitation management in the Medicine Bow Mountains, Wyoming. Botany Department, Univ. Wyoming, Laramie, WY 397 pp.

McNeal, A. and T. Weaver. 1982. Soil compaction as a determinant of subalpine snowdrift vegetation. Montana Acad. Sci. Proc. 41:46-50.

Webber, P., J. Emerick, D. May, and V. Komarkova. 1976. The impact of increased snowfall on alpine vegetation. *In*: H Steinhoff & J Ives eds. 1976. Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Colo. State Univ., Ft Collins CO. 489 pp.

Weaver, J. and F. Clements. 1938. Plant ecology. McGraw Hill. NY. 601 pp.

Weaver, T. 1974. Ecological effects of weather modification: effect of late snowmelt in Festuca idahoensis meadows. Amer. Mid. Nat. 92: 346-356.

Weaver, T. and D. Collins. 1977. Possible effects of weather modification (increased snowpack) on Festuca idahoensis meadows. J. Range Manag. 30: 451-456.

Carl L. Wambolt
Richard S. White
Todd P. Walton

AN EFFECTIVE METHOD OF MEASURING SEED DISSEMINATION

ABSTRACT

*Seed dissemination, an important factor in determining the reproductive success of many plant species, is seldom examined because effective measurement techniques have been lacking. A simple method for measuring seed dissemination is described that has low labor and material requirements. The method was developed to evaluate distribution of wind-borne seed of plains silver sagebrush (*Artemisia cana *ssp.* cana*). It was field tested successfully to determine how much, when, and where seed fell with reference to distance and direction traveled from the parent plant. The method should prove suitable for measuring seed dissemination of many other species under a variety of environmental conditions.*

Key words: *Artemisia*, dispersal, dissemination, methodology, propagule, seed.

INTRODUCTION

Successful reproduction of a plant species depends upon several interrelated factors. Attributes, such as seed production, germination variables, and early seedling growth, have all been recognized as important and have received considerable research attention. In contrast, seed dispersal, an important factor in establishment and maintenance of a plant population, is seldom studied. Knowledge of seed dissemination may be especially critical in achieving effective control of weeds.

Most research efforts dealing with seed dissemination have been directed toward defining the principle mechanism by which seeds are distributed from parent plants. As a result, seed can generally be categorized as wind (anemochory), water (hydrochory), or animal (zoochory) disseminated according to the primary method of distribution. Daubenmire (1967) considers wind to be the most common and efficient agent of seed dissemination among terrestrial plants. In conjunction with this observation, there have been numerous descriptions of seed adaptations, such as wings, that facilitate wind dispersal.

Quantitative measurements of wind dispersal with respect to seed number and dispersal distance have been very limited. In early work, Isaac (1930) described lateral distribution of seeds in Douglas fir (*Pseudotsuga menziesii*), and Siggins (1933) discussed distribution of conifer seeds with reference to their rate of fall. Mueggler (1956) documented potential distances that seed may be carried by wind, but did not quantify the number of seeds achieving this potential.

Quantitative data on seed dissemination is scarce, largely due to the lack of a suitable measurement technique. Available methods generally require elaborate seed traps and are usually labor intensive. Sindelar (1968), for example, described a method in which seeds were collected from layers

Carl L. Wambolt, Animal and Range Sciences Dept., Montana State University, Bozeman, MT 59717
Richard S. White, Northwest Research, Extension Center, Kansas State University, Colby, KS 67701
Todd P. Walton, Animal & Range Sciences Dept., Montana State University, Bozeman, MT 59717

of cheesecloth placed in the bottom of pie pans. Although accurate counts can be achieved by this method, development of a simple, inexpensive technique would facilitate routine measurement of seed dispersal.

The purpose of our research was to devise an effective method of collecting wind-borne seed under field conditions. To accomplish this successfully, it was desirable to determine time, direction, distance and quantity of seed disseminated from parent plants.

MATERIALS AND METHODS

The method we devised was used to measure seed dissemination in plains silver sagebrush (*Artemisia cana* ssp. *cana*) (Wambolt *et al.* 1989). Silver sagebrush is a widely distributed shrub that occupies an estimated 13 million ha in the western US (Beetle 1960). The plant is 1 m or less in height, although larger plants are not uncommon. Seed production is abundant and dispersal normally takes place by wind after seeds ripen in October or November. Each plant has been estimated to produce as many as 54,000 seeds per year, which average 2.14 mm in length, .90 mm in width, and 681 μg in weight (Harvey 1981). Therefore, these seed dimensions and weight are comparable to those of many other small-seeded species (Reed 1977).

Our seed collection technique was relatively straight-forward. The procedure involved: (1) selecting parent plants on which to make measurements, (2) placing collection equipment in the desired spatial configuration, and (3) removing and counting disseminated seed. Because each aspect of this procedure might require some changes for other species or the individual objectives being considered, we have not attempted to present a detailed description of the many variations that might be applied to the technique. Instead, a method is described that was successful for plains silver sagebrush.

Seasonal seed dissemination patterns were measured on 15 reproductively mature silver sagebrush plants, five each from three separate study sites in southeastern Montana. Variation among study sites is discussed in Wambolt *et al.* (1989), but all sites averaged 340mm of annual precipitation with a peak received in May and June. The first three weeks of November, when silver sagebrush seeds are disseminated, are typically dry. Individual plants were selected to typify the average adult size for this species in each community. Shrub heights ranged from 1.0 m to 1.5 m, and crown canopy cover varied from 1.0 to 4.0 m^2. During the selection process, care was taken to choose plants with sufficient area around them to accommodate at least six unobstructed line transects. This facilitated placement of collection equipment. Floral parts from nearby plants within a 10m radius were then cut off to eliminate cross contamination during the sampling period.

Seed collection devices consisted of thin (0.5 mm) aluminum sheet-metal plates (36 by 36 cm) that were coated with petroleum jelly as an adhesive. A 30.5 x 30.5 cm sampling grid with smaller 7.6 x 7.6 cm individual subsections was hand scribed on the sheet metal surface with an awl. The subsections simplified field counting of seeds. Two holes were drilled in opposite corners of the sheet metal plate, and 13 cm long nails were used to secure the plates to the ground. This insured that plates would not be blown away or otherwise moved, thereby allowing repeated measurements from the same locations.

Five aluminum plates were placed at 1 m intervals (0,1, 2, 3, and 4 m) from center to center along each of six equally-spaced line transects radiating from individual plants (Fig. 1). This sampling pattern resulted in a series of concentric circles around each plant and provided a spatial arrangement for

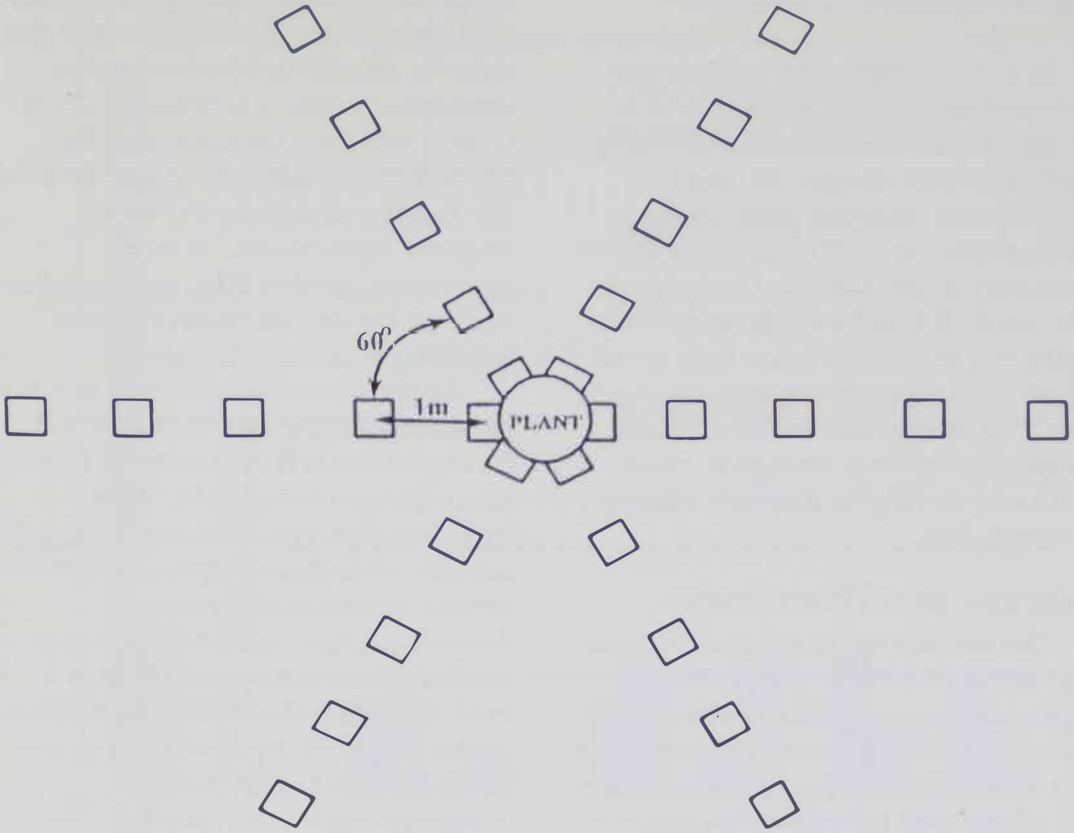


Figure 1. *Aerial view showing the spatial configuration of aluminum sheet metal plates used to catch seed from individual plants of plains silver sagebrush.*

evaluating direction and distance of seed dispersal. Seeds were collected and counted every 3 to 4 days throughout the seed dissemination period in November. After seeds had been removed, new adhesive was applied as needed to monitor seed fall during the subsequent sampling period.

Seeds that fell on the aluminum sheets were handled in one of two ways. If they were low in number and could be quickly counted, they were tallied in the field and removed by hand from the sampling grid. However, if seeds were numerous they were collected from individual aluminum sheets and saved for later enumeration. This situation was most commonly encountered immediately adjacent to parent plants where both filled and unfilled seed were present along with floral bracts. The collection procedure was rapid and simple. A paint scraper was employed to gather the petroleum jelly and seed mixture that was present on the sampling grid. This solidified mixture from each sheet was then placed in individual shallow-sided, disposable aluminum pans (22 x 15 x 3 cm) for later separation in the laboratory.

Seeds were separated by placing the solidified mixture on four layers of cheesecloth that had been stapled across the sides of the same aluminum pan. Pans were then placed in a 100 C oven until the petroleum jelly melted. After the petroleum jelly melted, it was drawn laterally along the surface of the cheesecloth. During this process, seed was spread across the cheesecloth and left behind after the liquid petroleum jelly ran into the pan below. Seeds could then be readily counted and evaluated with respect to filled or unfilled characteristics. Other debris that was originally present in the sample was also separated by using this approach.

In our experience, an appropriate statistical analysis of data collected by this technique was accomplished using a split-split plot design. We used transects and distances from mother plant as split plots. If measurements are taken over more than one time period, date would be used as a covariant. We conducted mean separation tests for all factors and combinations with Student's t test. We determined that our design sampled intensively enough for each parameter through a standard adequacy of sample test.

RESULTS AND DISCUSSION

The method we devised to evaluate seed dissemination in plains silver sagebrush was successful under a variety of field conditions. Quantitative data were obtained that estimated when and where seed fell during the dispersal period (Fig.2). However, patterns of seed dissemination were complex. Factors such as phenological status of the plant, wind direction, and wind velocity affected individual dispersal responses and caused considerable variation between sample periods, direction, and distance from plant ($P \leq 0.01$) (Wambolt *et al.* 1989). However, no significance ($P \leq 0.68$) was found among the three sites where the method was tested.

Careful *in situ* observations of actual seed fall showed virtually 100% retention of seeds that fell on the aluminum plates. Other plant materials such as floral bracts and leaves were also caught by the seed traps. This could present problems if litter fall was heavy, and it might necessitate fairly frequent cleaning of the plates. Separation of seed from other debris might also become a problem under these circumstances. If this problem was severe, it might be advantageous to construct a litter screen of hardware cloth or similar material to mount over the adhesive-coated seed plate to filter out larger debris. Problems might also occur in situations where extensive atmospheric dust was present. Under these conditions, the surface of the petroleum jelly adhesive might become less functional and require more frequent replacement. In our application, neither litter accumulation nor dust became disruptive factors requiring remedial attention.

Application of our method to other species appears to be very feasible. Incidental seeds from a number of other plant species were caught. These included: blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), crested wheatgrass (*Agropyron desertorum*), Japanese brome (*Bromus japonicus*), and cheatgrass (*Bromus tectorum*). Seeds from additional species would undoubtedly have been caught had they been present and disseminating seeds in late fall. The presence of incidental seeds that were caught demonstrates the potential application of the technique with respect to a variety of seed sizes, shapes and weights. However, the configuration of aluminum plates might need to be changed to accommodate research requirements in other species (Reed 1977). Factors such as the size or shape of plates, distance from the parent plant, and number of azimuth directions that are measured can be readily modified to fit individual circumstances that might vary with different seeds and environments.

The effectiveness of our technique was enhanced by using aluminum sheet metal for seed traps. Aluminum was selected because it is relatively light and could be easily cut into the desired size and shape for measurement. It was also relatively easy to transport and handle the large number of collection plates needed in the field. Measurements and maintenance on all 450 metal plates (15 plants, 30 plates/plant) required about 4 hours with three people on any given

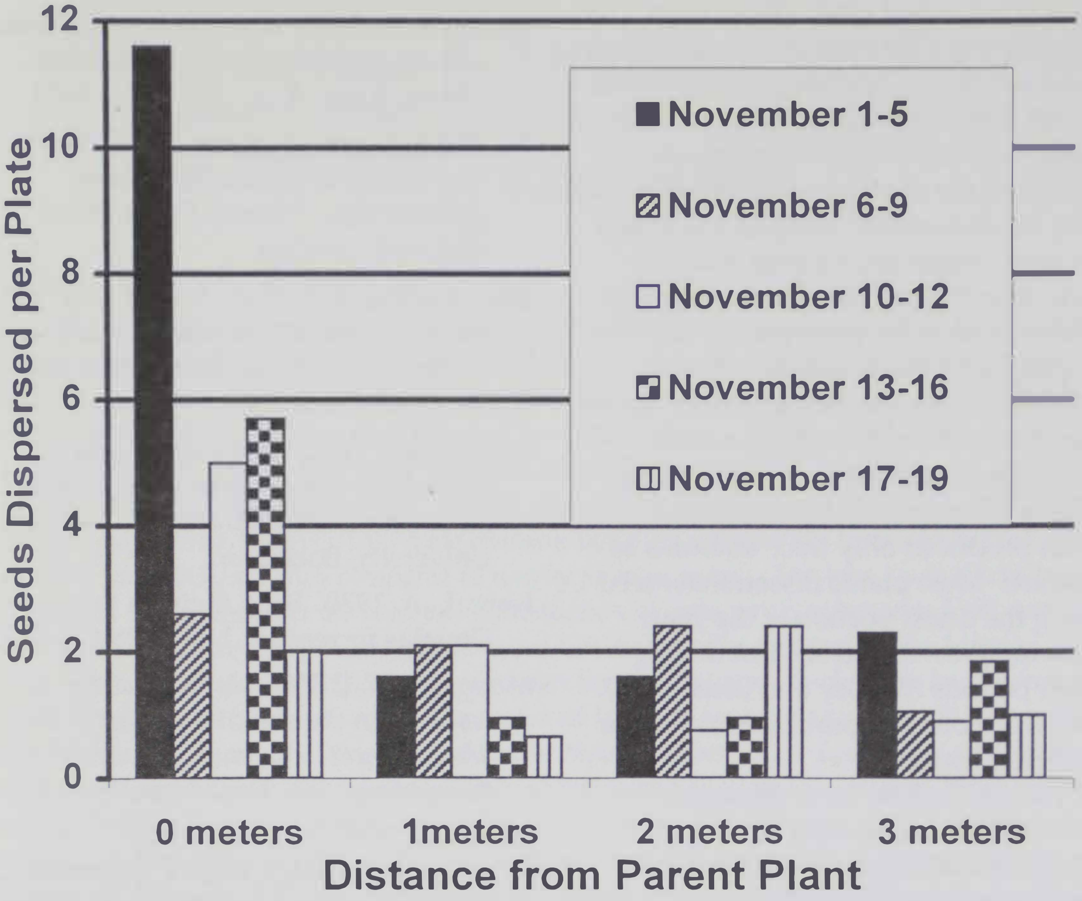


Figure 2. *Seed dispersal patterns measured for plains silver sagebrush in five intervals during the November 1 - 19 dissemination period. These data are means from a total of 15 plants at three sites (five plants per site). The seed counts were taken from 930 cm² sampling grids on each plate. Because almost no seeds were counted at the 4 m distance, these numbers are not included.*

sampling date. The method was relatively simple, but it enabled us to sample in a highly intensive manner. In addition, the shiny surface of the aluminum was readily detected, but not bothered by either livestock or wildlife.

Petroleum jelly was very effective in catching and holding seeds and offered several advantages as an adhesive. It is relatively inexpensive, yet it can be recovered and recycled if necessary. It is also easily applied and removed from the surface of the aluminum sheet metal. We placed solidified petroleum jelly in a clean metal can and heated it until it melted in the field over a portable camp stove. The melted petroleum jelly was then applied in a thin layer with a paint brush or roller. The most efficient application technique depended upon ambient temperature. If air temperatures were below 10 C, the roller was most efficient; at higher temperatures, the brush was more effective. Application by hand smearing was too slow and generally resulted in a thicker layer of adhesive than necessary.

Petroleum jelly also had an advantage over many adhesives because it could be used over a wide range of ambient temperatures. We used it successfully in late fall at temperatures that ranged from -18 to 25 C. Colder temperatures would probably present no difficulties. However, higher temperatures combined with direct solar radiation might melt the petroleum jelly on the sheet-metal plate. This could spread it into a very thin layer that would not be sticky enough to catch and hold all seeds. Precipitation caused no problems to seeds that were already adhered to the aluminum sheets, but water beads formed on top of the sheets that then caught and carried away newly fallen seed. An absorbent border of cloth around the perimeter of the sampling grid might alleviate these problems during extended rainfall. Our close observations found the problem was insignificant during our sampling because the infrequent precipitation events produced only trace amounts of moisture. Most plants disseminate seed during the driest portion of the year, following growth and seedset during wetter periods (Bewley and Black 1985). Thus, this potential problem should not occur frequently.

The method we have presented should prove useful for a variety of ecological and management oriented investigations that would be strengthened with knowledge of seed dissemination. Modification of our methodology may be necessary with different species or circumstances, but the general procedure should prove successful for measuring wind-disseminated seed.

LITERATURE CITED

Beetle, A. A. 1960. A study of sagebrush — Section Tridentatae of *Artemisia*. Wyom. Agric. Exp. Sta. Bull. 368.

Bewley, J.D. and M. Black. 1985. Seeds: Physiology of development and germination. Plenum Press. New York and London.

Daubenmire, R. F. 1967. Plants and environment, a textbook of plant autecology. 2nd ed. John Wiley and Sons, Inc., New York.

Harvey, S. J. 1981. Life history and reproductive strategies in *Artemisia*. M. S. Thesis. Montana State University, Bozeman.

Isacc, L. A. 1930. Seed flight in the Douglas fir region. J. For. 28:492-499.

Mueggler, W. F. 1956. Is sagebrush residual in the soil of burns or is it wind borne? Intermtn. For. and Range Exp. Sta. Res. Note 35.

Reed, C.F. 1977. Economically important foreign weeds: potential problems in the United States. USDA Agr. Handbook No. 498.

Siggins, H. W. 1933. Distribution and rate of fall of conifer seeds. J. Agric. Res. 47:119-128.

Sindelar, B. W. 1968. An investigation of the competitive ability of *Sitanion hystrix*. M. S. Thesis. University of Idaho, Moscow.

Wambolt, C. L., T. P. Walton, and R. S. White. 1989. Seed dispersal characteristics of plains silver sagebrush. Prairie Nat. 21:113-118.

J. Kirwin Werner
Truman Plummer
Joe Weaselhead

AMPHIBIANS AND REPTILES OF THE FLATHEAD INDIAN RESERVATION

ABSTRACT

Amphibians and reptiles on the Flathead Indian Reservation in western Montana were surveyed at 203 sites between 1993 and 1997. Each survey took 30 min to 2 hr and consisted of a thorough search of the wetland perimeter and netting of near-shore aquatic habitats for larvae and tadpoles. Some streams were sampled by electrofishing. We found 14 of the 18 species of amphibians and reptiles that most likely occur on the reservation. The long-toed salamander (Ambystoma macrodactylum), *Pacific chorus frog* (Pseudacris regilla), *and Columbia spotted frog* (Rana luteiventris) *were common but their populations were diminished in open areas of the Mission Valley compared to nearby forested areas. Western toads* (Bufo boreas) *were seen at 19 sites, but we observed reproduction at only six sites between 1993 and 1995. The northern leopard frog* (Rana pipiens), *which historically occurred in the Mission Valley, was not found anywhere despite extensive searches, including a search of six known historical sites. Tailed frogs* (Ascaphus truei) *were found in seven mountain streams. Bullfrogs* (Rana catesbeiana), *apparently introduced at two or three locations in the Lower Flathead River area in the 1970s, were reproducing successfully at two localities along the Flathead River and along approximately 14 km of Camas Creek. The painted turtle* (Chrysemys picta), *common garter snake* (Thamnophis sirtalis) *and western garter snake* (Thamnophis elegans) *were found in all regions surveyed. The western rattlesnake* (Crotalis viridis), *bullsnake* (Pituophis catenifer), *racer* (Coluber constrictor), *rubber boa* (Charina bottae), *and northern alligator lizard* (Elgaria coerulea) *were seen occasionally.*

Key Words: amphibian, decline, Montana, reptile, survey.

INTRODUCTION

Increasing concern about diminishing amphibian populations worldwide has prompted many state and federal agencies to inventory local species. On the Flathead Indian Reservation in western Montana, concern has been growing about apparent declines in populations of northern leopard frogs and western toads. In the spring of 1993, the Confederated Salish and Kootenai Tribal (CSKT) Wildlife Division requested a long-term survey of amphibian and reptile species present on the reservation. Previous sightings of some species within reservation boundaries were reported by Brunson and Demaree, (1951), Franz and Lee (1970), Franz (1971), and Miller (1975), but this represented the first comprehensive survey.

METHODS AND MATERIALS

For purposes of sampling, the reservation was divided into six geographic regions (Fig. 1): 1) Little

J. Kirwin Werner, Department of Environmental Sciences, Salish Kootenai College, Pablo, MT 59855.
Truman Plummer, Department of Environmental Sciences, Salish Kootenai College, Pablo, MT 59855.
Joe Weaselhead, Department of Environmental Sciences, Salish Kootenai College, Pablo, MT 59855.

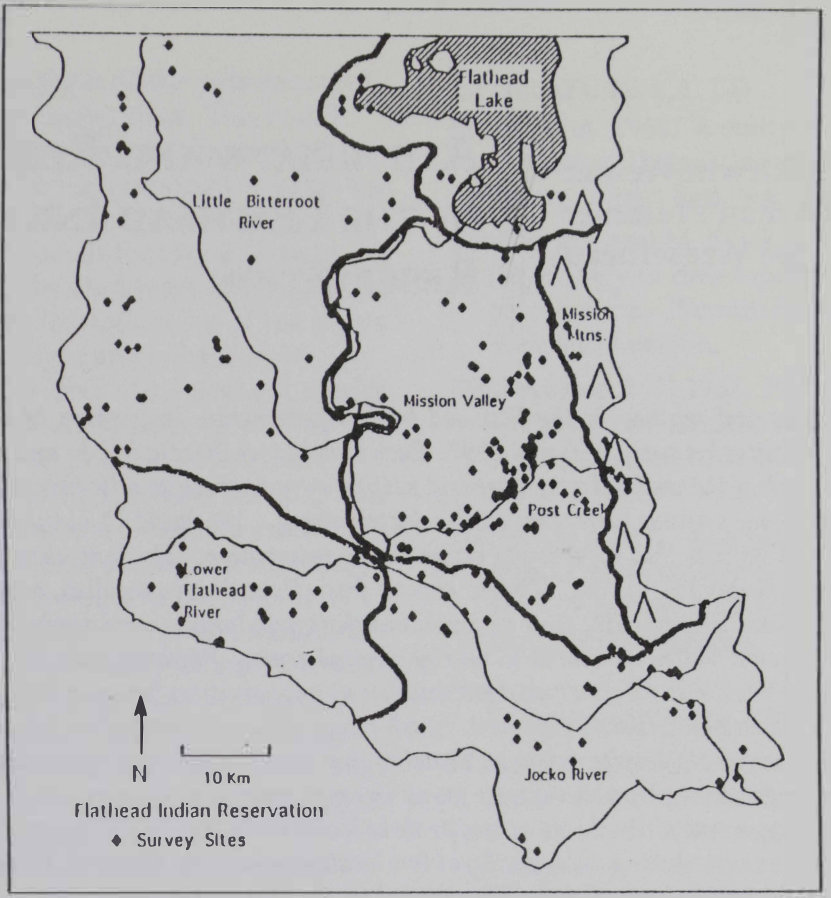


Figure 1. *Geographic regions and survey sites on the Flathead Reservation 1993-1997.*

Bitterroot River drainage in the northwest part of the reservation; 2) Flathead Lake region, which included areas within approximately 8 km of the lake shoreline; 3) Mission Valley, including the Kicking Horse and Ninepipes Tribal and National Wildlife Refuges, parts of the National Bison Range and several state wildlife management units; 4) Mission Mountains, above 1370 m elevation; 5) Jocko River drainage, in the southeastern part of the reservation; and 6) Lower Flathead River, from the confluence of the Jocko River to the western edge of the reservation, including the Camas Creek drainage. We sampled all areas to some extent but spent more time in the Mission Valley because of the extensive ponds and associated wetlands found there. We spent less time in the Mission Mountains, because of inaccessibility and time limits.

Extensive surveys were conducted during the spring and summers of 1993 and 1994. Resurvey of previous sites and a limited number of new surveys were conducted from 1995 to 1997.

Surveys were conducted by a team of 2 to 5 individuals. Each survey, 30 min to 2 hr in length, consisted of searches along the shoreline of a pond or wetland, and included overturning rocks and logs, dipnetting for tadpoles and larvae, and scanning the area with field glasses. Minnow traps and night (audio) surveys were used on an irregular basis. Canoes were used to access riparian habitats not available on foot including larger lakes, reservoirs and the Flathead River. In the summer of 1994, electrofishing was used in mountain streams to assess the status of the tailed frog. A section of stream 10 to 100 m in length was shocked, using a frequency of 120 cps and 200-250 volt output. As soon as tadpoles or adults were found, electrofishing stopped. This often occurred in the first 10 m of the stream. If no individuals were found in a 100 m stretch of stream, the stream was sampled at some other point, or not sampled again.

In each survey, we attempted to capture all individuals seen, which were then identified, measured for body and total lengths, sexed if possible, and released. Water temperature, pH, and a general description of the area were recorded. Casual observations and records of roadkills were made by the authors and tribal Fish and Wildlife personnel. Causal observations provided data on the species, date, time, and location.

We estimated egg numbers for some amphibian species via direct counts or volumetric displacement (Corn and Livo 1989).

We made 289 surveys and casual observations, which included 266 time-constrained surveys, four roadkills, eight night-time audio surveys, and 11 reliable observations from other wildlife personnel. The 266 surveys encompassed 203 sites (Fig. 1) (Appendix A). Multiple surveys were made at 46 of the sites.

Ninety-three sites were in the Mission Valley that included 35 pothole ponds around Ninepipes and Kicking Horse Reservoirs and ponds and wetlands on the National Bison Range. In the Little Bitterroot River drainage, 25 sites were surveyed that included three in the Mill Pocket Tribal Primitive area. Seventeen sites were surveyed around Flathead Lake, three of them along the lake shore, the others in nearby wetlands, ponds or lakes including one at the King's Point Nature Conservancy Area. Twenty-eight sites were surveyed in the Jocko River drainage that included four in the Jocko Tribal Primitive Area. The Lower Flathead River accounted for 30 sites, one of which encompassed the 1992 Conoco Oil Company oil spill on Camas Creek. Ten sites were surveyed in the Mission Mountains including two at Mollman Lakes, just east of the reservation boundary.

RESULTS

Amphibian and/or reptile species were found at 146 (72%) of the 203 surveyed sites in the six study areas (Figs. 2-5, Appendix A). The species included 1 salamander, 4 frogs, 1 toad, 1 turtle, 1 lizard, and 4 snakes. Records of collections and observations are summarized species-by-species in the text that follows.

Species Collected or Observed

Long-toed salamander. — Individuals were found throughout the reservation, from elevations of 804 m in ponds near Perma on Hwy 200 to 2,092 m in ponds near Mollman Lake in the Mission Mountains (Fig. 2a). Long-toed salamanders *(Ambystoma macrodactylum)* occurred commonly with the spotted frog (*Rana luteiventris)* in ponds, lakes or backwaters of streams but sometimes were the only amphibian present. Individuals were absent from the numerous ponds in and around the Ninepipes and Kicking Horse Wildlife areas but were found in forested habitat just east of the refuges and in ponds at the picnic area of the National Bison Range. The earliest observation of egg masses was 7 April 1995 at the Mollman Creek South Ponds. Egg masses varied from 1 to 72 eggs/mass (x = 28; n = 18). Body lengths of three adults were 45, 49 and 65 mm.

Pacific chorus frog. — Most chorus frogs *(Pseudacris regilla)* were found on the western side of the reservation along the Lower Flathead River and in the Little Bitterroot drainage (Fig, 2c). Breeding populations were encountered infrequently in the Mission Valley and along the base of the Mission Mountains. In the 1993-94 surveys, we observed individuals or heard calling at 29 sites between 3 May and 5 June. The highest elevation site was 1,222 m on

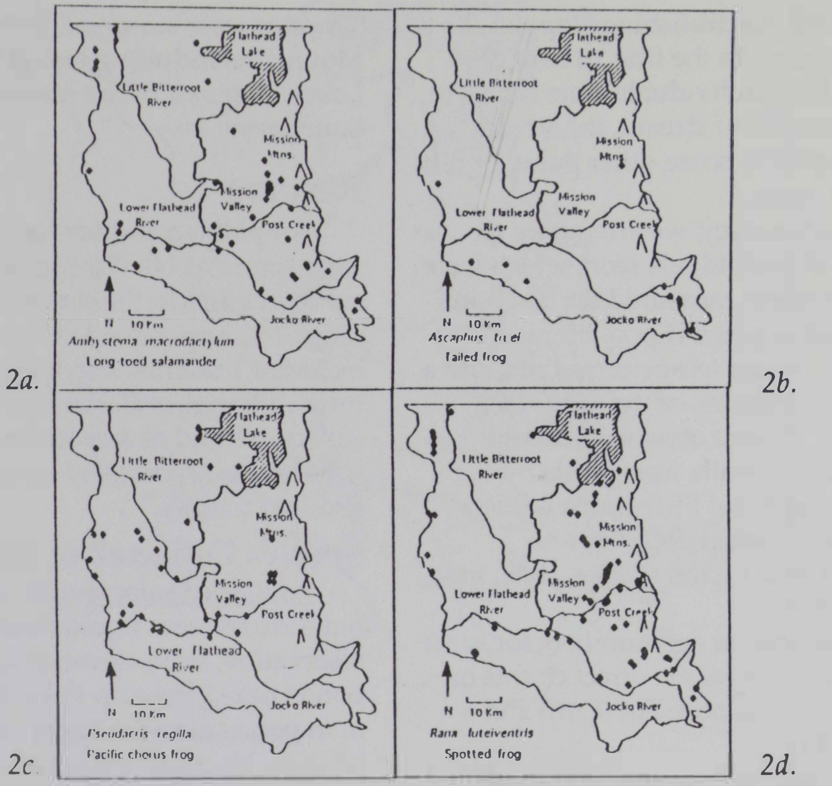


Figure 2. *Distribution of amphibians on the Flathead Reservation, through 1997.*

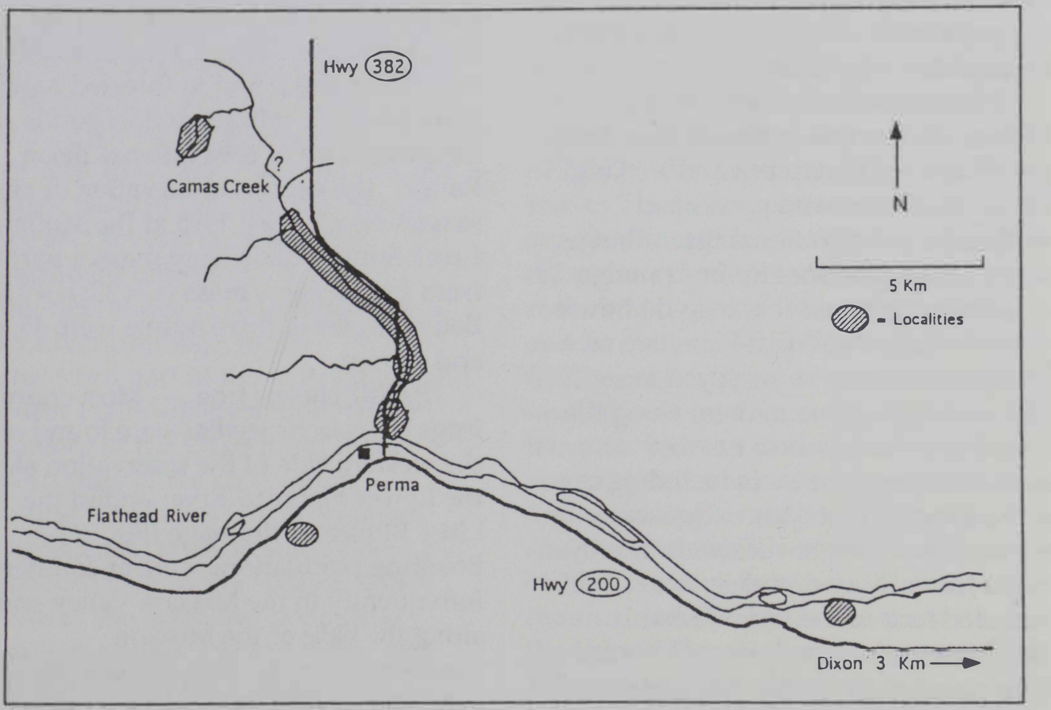


Figure 3. *Distribution of* Rana catesbeiana *(bullfrog) on the Flathead Reservation through 1997.*

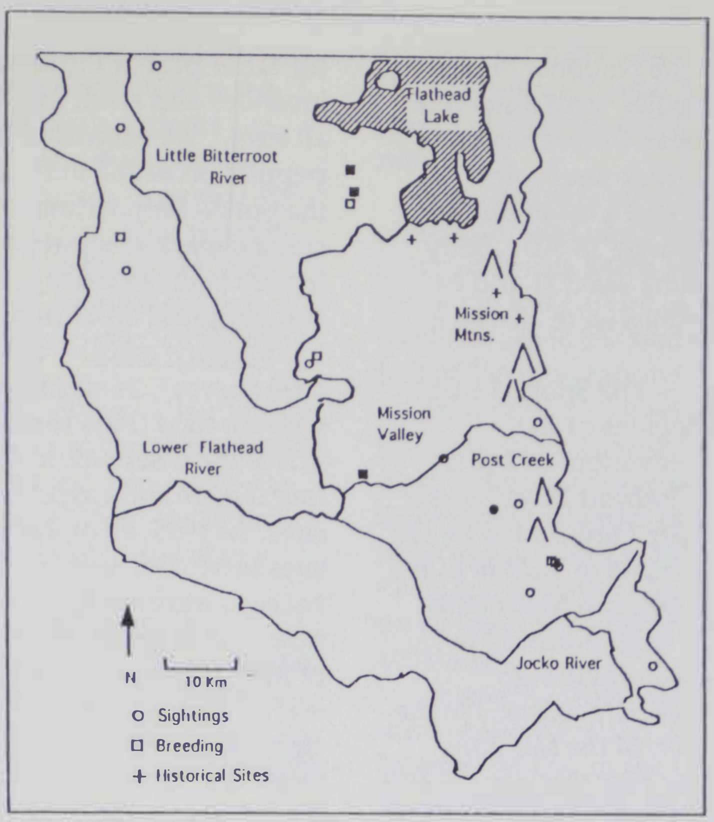


Figure 4. *Distribution of* Bufo boreas *(western toad) on the Flathead Reservation through 1997.*

5a.

5b.

5c.

5d.

Figure 5. *Distribution of reptiles on the Flathead Reservaton, through 1997.*

Triskey Creek on the National Bison Range, where tadpoles were observed. Many breeding areas were temporary ponds, including stock reservoirs. Seven egg masses had a mean number of 35 eggs/mass (range 18-52). Body lengths of two adults were 31 and 49 mm and two juveniles were 20 mm each.

Spotted frog. — The Spotted frog was found in all regions of the reservation from elevations of 762 m along the Lower Flathead River to over 2,072 m at the upper Three Lakes on the Reservation Divide and at 1878 m in the Frog Lakes of the Mission Mountains (Fig. 2d). Spotted frogs occurred in most wetland habitats although numbers were markedly reduced in the open pothole region of the Mission Valley. The earliest date that egg masses were found was 27 Mar 1994 at the State Fish Hatchery in Arlee. Breeding sites generally contained 3-15 egg masses but an exception was Pistol Creek Marsh where approximately 70 egg masses were observed in 1994 (>62,000 eggs). An average of 824 eggs per mass was determined (range 204-1319; n = 21). We observed some egg mortality in 1994 that resulted from pond waters receding before tadpoles had hatched. The average body length of 54 adults was 65 mm (range 50-90 mm); the average body length of 21 juveniles was 40 mm (range 30-55 mm).

Bullfrog. — The currently known range of the bullfrog *(Rana catesbeiana)* consists of two disjunct sites on the lower Flathead River and scattered sites along Camas Creek (Fig. 3). The two sites on the Flathead River were separated by 19 km of river in which no bullfrogs were found. Along Camas Creek, bullfrogs were present intermittently from the mouth of the creek to 14 km upstream, where they may have been introduced. There were small stretches of 50-400 m along the creek where they were not found because the stream had dried up during the latter part of the summer. Tadpoles, juveniles and adult frogs were found at all sites. We estimated a tadpole population of 287 individuals for one of the ponds (approximately 8 x 8 m) using a mark-recapture procedure. A freshly laid egg mass was found in another pond on 11 July.

Western toad. — During the 1993-1994 surveys, 16 sightings of the western toad (*Bufo boreas)* were made across the reservation (Fig. 4). We found eggs and tadpoles at six of these sites. In 1995, all of the previous known sites were resurveyed. Additional surveys were made in nearby areas. We observed tadpoles and/or eggs at three of the resurveyed sites and at one new site. Two other individual toads were sighted in 1996-97 for a total of 19 observations throughout the 4 yr study. Ten adults averaged 88 mm in body length (range 60-110 mm).

Western Painted turtle. — Painted turtles (*Chrysemys picta)* were present in most lowland aquatic habitats below 1,067 m (Fig. 5a). Densities were particularly high in ponds in and around the Ninepipes and Kicking Horse Wildlife Refuges and may have resulted from efforts to increase waterfowl production by eliminating egg predation from skunks, raccoons, and weasels. These are the same ponds where spotted frogs and long-toed salamanders were absent. Egg laying was observed 9 June 1993 at the Pablo Reservoir. The carapace length of four adults averaged 173 mm (range 150-200 mm).

Common Garter snake. — The common garter snake *(Thamnophis sirtalis)* occurred in all regions of the reservation between elevations of 766 and 1,268 m (Fig. 5c). Two color variants were observed; one with a red-spotted, bright yellow stripe (28 of 48 specimens) and a second with more dull yellow stripes and few or no red spots (20 of 48 specimens). Both variants occurred together, as well as with the western garter snake. We could find no geographical correlation between the two color variants. Both variants are described by Rossman *et al.*, (1996). Body lengths of 16 adults averaged 463 mm (range 290-680 mm), total lengths averaged 577 mm (range 320-810 mm). Young were seen in August, but, we have no other information concerning reproduction.

Western Garter snake – Distribution of the western garter snake *(Thamnophis elegans)* overlapped the common garter snake in all regions of the reservation, but, was the only snake found above 1,524 m (Fig. 5c). The highest occurrence was at 1,878 m, Frog Lake in the Mission Mountains. There was one western garter snake sighting for every three common garter snakes. Body lengths of seven individuals varied from 305-580 mm, (x = 401 mm). Total lengths averaged 533 mm (range 410-720 mm).

Species Observed Infrequently

We found tailed frogs (*Ascaphus truei)* in three streams from the Mission mountains on the east, three streams from the Reservation Divide on the south and one stream from the Salish mountains on the western edge of the Reservation (Fig. 2b). Tadpoles were encountered in all streams and juveniles and adults were found occasionally. Body lengths of two adults were 36 and 45 mm.

One alligator lizard *(Elgaria coerulea)* was observed in 1993 in the North Crow Canyon of the Mission Mountains at 1372 m (Fig. 5b). A second sighting was made in 1997 along McDonald Lake (1128 m) also in the Mission Mountains. Both sites were on south-facing talus slopes.

Rubber boas *(Charina bottae)* were seen primarily along small streams in ponderosa pine forests. The four localities, North Crow Canyon, Mill Pocket Tribal Primitive Area, Magpie and Seepay Creek drainages, are on the forested eastern, western and southern edges of the reservation (Fig. 5b). The single adult measured had a body length of 490 mm and total length of 560 mm.

One juvenile racer *(Coluber constrictor)* was observed along Hwy 382 north of Perma and a second individual along the Ronan-Hot Springs road. Both localities are in the more arid, western half of the reservation (Fig 5d).

Roadkills in the western half of the reservation accounted for two of the three bullsnake observations (Fig. 5d). Bullsnakes *(Pituophis catenifer)* also were observed at Hillside Reservoir east of the Flathead River. Total lengths of four bullsnakes averaged 880 mm (range 770-1028 mm).

Western rattlesnakes *(Crotalis viridis)* were observed in the western half of the Mission Valley, in the Little Bitterroot drainage and along the lower Flathead River (Fig. 5d). Three individuals were found in open sagebrush country and two sightings were in ponderosa pine forests. Total lengths of three rattlesnakes averaged 714 mm (range 530-1012 mm).

Species Potentially Present on The Reservation

Tiger salamander. — One historical sighting of the tiger salamander (*Ambystoma tigrinum*) was made on the reservation near Ravalli in the late 19th century (Test 1891). Efforts to locate individuals near the historical site were unsuccessful, nor were they found elsewhere. The Ravalli specimens, which are in the National Museum of Natural History, Washington D. C., were re-examined by Dr. R. P. Reynolds in March 1998, and identified as long-toed salamanders based on gill-raker count.

Coeur d'Alene salamander. — The nearest location for the Coeur d'Alene salamander *(Plethodon idahoensis)* is Cascade Creek, 9.7 km west of the reservation (Teberg 1965.) Suitable habitat (springs, seeps) are present in nearby Seepay Creek drainage, but efforts to locate the species were unsuccessful.

Leopard frog. — No leopard frogs *(Rana pipiens)* were seen at any of the 203 survey sites including surveys of eight known historical sites. Populations may exist in areas not covered by our surveys, but it probably should be considered as extirpated from the reservation.

Western skink. — Reports were received of the western skink *(Eumeces skiltonianus)* on the lower Flathead River, and near Evaro within reservation boundaries, but, we have no confirmed records. Western skinks have been reported in the Bitterroot Valley (Rodgers and Jellison 1942) and in the Kootenai National Forest (Werner and Reichel 1994).

DISCUSSION

The probable decline of the northern leopard frog follows a pattern observed in Colorado (Corn and Fogelman 1984), Washington (Leonard and McAllister 1996), and other parts of the country (Hine *et al.* 1981). In western Montana, surveys done for the Montana Natural Heritage Program in the Bitterroot (Hendricks and Reichel 1996) and the Kootenai (Werner and Reichel 1994, 1995) National Forests found only one population in the Fortine District near Eureka. Additional surveys by the authors and others in the Flathead National Forest and surrounding areas, including surveys of over 20 historical sites, revealed one additional population near Kalispell. Although some populations probably were missed in our surveys, we conclude that a major decline of the Northern leopard frog has occurred in western Montana, including the Flathead Reservation.

The western toad recently has been of special concern to biologists because of dwindling populations throughout the west (Blaustein and Olson 1991, Carey 1993, Corn *et al.* 1997). Additional concern arose when Blaustein *et al.* (1994a) showed that the eggs of the western toad were especially sensitive to UV-B radiation and may suffer damage as a result of ozone destruction in the stratosphere. In experiments similar to those of Blaustein et al. (1994a), Corn (1998) was unable to find UV-B effects on the western toad in Colorado. Apparently a worldwide pathogenic fungus (*Saprolegnia*) is also contributing to western toad declines in Oregon (Blaustein *et al.* 1994b).

Brunson (1952) regarded the western toad as one of the most common anurans in western Montana. Black (1970) supported its common occurrence not only in the west, but also in many counties east of the continental divide. From historical records and the 1993-95 surveys, 22 sightings and/or breeding sites are known on the reservation (Fig. 4). Two of the historical sites were on Flathead Lake where no toads were seen in the present surveys.

Surveys in the Kootenai National Forest (Werner and Reichel 1994, 1995) indicated 15 breeding sites throughout the forest although large tracts of the forest were not surveyed. Reichel (1995) found only one breeding site in surveys of the Lewis and Clark National Forest. Three of 16 western toad sightings in the Bitterroot National Forest (Hendricks and Reichel 1996) were indicated as reproductive (eggs and tadpoles) and Marnell (1997) listed 14 documented breeding sites in Glacier National Park. Given the area encompassed in the above references and the comments by Brunson (1952) and Black (1970), the data suggest a population reduction. However, without a larger historical database, it is difficult to ascertain whether the numbers are a low point in a long term population fluctuation or an anthropogenic related decline.

The bullfrog has been widely introduced throughout the western United States from its native habitat in eastern North America. It has been implicated as displacing other species in California (Kupferberg 1994, 1997), Iowa (Lannoo *et al.* 1994) and Ontario (Hecnar and M'Closkey 1997) because of its aggressive feeding and territorial behavior. Bullfrogs apparently were introduced into the Bitterroot Valley of western Montana by unknown sources in the 1920s (Black 1970). Based on conversations with local residents, we believe that introductions on the Flathead Reservation occurred at two and perhaps three sites in the 1970's. The geographical source(s) of the introduced populations is unknown. Populations along Camas creek appear to be the result of a range expansion, individuals moving downstream from a release site.

It is speculative whether bullfrogs are displacing native species on the reservation. Pacific chorus frogs were heard calling from two sites simultaneously with bullfrogs but whether the chorus frogs successfully reproduced is unknown, because no thorough searches were done for tadpoles at later dates. There were no spotted frogs observed at any of the bullfrog sites although spotted frogs were found in nearby areas.

Although the reservation was divided into six geographic regions for survey purposes, differences in amphibian/reptile distribution corresponded somewhat to three north-south zones. The three zones are delineated by elevation and rainfall. An eastern zone, formed by the higher elevations of the Mission Mountains, supported four species, long-toed salamander, spotted frog, western toad, and western garter snake. A central zone consisting of the Flathead Lake region, the Mission Valley and Jocko River drainage, contained all 14 species, dominated by the long-toed salamander, spotted frog, painted turtle, common garter snake and western garter snake. A more arid western zone, which inluded the Little Bitterroot drainage and lower Flathead River, had the same number and dominate species as the central zone, but supported larger populations of three snake species (racer, bullsnake, western rattlesnake) and had a higher incidence of the Pacific chorus frog.

Conclusions

Based on a literature review, personnel observations, and general field guides, nine amphibian and nine reptile species were considered possible inhabitants of the Flathead Reservation. This survey found six amphibian species and eight reptile species.

Although most amphibian species appeared to be successfully reproducing in suitable habitats, evidence suggests that the northern leopard frog has been extirpated from most, if not all, of its historical range and that populations of the western toad are at low levels. Populations of the spotted frog, long-toed salamander and Pacific chorus frog were diminished in open agricultural lands and in wildlife refuges of the Mission Valley in comparison to nearby forested areas.

The single historical record of the tiger salamander on the reservation was apparently a misidentification and there were no other sightings of the tiger salamander during these surveys. Two other species, the Coeur d'Alene salamander and western skink, which do not have historical records on the reservation, may be present, but have not been found to date.

Among reptiles, the painted turtle, common and western garter snakes were frequently encountered, but, the status of their populations is unknown due to a lack of current and historical data. Five other reptile species were seen occasionally.

Acknowledgments

Funding for this study was provided by the Confederated Salish and Kootenai (CS&K) Tribal Wildlife

Division, Salish Kootenai College (SKC), the American Indian Research Opportunities Program (AIRO), Montana State University, Bozeman, and the Minorities in Science Program, U. S. Department of Energy, Los Alamos, NM. The authors wish to thank Brian Lipscomb, Dale Becker, Joe DeSantos, and Les Everts of the CS&K Tribal Wildlife Division and Joe McDonald, Gerry Slater, Lois Slater and Pat Hurley of SKC for their encouragement and support. Thanks are also extended to Marci Bishop of the National Bison Range, Moiese, and to the following SKC students who participated in the study: Althea Liberty, Carlos Matthews, Stephanie Traham, Guy Gies, Mike McCrea and Dusti Shoop.

LITERATURE CITED

Black, J. 1970. Amphibians of Montana. Montana Wildlife Jan, 1970. 32 pp.

Blaustein, A. R., P. D. Hoffman, D. G. Hokit, J. M. Kiresecker, S. C. Walls, and J. B. Hays. 1994a. UV repair and resistance to solar UV-B in amphibian eggs: A link to population declines? Proc. Natl. Acad. Sci. 91:1791-1795.

Blaustein, A. R., D. G. Hokit, R. K. O'Hara, and R. A. Holt. 1994b. Pathogenic fungus contributes to amphibian losses in the Pacific northwest. Biol. Conserv. 67:251-254.

Blaustein, A. R. and D. H. Olson. 1991. Declining Amphibians. Science 253:1467.

Brunson, R. B. 1952. Recent collections of *Bufo boreas boreas* from western Montana. Proceedings of the Montana Academy of Sciences 11:17-19.

Brunson, R. B., and H. A. Demaree. 1951. The herpetology of the Mission Mountains, Montana. Copeia 1951:306-308.

Carey, C. 1993. Hypothesis concerning the causes of the disappearance of boreal toads from the mountains of Colorado. Conserv. Biol. 7(2):355-362.

Corn, P. S. 1998. Effects of ultraviolet radiation on boreal toads in Colorado. Ecological Applications 8(1):18-26.

Corn, P. S., and J. C. Fogleman. 1984. Extinction of montane populations of the northern leopard frog (*Rana pipiens*) in Colorado. Journal of Herpetology 18:147-152.

Corn, P. S., M L. Jennings, and E. Muths. 1997. Survey and assessment of amphibian populations in Rocky Mountain National Park. Northwestern Naturalist 78:34-55.

Corn, P. S., and L. J. Livo. 1989. Leopard frog and wood frog reproduction in Colorado and Wyoming. Northwestern Naturalist 70:1-9.

Franz, R. 1971. Notes on the distribution and ecology of the herpetofauna of northwestern Montana. Bull. Maryland Herp. Soc. 7:1-10.

Franz, R. and D. S. Lee. 1970. The ecological and biogeographical distribution of the tailed frog, *Ascaphus truei*, in the Flathead River drainage of northwestern Montana. Bull. Maryland Herp. Soc. 6: 62-73.

Hecnar, S. J. and R. T. M'Closkey. 1997. Changes in the composition of a ranid frog community following bullfrog extinction. Am. Midl. Nat. 137:145-150.

Hendricks, P. and J. Reichel. 1996. Amphibian and reptile survey of the Bitterroot National Forest 1996. Montana Natural Heritage Program. Helena, MT. 95 pp.

Hine, R. L., B. L. Les, and B. F. Hellmich. 1981. Leopard frog populations and mortality in Wisconsin. Tech. Bull.

No. 122, Dept. of Nat. Resources, Madison Wisconsin. 39 pp.

Kupferberg, S. J. 1994. Exotic larval bullfrogs (*Rana catesbeiana*) as prey for native garter snakes: Functional and conservation implications. Herp. Rev. 25(3):95-96.

Kupferberg, S. J. 1997. Bullfrog (*Rana catesbeiana*) invasion of a California river: the role of larval competition. Ecology 78(6):1736-1751.

Lannoo, M. J., K. Lang, T. Waltz, and G. S. Phillips. 1994. An altered amphibian assemblage: Dickinson County, Iowa, 70 years after Frank Blanchard's Survey. Am. Midl. Nat. 131:311-319.

Leonard, W. P. and K. R. McAllister. 1996. Past distribution and current status of the northern leopard frog (*Rana pipiens*) in Washington. Wash. Dept. of Fish and Wildlife Report, February 1996. 17 pp.

Marnell, L. 1997. Herpetofauna of Glacier National Park. Northwestern Naturalist 78:17-33.

Miller, J. D. 1975. Interspecific food relationships of Anurans in northwestern Montana and fluoride accumulation in amphibians and reptiles in northwestern Montana. M. S. Thesis, University of Montana, Missoula, Montana 105 pp.

Reichel, J. D. 1995. Preliminary amphibian and reptile survey of the Lewis and Clark National Forest: 1994. Montana Natural Heritage Program. Helena, Montana 59620-1800. 60 pp.

Rodgers, T. L. and W. L. Jellison. A collection of amphibians and reptiles from western Montana. Copeia 1942(1):10-13.

Rossman, D. A., N. B. Ford, and R. A. Seigel. 1996. The garter snakes. Evolution and Ecology. Univeristy of Oklahoma Press, Norman OK. pp. 259-264.

Test, F. C. 1891. Fish-cultural investigations in Montana and Wyoming. Annotated list of Reptiles and Batrachians collected. Bull. U.S. Fish Commission for 1891: 57-59.

Teberg, E. K. 1965. Range extensions of the salamander *Plethodon vandykei idahoensis*. Copeia 1965:244.

Werner, J. K., and J. D. Reichel. 1994. Amphibian and Reptile survey of the Kootenai National Forest 1994. Montana Natural Heritage Program, Helena, MT 104 pp.

Werner, J. K. and J. D. Reichel. 1995. Amphibian and Reptile monitoring/ survey of the Kootenai National Forest: 1995. Montana Natural Heritage Program. Helena, MT 115 pp.

Appendix A. Summary of amphibian/reptile surveys and observations on the Flathead Indian Reservation 1993-1997. Data are arranged by geographic region.[1]

Survey/	Geographic Region	UTM Zone 11		Elev.	Species
Other[2]	Locality	East.	North.	(m)	Year,Reprod.[3]
Little Bitterroot River					
S	Dry Fork Creek, 1.3 km W of D. Fk. Res.	671774	5291552	927	NSF 94
S	Dry Fork Reservoir	674172	5285967	966	BUBO 93R, 95; THSI 93
S	Flathead R. backwater 1 km N. Sl. Bri.	701716	5263432	783	CHPI 94
L	Garceau Gulch Rd, 14.5 km E. of Hwy 28	689330	5286071	1167	COCO 94
S	Garden Cr. Rd., 3.2 km W Hwy 28.	674904	5280860	866	BUBO 93
S	Garden Cr. by Morigeau Rd	674172	5280189	866	RALU 93
S	Garden Cr. Trib. 6.4 km W. of Hwy 28	672112	5280715	975	RALU 94
S	Hot Springs Cr. 1.6 km W. of Hot Spr.	673376	5275376	974	PSRE 94R
A	Hot Springs by H.S. Athletic Field	675584	5274980	861	PSRE 93R
S	Hwy 28, 4.8 km NE of Toolman Slough	675743	5268465	1009	PICA 94
S	Little Bitter. R. at Lozeau Flats Cmpgrd	673885	5304497	957	RALU 93, 94, 95R THSI 93; THEL 95
S	Little Bitterroot R. below Lozeau Canyon	674154	5299434	876	RALU 95
S	Little Bitterroot R. Lozeau Canyon Site	674094	5302279	902	AMMA 93R, 94R, 95R RALU 93R, 94, 95R BUBO 94 THSI 93, 95; THEL 93, 94
S	Little Bitterroot R. on Far West Rd.	675197	5294032	850	CHPI 93
S	Lit. Bitter. R, 1 km below Lit. Med. Cr.	673586	5305972	939	AMMA 93R; RALU 93 THSI 93
S	Lit. Meadows Cr. 2 km NW of Flat. Mine	679254	5312356	1202	BUBO 93; AMMA 95R RALU 93, 95
S	Mill Creek where crosses irrigation ditch	673563	5300007	890	AMMA 93R; CHBO 93 THEL 93
S	Mill Creek 0.8 km above Little Bitter. R.	673278	5299501	908	NSF 94
S	Oliver Point area N. of Oliver Point	696353	5273611	1341	NSF 94
S	Ronan-Hot Springs Rd. J. Malinak Res.	690476	5270071	829	PSRE 93R, 95R
A	Ronan-Hot Spr. Rd, 7 km W. Sloan Br.	695641	5261145	838	PSRE 93R
A	Ronan-Hot Spr. Rd, 15 km W. Sloan Br.	691630	5264267	849	PSRE 93R
A	Ronan-Hot Spr. Rd, 7 km E. Hwy 28	685005	5275889	832	PSRE 93R
A	Ronan-Hot Spr. Rd, 10 km E. Hwy 28	686447	5273490	827	PSRE 93R
L	Ronan-Hot Spr. Rd, 9 km E. Hwy 28	685201	5274906	838	CRVI 93
R	Ronan-Hot Spr. Rd., 11 km E. Hwy 28	685913	5273600	832	PICA 93
S	Schmitz Lakes, 1.6 km E of Hwy 382	681736	5269707	974	NSF 93, 94
R	Skunk Alley Rd., 0.5 km W. of Hot Spr.	674545	5274763	887	THEL 93
S	Sull. Cr., 3.4 km S of Nirada	689501	5295680	868	NSF 93
S	Sull. Cr., 8 km N of Hwy 28, B. M. Rd.	683905	5307282	978	NSF 93
S	Upper Dry Fork Reservoir, South side	673482	5290704	892	THEL 93
S	Valley Creek 12.8 km WSW of Hwy 93	709544	5227580	1061	NSF 93
S	W. Flat. Mine Rd, Springs W. of road	679644	5309186	1073	AMMA 94R
Flathead Lake Drainage					
S	Black Lake	700252	5304456	988	CHPI 93, 95
S	Dayton Cr. at Black Creek Road	702253	5304834	899	RALU 93, 94, 95R PSRE 93R
S	Finley Point Rd, Pond 0.8 km SE of Rd	721388	5289678	888	RALU 93; CHPI 93
S	Flathead Lake by old Hwy 93 at Dayton	703496	5304509	882	NSF 93
S	Flathead Lk., S. Shore on Ducharme Ln.	719936	5286191	882	RALU 93R
S	Hellroaring Reservoir - outlet	726637	5293962	1097	RALU 95
S	Jette Lake	706191	5293074	1093	BUBO 95R; CHPI 94, 95
S	Jette Mead. Pnd, 3.2 km W of Hwy 93	705631	5291293	1039	BUBO 93R; CHPI 94

Appendix A. Continued.

Survey/ Other[2]	Geographic Region Locality	UTM Zone 11 East.	North.	Elev. (m)	Species Year, Reprod.[3]
S	Jette Pnd., 1.6 km W of Hwy 93	705469	5296294	1219	AMMA 94R, 95R BUBO 94R, 95R PSRE 94R, 95R; THSI 94
S	King's Point Nature Conservancy Area	713503	5296028	881	PSRE 93R, 95R; CHPI 93 THEL 93
S	Loon Lake south of Big Arm	701097	5290944	1052	NSF 93
S	Mike's Ponds	702387	5306974	948	NSF 94
S	Red Lake	700042	5305872	992	NSF 94
S	Spring Creek Pond ENE of Proctor	702297	5308483	1094	AMMA 94R, PSRE 94R THSI 94
S	Station Creek on Boulder Creek Road	725356	5294032	1186	NSF 93
S	Turtle Lake, 2.4 km S. of Hwy 35	719514	5283640	942	RALU 93, CHPI 93, THSI 93
S	Wymore Lake on Matterhorn Pt. Rd.	712018	5296414	881	NSF 93
Jocko River Valley					
S	Agency Cr. where crosses feeder canal	727810	5223368	1122	NSF 93
S	Belmore Sloughs, off S. Fk. of Jocko R.	739984	5229631	1506	RALU 93R, 95R; THSI 93
S	Boles Meadow on Boles Creek	747329	5221307	1728	AMMA 93R, 94R RALU 93R, 94R; BUBO 94
S	Falls Cr. crosses Jocko R. Div. Can.	737270	5234839	1268	ASTR 94R
S	Feeder Can. 2.1 km mi NE of Agency Cr.	728950	5225738	1125	AMMA 93R; RALU 93R THSI 93
S	Finley Cr. Tributary, 1.6 km S of Arlee	721104	5226208	948	NSF 93
S	Finley Creek, 3.2 km ESE of Evaro	723446	5212139	1253	NSF 93
S	Frog Creek, 1.6 km N of Evaro	721440	5213789	1228	NSF 93
S	Hwy 93 Grav. Pit, 3.2 km SE of Arlee	723457	5225212	975	AMMA 93R
S	Hwy 200, 2 km E. of Dixon. Pnd on N.	704804	5242524	796	PSRE 93R
S	Hwy 200, 3 km E. of Dixon. Pnds on N.	706165	5242138	782	RALU 93; CHPI 93; THSI 93
S	Jocko R. at Jocko R. Diversion Can.	712240	5239882	817	RALU 94
S	Jocko R. backwater, 1 mi W of Ravalli	712783	5239434	825	NSF 94
S	Jocko R. Diversion Canal. Pond on W.	740665	5234141	1283	RALU 93, 95R
S	Jocko R., 6 km below Lower Jocko Lk.	739644	5234440	1270	AMMA 93R; RALU 93 THSI 93
S	Jocko R., Mid. Fk., 1 km above dam	740327	5234623	1268	RALU 94
S	Jocko R., Mid. Fk., 1 km W of div. dam	739644	5234440	1267	AMMA 93R; RALU 93
S	Jocko R., River. Cpgrd. 2 km N Arlee	719909	5228758	905	CHPI 93
S	Jocko R., S. Fk. at Entrance Cpgrd.	739148	5231546	1222	ASTR 94R
S	Jocko R., S. Fk, 3 km above Liberty Cr	745440	5220672	1570	ASTR 94R
S	Jocko R., S. Fk., 3 km ESE of Entrance	742001	5230393	1284	ASTR 94R; RALU 94
S	Jocko R., S. Fk., 5 km ESE of Entrance	742343	5229102	1326	ASTR 93, 94
S	Liberty Meadows on Liberty Creek	748324	5224750	1692	AMMA 93R; RALU 93R
S	Montana State Fish Hatchery, Arlee	721035	5228057	911	AMMA 93R; RALU 93R,94R
S	Nat. Bison Range, Elk Cr. on Per. Rd.	708548	5241296	838	AMMA 93R; RALU 93R
S	National Bison Range, Ravalli Potholes	714714	5241826	948	CHPI 93
S	Nat. Bison Range, Trisky Cr.	712517	5243755	1222	AMMA 93R; PSRE 93R
S	Pistol Cr. Marsh, 1.6 km N of Jocko R.	729550	5232780	1244	AMMA 93R, 94R, 95R RALU 93R, 94R, 95R BUBO 94
Lower Flathead River					
S	Burgess Lake	677038	5244870	883	NSF 93
S	Cam Cr. by Hwy 382, 5 km N Hwy 200	682884	5252741	814	RACA 93R, 95; PSRE 95R
S	Camas Cr Cont. Pnds '92 Oilspill	673176	5262125	988	RALU 93, PSRE 93
S	Clear Creek Drainage, Ponds on South	680846	5249989	1030	AMMA 95R; PSRE 95R THSI 95

Appendix A. Continued.

Survey/	Geographic Region	UTM Zone 11		Elev.	Species
Other[2]	Locality	East.	North.	(m)	Year,Reprod.[3]
S	Flathead R. backwater, Big Bend Moeise	701618	5248471	808	CHPI 93
S	Flathead R. old river channel, Big Bend	703919	5248179	807	PSRE 93; CHPI 93
S	Flathead R. backwater, N. of Old Agency	704217	5246150	770	CHPI 93
S	Flathead R., 1.6 km NW of Dixon	702121	5244842	768	CHPI 93
S	Flathead R., 3.7 km W of Rev. Cr.	694023	5243892	765	NSF 93
S	Flathead R., 1.3 km W of Mag. Cr.	689406	5244852	767	PSRE 93R
S	Flathead R., 4 km W. of Moiese	702763	5249469	774	CHPI 93
S	Hwy 200, 0.3 km E. of Mag. Cr.	690921	5244345	765	RALU 94; PSRE 94R
S	Hwy 200, 0.5 km E of Mag. Cr.	691148	5244321	762	PSRE 94R
S	Hwy 200, 3 km W. of Perma. Pnd on S	680467	5246609	766	RACA 93R, 95; PSRE 93R CHPI 93;THSI 93; THEL 93 CRVI 93
L	Hwy 382 Grav. Pit 6 km N of Hwy 200	682603	5253040	814	COCO 93R
S	Magpie Creek, 3 km S. of Hwy 200	690333	5241698	898	ASTR 94R
S	Magpie Creek, 3.7 km S of Hwy 200	690601	5241120	939	AMMA 93R
S	Nat. Bison Range, Pauline Cr.	709614	5246217	1082	AMMA 93R; PSRE 93R
S	Nat. Bison Range, Snake Pit on Per. Rd.	706250	5244357	917	NSF 93
S	Perma Pnd 3 km W of bri. on Hwy 382	680261	5247159	804	AMMA 93R; PSRE 93R,95R THSI 93, 94; CRVI 93
S	Rainbow Lake (Dog L) on Hwy 28	669410	5266115	1094	THSI 93; THEL 93
S	Rainbow Lk. Trib., 1.3 km N. of Cpgrd	669581	5267232	1195	ASTR 94R
L	Revais Cr., 0.8 km S. of Hwy 200	697849	5242533	835	CABO 94
S	Revais Creek 7.2 km S. of Hwy 200	696363	5236057	1134	ASTR 94R
S	Seepay Creek 4.8 km S. of Hwy 200	679862	5242389	890	ASTR 94R
S	Seepay Creek 8 km S of Hwy 200	680671	5240684	1002	ASTR 94R; CHBO 94
S	Sheep Springs on Br. of Gunderson Cr.	694093	5241697	1059	AMMA 93R
S	Sinkhole, Flat. R. by Revais Cr.	696887	5244386	789	RACA 93R; CHPI 93R THSI 93
S	Three Lakes, Lower (East) Lake	685181	5236375	1972	RALU 95
S	Three Lakes, Middle Lake	685211	5236128	2073	AMMA 93R; RALU 93
S	Three Lakes, Upper (West) Lake	684829	5236239	2085	AMMA 93R; RALU 93, 95
S	Toolman Marsh along Hwy 28	671801	5267297	1103	AMMA 93R, 94, 95R RALU 93R, 94, 95R PSRE 93R, 94R, 95R CHPI 93; THSI 93, 94, 95
Mission Mountains					
S	Frog Lake, North. Mission Mtns.	732496	5258430	1878	RALU 94R
S	Frog Lake, South. Mission Mtns.	732369	5258108	1878	BUBO 93; RALU 94R THEL 94
S	Long Lake	733425	5257602	1815	NSF 94
S	Mollman Lake, East	731374	5261975	2092	NSF 92, 94
S	Mollman Lk. West and Pond off SW end	730827	5262530	2092	AMMA 92R
S	Moon Lake	733298	5256728	1748	NSF 94
S	Mud Lake	725734	5277913	1765	NSF 94
S	Mud Lk. drainage, 1 km above Mud Lk.	726485	5277703	1832	NSF 94
S	Summit Lake	731554	5258850	1925	NSF 94
S	Summit Lk., Pond S. of, Mission Mtns.	731917	5258832	1606	RALU 94
Mission Valley					
S	Pnd, 3 km W of Hwy 93. W. Ps. Cr. Rd.	716464	5253698	887	RALU 97; CHPI 97
R	Can. Mill Rd. 1 km N. Jct N. Crow Rd.	722433	5273333	1036	THSI 93
A	Canyon Mill Rd., end of Rd.	722624	5273866	1044	PSRE 93R
S	Charlo Potholes 3.2 km NW of Charlo	710591	5261149	902	THSI 93

Appendix A. Continued.

Survey/	Geographic Region	UTM Zone 11		Elev.	Species
Other[2]	Locality	East.	North.	(m)	Year,Reprod.[3]
S	Charlo Potholes 4.8 km NW of Charlo	710536	5262661	917	CHPI 93; THSI 93
S	Crow Cr. below Lower Crow Reservoir	707918	5263959	829	AMMA 95
S	Dinwoodie Pond, Hwy 93 by Allentown	719069	5256359	922	THEL 97
S	Dublin Gulch Creek by Dublin Gulch Rd	712879	5251899	838	NSF 93
S	Duck Rd. 0.6 km W of Hwy 93. N/S Pnds	718141	5261675	929	NSF 93
S	Duck Rd. 0.8 km W of Hwy 93. Pnds on S	718101	5261611	929	NSF 93
S	Duck Rd. 1.1 km W of Hwy 93. Pnds on N	717905	5261821	929	NSF 93
S	Eagle Pass Rd, Jct Hill. Rd. Pnds on N&S	722226	5258364	944	AMMA 93R, 94R; RALU 94 CHPI, 93
S	Ealge Pass Rd., 2 km E of Hwy 93	720681	5258089	930	THSI 93
S	F Canal S of McDonald Lake Rd.	720883	5254643	860	THSI 93
S	Flathead River at Buffalo Bridge	699392	5280412	808	THEL 94
S	Flathead R., 3 km above Buffalo Brid.	704518	5281532	820	NSF 94
S	Flathead R. 1.6 km below Buffalo Brid.	698952	5279223	802	PSRE 94
S	Pond 5 km W of Hwy 93 on W. P. Cr. Rd	714883	5252770	881	NSF 97
S	Gunlock Rd, 0.3 km E of Hwy 93	719672	5256378	922	NSF 93
S	Harriman Trt. Farm, 1 km W of Hwy 93	718482	5252443	832	AMMA 97R; RALU 93, 97 BUBO 93; THSI 93
A	Hillside Rd, 1.6 km S. of M. C. Rd	721895	5259928	974	PSRE 93R
S	Hillside Rd, 0.5 km N of Red. Rd	722457	5252253	884	RALU 93; THSI 93
S	Hillside Reservoir	707252	5253581	817	CHPI 93; PICA 93 CRVI, 93, 95
S	Horte Res., 4 km W of Round Butte Rd.	705264	5268470	920	CHPI 93; THSI 93
S	Hwy 93, 5 km S. of Ronan, Pnd on W	718529	5262955	921	CHPI 93
S	Kicking Horse Pond KH1	720787	5259268	931	CHPI 94
S	Kicking Horse Pond KH6	719965	5259453	931	CHPI 94; THSI 94
S	Kicking Horse Pond KH11	719783	5260868	931	THSI 94
S	Lower Crow Reservoir	709208	5264619	881	NSF 94
S	McDonald Lk., Dam and Post Crk. outlet	726883	5256626	1097	RALU 93; THEL 93
L	McDonald Lake, trail on North side	728151	5256459	1128	ELCO 97
S	Marsh Cr. Rd. 0.2 km N of Marsh Cr.	720962	5254869	866	NSF 93
S	Marsh Cr. Rd. 1.1 km S of E. P. Rd.	720856	5256701	933	NSF 93
S	Marsh Cr. Rd. 1.3 km S of E. P. Rd.	720861	5256553	933	NSF 93
S	Mission Cr. 1.3 km below Mission Res.	724409	5243486	963	THEL 94
S	Mission Cr. 2.9 km below Mission Res.	722880	5243146	943	NSF 94
S	Mission Creek along Sabine Road	717390	5245258	838	NSF 94
S	Mission Creek at bridge on Sabine Road	716197	5246579	836	RALU 94
S	Mission Cr. 0.8 km above Mission Res.	728256	5245210	1058	AMMA 93R; RALU 93 THSI 93
S	Mission Cr. 1.3 km above Res. by Cpgrd	728665	5245381	1070	BUBO, 94; THSI 94
S	Mission Dam	725180	5244103	1036	RALU 95; THEL 95
S	Mission Meadow Rd 3 km W of Hwy 93	715980	5272504	933	RALU 93R
S	Mission Mead. Rd. by RR tracks	716282	5272298	921	RALU 93; CHPI 93
L	Mission Reservoir, Rd. on North side	725284	5244755	1042	BUBO 94, 95R
S	Mollman Creek Rd , North Pond 2	722986	5262598	968	AMMA 93R, 95R RALU 93R, 94R, 95R THSI 93
A	Mollman Creek Rd., South Pond A	722204	5262319	952	PSRE 93R
S	Mollman Creek Rd., South Pond K1	723060	5261607	960	NSF 93, 95, 96
S	Mollman Creek Rd., South Pond K3	722916	5261635	960	AMMA 95R; 96R RALU 94, 95
S	Mollman Creek Rd., South Pond K4	722815	5261540	960	AMMA 94R, 95R RALU 94R 95R, CHPI 94, 96

Appendix A. Continued.

Survey/ Other[2]	Geographic Region Locality	UTM Zone 11 East.	 North.	Elev. (m)	Species Year,Reprod.[3]
S	Mollman Creek Rd., South Pond K9	723369	5261767	960	NSF 94, 95, 96
S	Mollman Creek Rd., South Pond K10	723270	5261866	960	AMMA 95R; RALU 94R, 95R CHPI 94; THSI 94
S	Mollman Creek Rd., South Pond K13	722804	5261416	960	AMMA 95R, 97R RALU 95R, 97R
S	Mollman Creek Rd., South Pond S2	722875	5261140	960	AMMA 94R, 95R, 97R RALU 94R, 97R THSI 95, 97
S	Mollman Creek Rd., South Pond S5	722749	5261074	960	AMMA 95R; RALU 94R CHPI 94
S	Mollman Cr. Rd. & Hwy 93, Pnds to NE	719258	5262057	927	NSF 93
S	Mollman Cr. 1.3 km S of M. Cr. Rd.	725378	5260193	1001	NSF 94
S	Mud Creek, 4.8 km E of Hwy 93	721826	5278782	991	THSI 94
L	Mud Lake Trail, 2 km from trailhead	724959	5278224	1433	THSI 94
S	Naitonal Bison Range, Mission Creek	712349	5249034	805	THSI 93
S	National Bison Range, Fishing Access	708087	5249624	786	THSI 93; CHPI 93
S	Nat. Bison Range, Picnic Area Ponds	707155	5249900	777	AMMA 93R; PSRE 93R CHPI 93
L	Nat. Bison Range, Picnic Area Pond 4A	707155	5249900	777	BUBO 95R
S	Ninepipes Reservoir, both sides by dam	715931	5259540	916	NSF 96
R	N. Foothills Rd, 1 km N. of Terr. L. Rd.	720636	5269193	945	THSI 93
L	N. Foothills Rd. 3 km N. of Terr. Lk. Rd.	720594	5270638	967	RALU 93
L	N. Crow Can. Tr., 2.6 km E of trailhead	727080	5273698	1378	CHBO 93
S	N. Crow Can. Tr., 3.2 km E of trailhead	727686	5273814	1402	ELCO 92
S	N. Crow Cr. Div. Pond off Cany. Mill Rd.	722598	5271104	991	NSF 93
S	North Crow Creek at Campground	724433	5273410	1122	ASTR 94R
S	Olson Rd 0.5 km W of Hwy 93. Pnd on N	718568	5256281	917	NSF 93
S	Olson Rd 0.8 km W of Hwy 93. Pnd on S	718498	5256130	915	NSF 93
S	Pablo F.C. bet. Terr. Lk. & Can. Mill Rds	723007	5270582	997	NSF 93
D	Pablo F. C., 0.5 km N of Canyon Mill Rd.	721607	5271400	998	AMMA 93
S	Pablo Reservoir, NW section by Res. Rd.	712705	5280729	972	AMMA 93R; RALU 93R CHPI 93
S	Pablo Res., Pnds on E. by spillway.	714739	5280031	969	RALU 93R; CHPI 93R THSI 93
S	Pistol Cr. Tributary along Pistol Cr. Rd	717577	5240870	978	NSF 93
S	Post Creek at bridge on Sabine Road	715437	5249580	814	THSI 94
S	Post Creek at Pablo Feeder Canal	725624	5257736	1006	NSF 94
S	Post Creek just W of Hwy 93	718961	5252921	835	NSF 97
S	Post Creek, 0.2 km above McDonald Lk.	729458	5255675	1100	AMMA 94R
S	Post Cr. 0.8 km S of Eagle Pass Cr. Rd.	724297	5257870	951	NSF 94
S	Redhorn Rd, 3.2 km E of Hwy 93	723248	5252530	896	RALU 93R; CHPI 93
S	Redhorn Rd, 3.2 km E of Hwy 93	723249	5251912	896	CHPI 93
S	Rnd. Butte Rd., Res.16 km W of Hwy 93	701217	5268051	872	BUBO 94R
S	Ronan-Pablo Hwy 93 Ponds W/E of Hwy	717609	5270879	927	RALU 93R; CHPI 93
S	Round Butte Road, Pond on South	699915	5266825	872	BUBO 95
S	Salish Kootenai College Ponds	717315	5275273	936	CHPI 93
S	South Crow Creek at Hammer Dam	724010	5263811	1003	RALU 94; THEL 94
S	S. Crow Cr. below Swartz Lake Road	725696	5264026	1134	NSF 94
S	St. Marys Lake, Springs 0.8 km South	732508	5237481	1253	NSF 94
S	St. Wild. Mgt. Area 4 km W of Hwy 93	715292	5254736	893	CHPI 93
S	Swartz Lake	726307	5265074	1196	AMMA 93R, 94R RALU 93, 94, 95 THSI 93, 94, 95

Appendix A. Continued.

Survey/ Other[2]	Geographic Region Locality	UTM Zone 11 East.	North.	Elev. (m)	Species Year,Reprod.[3]
S	Timberlane Rd., by Clarice Home Sites	722079	5265594	951	NSF 93
S	Timberlane Rd., by Woodcock Home Site	722350	5266622	948	AMMA 93R
S	Twin Lakes Marsh	734103	5236135	1253	AMMA 93R, 94R, 95R RALU 93R, 94R, 95R BUBO 93; THSI 93
S	Twin Lakes, North Lake	733605	5236826	1265	BUBO 94R, 95R
S	Twin Lakes, South Lake	733828	5236557	1265	BUBO 94R; THSI 94
S	Twin Lakes, Pond NW of North Lake	733584	5236980	1265	AMMA 94R; RALU 94
S	Twin Lks., Slew 3 km S. of South Lake	733656	5235159	1222	RALU 94, 95
S	Two Cr. Lane off Hill. Rd. Dennis Prop.	723074	5260282	981	RALU 93; CHPI 93
S	Two Cr. Lane off Hill. Rd. Martin Prop.	723054	5260188	951	RALU 93; PSRE 93R
S	Valley View Rd, 2 km N. of Rd. But. Rd.	676199	5268571	930	CHPI 93
S	W. Post Crk Rd 0.5 km E of Hwy 212	712090	5252687	881	CHPI 93
S	W. Post Cr. Rd 1.3 km W of Hwy 212	710123	5253127	871	CHPI 93
S	W. Post Cr. Rd 3-4 km W Hwy 93	713670	5253579	879	CHPI 93

[1] It is illegal to collect plant and animal specimens on the Flathead Reservation without the permission of the Confederated Salish and Kootenai Tribal Council.

[2] Other includes: A = Audio call; D = Found dead but other than roadkill; L = Observed alive; R = Roadkill

[3] Species: AMMA = *Ambystoma macrodactylum*; ASTR = *Ascaphus truei*; BUBO = *Bufo boreas*; CHBO = *Charina bottae*; CHPI = *Chrysemys picta*; COCO = *Coluber constrictor*, CRVI = *Crotalus viridis*; ELCO = *Elgaria coerulea*; NSF = No species found; PICA = *Pituophis catenifer*, PSRE = *Pseudacris regilla*; RACA = *Rana catesbeiana*; RALU = *Rana luteiventris*; THEL = *Thamnophis elegans*; THSI = *Thamnophis sirtalis*.
R - after the year indicates evidence of reproduction, i.e. eggs, larvae/tadpoles or calling adults

Thomas Fillmore
Will Wickun

AN INTODUCTORY-LEVEL EXPERIMENT FOR THE ELECTROCHEMICAL RECOVERY AND SPECTROPHOTOMETRIC DETERMINATION OF COPPER

ABSTRACT

Procedures suitable for an introductory-level laboratory experiment were developed for the electrogravimetric determination of copper. The method involves deposition of the reduced metal onto the working electrode at low current levels. The electrolysis reaction is driven without the need for potentiometric control and the cathodic reduction of the metal proceeds to near thermodynamic completion. When separate cell compartments are used, purity of the recovered metal should also be high. These characteristics of electrolysis were confirmed by the electrogravimetric analysis of copper that yielded a recovery of 93.93 ± 5.74 percent. Purity of the recovered copper, determined through spectrophotometric methods, was shown to be 97.82 ± 3.24 percent.

Key words: electrolysis, electrogravimetric analysis, spectrophotometric analysis.

INTRODUCTION

The electrolytic cell is commonly used throughout industry for electrorefining metals, electroplating, and recovering valuable metals from solution. Established industrial procedures indicate that the currents required are generally unachievable with the standard power supplies available in an academic laboratory. In addition, little information is readily available on the simple electrolytic recovery of metals for analytical purposes. Many procedural approaches used in a quantitative chemistry laboratory (Petrucci and Moews 1964, Tackett and Knowles 1966, Kennedy and Adams 1970) are controlled potential electrolysis experiments requiring precise current monitoring. Other electrogravemetric methods (Skoog, West, and Holler, 1992) require the use of expensive platinum electrodes. For these reasons, a simple, inexpensive experiment for the electrolytic recovery of copper from solution was developed. The scope of the experiment can be expanded easily to include the spectrophotometric determination of the purity of the recovered metal.

PROCEDURE

The 0.25 M salt solution used for this investigation was prepared from reagent grade $CuSO_4 \bullet 5H_2O$. This salt was selected for its high solubility in water and its brilliant blue color, which was useful in visually monitoring the progress of the reaction and in spectrohotometrically establishing the purity of the recovered metal.

Salt bridges were prepared from a saturated solution of KCl in agar (Harris, 1995) and constructed with approximately 50 cm of folded 24 gauge nichrome wire anode embedded within

Thomas Fillmore, Department of Biological and Physical Sciences, Montana State University - Billings, Billings, MT 59101-0298.
Will Wickun, Department of Biological and Physical Sciences, Montana State University - Billings, Billings, MT 59101-0298.

them in order to maximize the current flow. For the cathode, a premassed copper strip, approximately 1 cm, (5 cm) was connected to a standard regulated laboratory power supply with an allegator clip and immersed in the center of a 250 mL beaker containing 100.0 mL of the copper sulfate solution. The beaker was periodically swirled without removing the salt bridge or cathode. The current was monitored with the power supply's internal ammeter. Faraday's constant and the relationship of current and time allowed a rough estimate of the time required for total deposition. However, since the concentration of the Cu (II) in solution continually decreases as the experiment progresses, the time required to reach completion increases accordingly.

For the percent recovery determination, the contents of the cathode compartment were quantitatively transfered into a glass funnel containing premassed filter paper and the premassed cathode with copper deposits. The filter paper and cathode with deposits were washed with deionized water, dried for several hours at 110°C, cooled in dessicator, and then weighed (Table 1). For purity determinations, most of the recovered copper was dissolved in 6 M HNO_3 and the solution was heated without boiling until the evolution of NO_2 was no longer evident. An excess of 6 M NH_3 was added and absorbances were measured against standards on a Shimadzu UV2100 UV-vis recording spectrophotometer. From absorbance data, corresponding concentrations were established by comparison with the concentrations of standard tetraammine Cu (II) solutions (Table 2 and 3). The standard deviations for the data in Tables 1 and 2 were calculated using the equation

$$s = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}}$$

where N is the number of replicate data in the set.

Table 1: *Mass and percent copper recovered*

Sample	Theoretical mass (g)	Experimental mass (g)	Percent copper recovered
R-1	0.3176	0.2825	88.95
R-2	0.3176	0.2942	92-63
R-3	0.3176	0.2806	88.35
R-4	0.3176	0.3478	109.5
R-5	0.3176	0.2990	94.14
R-6	0.3176	0.2801	88.19
R-7	0.3176	0.2910	91.62
R-8	0.3176	0.3001	94.49
R-9	0.3176	0.3044	95-84
R-10	0.3176	0.2903	91.40
R-11	0.3176	0.3098	97.54
R-12	0.3176	0.3001	94.49

Mean percent copper recovered: 93.93 ± 5.74%

Table 2: *Standard concentrations used to determine molar absorptivity*

Standard	Concentration	Absorbance	Molar Absorptivity
S-1	3.809×10^{-3} M	0.192	50.4 M^{-1} cm^{-1}
S-2	3.174×10^{-3} M	0.164	51.7 M^{-1} cm^{-1}
S-3	2.592×10^{-3} M	0.132	50.9 M^{-1} cm^{-1}

Mean molar absorptivity: 51.0 ± 0.8 M^{-1} cm^{-1}

Because all samples have a similar composition and have been analyzed in the same way, the mean percent purities from the 12 sets of data in Table 3 were pooled to improve the reliability of the standard deviation, which was then calculated with

$$s_{pooled} = \sqrt{\frac{\Sigma(x-x_1)^2 + \Sigma(x-x_2)^2 + \Sigma(x-x_3)^2 + \ldots}{N_1 + N_2 + N_3 + \ldots - N_{total}}}$$

where N_1 is the number of data in set R-1, N_2 is the number of data in set R-2, and so forth, and N_{total}, the total number of data sets pooled, is 12 in this case.

Table 3: *Purity verification based on absorption (λ = 600 nm)*

Sample and replicate		Theoretical conc x 10^3 (M)	Exptl conc x 10^3 (M)	Absorb	% purity	Mean % purity
R-1	a	3.758	3.270	0.168	87.01	
	b	3.132	2.706	0.139	86.39	86.55
	c	2.505	2.161	0.111	86.27	
R-2	a	3.803	3.679	0.189	96.74	
	b	3.169	3.212	0.165	101.40	98.00
	c	2.535	2.433	0.125	95.98	
R-3	a	3.854	3.834	0.197	99.48	
	b	3.212	3.309	0.170	103.00	98.53
	c	2.570	2.394	0.123	93.15	
R-4	a	3.901	3.854	0.198	98.80	
	b	3.251	3.464	0.178	106.60	101.60
	c	2.601	2.589	0.133	99.54	
R-5	a	3.818	3.776	0.194	98.90	
	b	3.182	3.192	0.164	100.30	99.53
	c	2.546	2.530	0.130	99.37	
R-6	a	3.869	3.834	0.197	99.10	
	b	3.224	3.270	0.168	101.40	99.27
	c	2.580	2.511	0.129	97.33	
R-7	a	3.814	3.854	0.198	101.00	
	b	3.179	3.270	0.168	102.90	101.10
	c	2.543	2.530	0.130	99.49	
R-8	a	4.000	3.971	0.204	99.28	
	b	3.333	3.698	0.190	111.00	107.10
	c	2.666	2.958	0.152	111.00	
R-9	a	3.830	3.601	0.185	94.02	
	b	3.191	3.134	0.161	98.21	96.86
	c	2.553	2.511	0.141	98.35	
R-10	a	3.869	3.640	0.187	94.08	
	b	3.224	3.134	0.161	97.21	96.20
	c	2.580	2.511	0.142	97.33	
R-11	a	3.832	3.737	0.192	97.52	
	b	3.193	2.978	0.153	93.27	96.32
	c	2.554	2.511	0.129	98.32	
R-12	a	3.799	3.562	0.183	93.76	
	b	3.166	2.842	0.146	89.77	92.68
	c	2.533	2.394	0.123	94.51	

Overall mean purity: 97.82 ± 3.24%

DISCUSSION

In the initial design of the electrolytic cell constructed for this investigation, the Cu cathode and Zn anode were immersed in the same 250 mL beaker. As concentration of the Cu (II) became very dilute, Zn (II), present in solution from the oxidation of the zinc anode, deposited on the copper cathode. Because of this, impurities were inherently present in the copper. The use of separate anode and cathode compartments produced reasonably good results. However, in order to keep the current flow sufficiently high, repeated hand-agitation of the anode compartment was necessary. This difficulty was overcome by completely eliminating the anode compartment and constructing the anode as an integral part of the salt bridge (Fig. 1). Current flow was optimized easily while avoiding the zinc impurity in the deposited copper.

For this cell, an initial current of 1 A was applied for four to five hours or until the current became essentially zero. No attempt was made to control the working electrode potential. Using Faraday's constant and the relationship between charge and time, the theoretical minimum time for a complete reaction was calculated at 1.1 hours. However, this calculation does not account for *IR* drop nor the decrease in current with decreasing Cu (II) concentration. For this reason, the cell was allowed to run significantly longer than the theoretical time in order to maximize recovery of the copper. The disappearance of the blue color of the solution and the cessation of current were reliable indicators that deposition of the copper was complete.

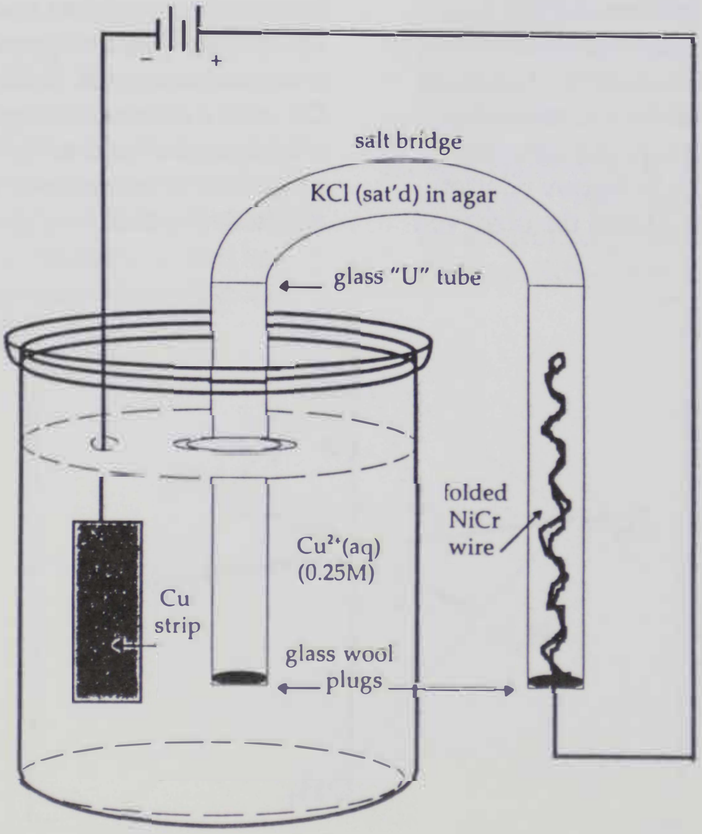


Figure 1. *Sketch of electrochemical cell construction.*

The purity of the 12 samples, split into three replicates each, was determined spectrophotometrically. Although the aqueous solution of the recovered Cu (II) was a faint blue color, the intensity of this absorption was insufficient to be quantitatively useful. Therefore, the $[Cu(H_2O)_6]^{2+}$ was converted to the much more intensely blue $[Cu(NH_3)_4(H_2O)_2]^{2+}$ by the addition of an excess of 6 M NH_3. Addition of ligands to such aqueous solutions leads to the formation of coordination compounds by successive displacement of water molecules (Cotton and Wilkinson 1972). Ammonia is a much stronger ligand than water, easily displacing the four water molecules from the equatorial positions of the Cu (II) ion and, at the same time, causing the absorption band to move from the far red to the middle of the red region of the spectrum (Fig. 2). However, the axial bond lengths are Jahn-Teller distorted by the presence of the four equatorial NH_3. Because of this effect, it is impossible to displace the two axial H_2O molecules unless the solution is diluted with pure liquid ammonia. Comparison of the literature (Cotton and Wilkinson 1972) and the observed maximum wavelength (~600 nm vs. 601.5 nm, respectively) unambiguously confirmed that the ion formed was indeed the octahedral $[Cu(NH_3)_4(H_2O)_2]^{2+}$. Initial serial dilutions of the sample were also made with 6 M NH_3 to ensure the predominance of the $[Cu(NH_3)_4(H_2O)_2]^{2+}$ even after subsequent dilution of the aliquots with water.

Molar absorptivity was derived from the concentrations and the absorbances of the tetraammine Cu (II) standards. This absorptivity was used to determine the concentration of the recovered Cu (II) in each of the samples. Percent purity was then calculated from a comparison of the concentrations obtained for the recovered Cu (II) solutions to the concentrations of the standard solutions.

Based on the data collected and summarized in Tables 1 and 3, electrolytic deposition can serve well as an introductory-level analytical method. For this simple, inexpensive procedure, a mean recovery of 93.93 ± 5.74 percent Cu with a corresponding purity of 97.82 ± 3.24 percent was achieved. It was noted that when a lower current was applied, deposition of the copper

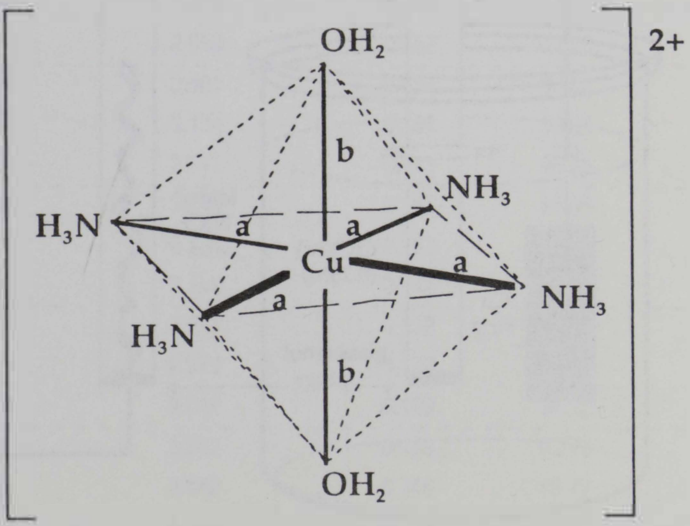


Figure 2. *Jahn-Teller distortion (i.e. b>a) in the octahedral complex lowers symmetry and energy.*

required a longer time, however, the copper was generally of higher purity. It is assumed here that, as in a rapid precipitation reaction, at high current and high deposition rates, other ions from the solution are likely to become trapped in the deposited copper. This phenomenon would account for the impure appearance of the copper resulting from deposition at high current levels. In industrial electrorefining, a low current is supplied over several weeks in order to recover large sheets of high-purity copper.

Although electrogravimetric analysis is an established method, many published procedures may be difficult or time consuming. The procedure presented in this paper is uncomplicated enough for an introductory-level chemistry student to follow and to retrieve valid data. Other metals in solution could also be recovered in a similar manner. With the possible exception of the recording spectrophotometer, for which a Spec-20 could be substituted, all apparatus and materials used are common to secondary and higher-level educational institutions. An informative review of ligand field theory and determination of a coordination compound, as well as quantitative determinations using the UV-vis spectrophotometer, are additional pedagogic benefits of this otherwise simple experiment.

LITERATURE CITED

Cotton, F. Albert and Geoffrey Wilkinson. 1972. Advanced Inorganic Chemistry, 3rd ed. John Wiley and Sons. New York, NY. p. 916-918

Harris, C. Daniel. 1995. Quantitative Chemical Analysis, 4th ed. W. H. Freeman. New York, NY. p. 350.

Kennedy, John H. and Frank Adams. 1970. Controlled potential electrolysis: An experiment for elementary quantitative analysis. J. Chem. Educ. 47: 461-463.

Petrucci, R. H. and P. C. Moews. 1964. A simple quantitative electrolysis experiment for first year chemistry. J. Chem. Educ., 41(10): 552-553.

Skoog, Douglas A., Donald M. West, and F. James Holler. 1992. Fundamentals of Analytical Chemistry, 6th ed. Saunders. Orlando, FL. p. 874-876.

Tackett, Stanford L. and John A. Knowles. 1966. Simple potentiostat for controlled potential electrolysis. J. Chem. Educ., 43(8): 428-431.

SPONSORING ORGANIZATIONS AND 1998 OFFICERS

MONTANA ACADEMY OF SCIENCES

President	Sharon Eversman, Biology Dept. Montana State University - Bozeman
President Elect	Gil Alexander Canyon Ferry Limnological Institute, Helena, MT
Past President	Craig Johnston, School of Pharmacy University of Montana - Missoula
Executive Director	Paul Sawyer, Dept. of Biology University of Montana, Montana Tech - Butte
Treasurer	Marilyn Alexander Canyon Ferry Limnological Institute, Helena, MT
Board Member	Jeanette Oliver Flathead Community College - Kalispell, MT
Board Member	Linda DeKort 1290 Lost Creek Dr., Kalispell, MT
Board Member	Kenneth Harper, Biochemistry Montana State University - Bozeman
Newsletter Editor	Vacant
Records	Clint Carlson USDA Forest Service, Missoula, MT

THE MONTANA CHAPTER OF THE WILDLIFE SOCIETY

President	Dale Becker Confederated Salish & Kootenai Tribes - Pablo, MT
President Elect	John Vore Montana Fish, Wildlife and Parks, Kalispell
Past President	Dan Pletscher , School of Forestry University of Montana - Missoula
Secretary-Treasurer	Frank Pickett Montana Power Company - Butte, MT

THE MONTANA CHAPTER OF THE AMERICAN FISHERIES SOCIETY

President	Mark E. Lere Montana Fish, Wildlife & Parks, Helena
President Elect	Tom MacMahon Montana State University - Bozeman
Past President	Dan Carty U. S. Fish and Wildlife Service, Creston, MT
Secretary-Treasurer	Greg Kindschi U. S. Fish and Wildlife Service, Bozeman, MT