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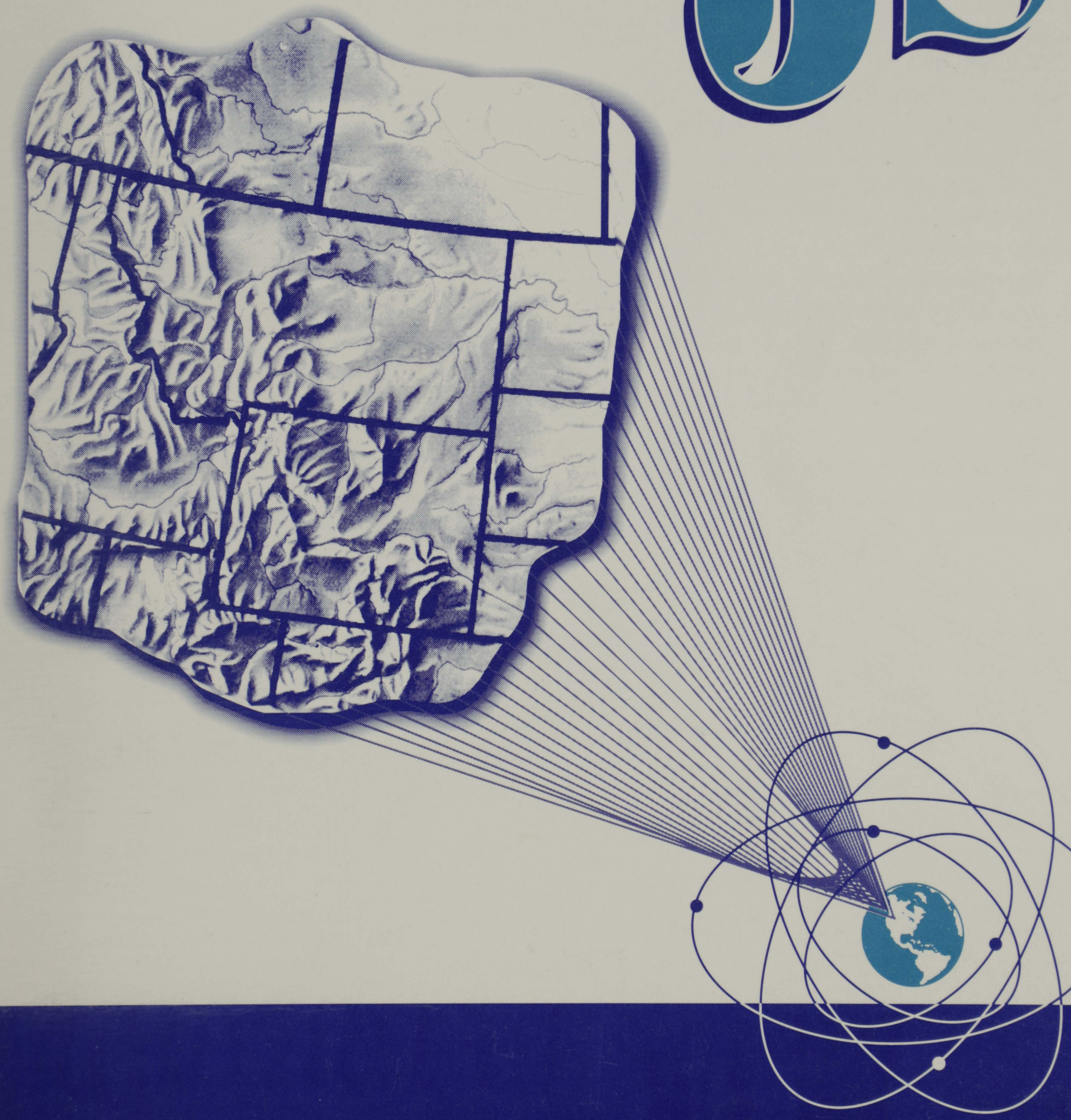

INTERMOUNTAIN JOURNAL OF SCIENCES

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Submitted by Kenneth L. Hamlin, BusinessManager - IJS

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Richard B. Keigley

ARCHITECTURE OF COTTONWOOD AS AN INDEX OF BROWSING HISTORY IN YELLOWSTONE

ABSTRACT

*I determined the history of browsing by elk (*Cervus elaphus*) on narrowleaf cottonwood (*Populus angustifolia*) at a site in northern Yellowstone National Park (YNP). I aged cottonwoods in three stands by dendrochronology and classified them into four architectural categories that I postulated were produced by four browsing regimes: 1) uninterrupted-growth type (light-to-moderate browsing), 2) arrested-type (intense browsing), 3) retrogressed-type (a change from light-to-moderate browsing to intense browsing), and 4) released-type (a change from intense browsing to light-to-moderate browsing). Cottonwood trees established prior to 1947 were of uninterrupted-growth type architecture. Trees established between 1947 and 1968 were of uninterrupted- and released-type architectures. With the exception of individuals short enough to be protected from winter browsing by snowpack, all individuals established after 1968 were of arrested- and retrogressed-type architectures. Cottonwoods in the study area experienced the following browsing history: (1) light-to-moderate until 1951, (2) intense from 1952 to 1962, (3) light-to-moderate from 1963 to 1974, and (4) intense since 1975. Architecture-based methods can be used to determine the rank order sequence in which elk currently prefer different species of browse. Once determined, that rank order sequence can be used to test competing hypotheses about the declines in woody plants in YNP.*

Key words: architecture, browsing history, *Cervus elaphus*, elk, growth form, Yellowstone National Park

INTRODUCTION

The condition of elk (*Cervus elaphus*) winter range in northern YNP has been controversial for decades (Chase 1987, Despain *et al.* 1986, Kay 1990). Much of the controversy has focused on differing explanations for a decline in abundance of aspen (*Populus tremuloides*) and willow (*Salix* spp.).

Some believe that the northern range deteriorated because of overpopulation by elk (Wright and Thompson 1935, Leopold *et al.* 1963, Kay 1997). The northern elk herd increased in the late 1800s when elk were protected from hunting, predators were eliminated, and elk migration to ancestral winter range north of YNP was impeded (Pitcher 1905, Smith *et al.* 1915, Graves and Nelson 1919).

Houston (1982) and Despain *et al.* (1986) believe that the northern range has remained unchanged from the pristine condition that existed prior to the Park's establishment. Houston also contends that the northern elk herd fluctuates within natural limits of variation. Previous research attributes change in condition and abundance of vegetation to past fire suppression (Houston 1982, Despain *et al.* 1986) or climate change (Despain 1990, Singer *et al.* 1994).

Additionally, young cottonwood (*Populus* spp.), Engelmann spruce (*Picea engelmannii*), Douglas fir (*Pseudotsuga*

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menziesii), pine (*Pinus* spp.), juniper (*Juniperus scopulorum*), sagebrush (*Artemisia* spp.), greasewood (*Sarcobatus vermiculatus*), birch (*Betula occidentalis*), alder (*Alnus* spp.), and chokecherry (*Prunus virginiana*) are heavily browsed and dead plants are common (pers. obs.). The mortality of young plants suggests that these browse species are in decline. In national parks, ecologic changes caused by natural processes are to be preserved, while changes due to EuroAmerican influences may be mitigated (National Park Service 1988). An objective of my research was to develop an approach for evaluating two competing explanations: one which attributes the declines to EuroAmerican influences; the other attributes declines to natural processes.

Any evaluation of cause and effect must be based on how ungulate use of browse has historically varied in response to controlling factors. Some studies inferred levels of browse use that occurred at discrete points in time (Houston 1982, Kay 1990, Singer and Renkin 1995, Romme *et al.* 1996). For example, Houston (1982) and Kay (1990) interpreted browse use from historic photographs. Such interpretations are limited to the time and place documented by the photographs. I am aware of no study that describes a year-by-year history of browse use for any species. Here, I describe a year-by-year browse-use history of narrowleaf cottonwood (*Populus angustifolia*) that grow in one area on YNP's northern range. I also describe a method to test hypotheses about the causes of the decline in YNP's woody plants.

STUDY AREA AND METHODS

Narrowleaf cottonwood is a riparian tree that grows to 20 m tall (Harrington 1964). Trees established from seed along stream banks often form gallery forests where stands of different age provide a record of stream channel migration (Everitt 1968). Plants also may be established from root suckering. Outside YNP, narrowleaf cottonwood typically grows to a height of 1 m within 2-3 years of establishment (pers. obs.). On the northern range of YNP, narrowleaf cottonwood communities consist of older mature trees and younger plants so heavily browsed they have assumed a bush-like growth form (Keigley 1997b) (Fig. 1).

I conducted this study in 1992 near the confluence of Soda Butte Creek and the Lamar River in northern YNP (elev. 2010 m). This area was selected because of the diverse group of cottonwood age classes found there.

I examined three adjacent stands of cottonwoods growing in abandoned channels of the Lamar River. Stand 1 consisted of 14 very large trees up to 20 m tall and averaging about 1 m diameter at breast height (dbh). Stand 2 contained 45 trees up to 15 m tall and 30-50 cm dbh. Stand 3 consisted of 53 trees ranging up to 10 m tall, and many bush-form plants from 0.1-1.5 m in height.

Architectures

Ungulate browsing can permanently modify the architecture of woody plants (Cole 1958, Ferguson and Basile 1966, Riney 1982, Bergström and Danell 1987, Bilbrough and Richards 1993). Keigley (1997a) postulated that four general architecture types develop in response to four browsing regimes. A light-to-moderate browsing regime produces uninterrupted-growth type architecture of which a simple, non-forking trunk is characteristic. These are "typical" cottonwood trees.

Chronic intense browsing of a young plant produces arrested-type architecture (see Fig. 1). Browsing kills the tip of the terminal leader and promotes development of lateral branches from lower regions of the plant. Because browsing primarily occurs during winter, height of arrested-type plants is influenced by snowpack

Figure 1. *A bush-form (arrested-type) cottonwood about 50 cm tall growing adjacent to the Gardner River north of Mammoth Hot Springs, Yellowstone National Park. Ungulate bite-marks are visible on many branches. Above a height of about 20 cm, the primary stem branches profusely, indicating that stems were intensely browsed once they grew taller than the protection afforded by snowpack.*

Figure 2. *A retrogressed-type cottonwood about 75 cm tall growing adjacent to the plant in Fig. 1. In contrast to the flat-topped appearance of the plant in Fig. 1, this individual has three protruding stems. The ability of these stems to grow to 75 cm tall indicates that, early in its life, this plant experienced less intense browsing than the plant in Fig. 1. The upper portion of this retrogressed-type individual is dead. Leaves are borne on lateral branches that developed from the base of the plant.*

thickness. In a 17 year old stand of arrested-type cottonwoods located 5.5 km upstream from this study area (elev. 2050 m), average height was 18 cm; the tallest arrested-type individual was 42 cm (Keigley 1997b).

Retrogressed-type architecture is produced when browsing changes from a light-to-moderate level to an intense level. During the early period of light-to-moderate browsing, the plant may grow taller than the arrest zone (i.e., taller than 40-50 cm). When the browsing level changes to intense, the upper region of the plant's primary stem dies. A dense thatch of dead branches may form and protect new lateral branches that may develop from the lower region of the plant (Fig. 2). At the site previously described by Keigley (1997b), retrogressed-type cottonwoods grew as tall as 1.7 m before the upper stem was killed by browsing.

Released- type architecture is produced when the browsing regime changes from intense to light-to-moderate (Fig. 3). During the period of intense herbivory, an arrested- or retrogressed-type architecture develops. After the browsing level changes to a light-to-moderate level, a lateral branch assumes the role of a trunk. The individual is classified as "released" when the trunk grows taller than 2.5 m above ground level.

I assigned each individual cottonwood plant in my study to 1 of 3 categories: (1) uninterrupted-growth-type, (2) a combined arrested- and retrogressed-type, and (3) released-type. I assigned trees with trunks that did not fork within a zone between ground level

Figure 3. *A released-type cottonwood. In its youth, this tree resembled the cottonwood shown in Fig. 2. Evidence of retrogressed-type architecture is preserved in the dead stems at the right-hand side of the lower trunk. Above the point where retrogressed-type stems are attached to the trunk, trunk girth diminishes markedly. The large girth at point of attachment indicates that the dead stems were produced early in the tree's life. The near-vertical orientation of those stems indicates that they developed before elongation of what is now the trunk. A reduction in browsing intensity enabled a stem of the retrogressed-type plant to grow to ca. 4 m tall, producing the released-type architecture. Lateral branches within the browse zone have been intensely browsed, indicating that browsing level increased to intense after the trunk grew through the browse zone.*

and 1 m to the uninterrupted-growth-type category. The continuity of the primary stem was evidence of uninterrupted-growth when the terminal leader grew within that zone.

I assigned plants to the arrested- and retrogressed-type category if a complete annual segment of the primary stem died due to browsing. Bite marks at the end of branches attest to ungulate herbivory as the principal determinant of growth form. Arrested- and retrogressed-type plants branch profusely as a result of pruning and appear bush-like. Both the arrested- and retrogressed-type architectures indicate intense current browsing.

I assigned plants to the released-type category in two steps. In the first step, I tentatively categorized them based on height growth that permitted the current primary stem to grow taller than the browse zone (ca 2.5 m), and on evidence of previous arrest or retrogression. Forking of a live stem from a dead, near-vertical stem was taken as potential evidence of arrest or retrogression. In the second step described below, I confirmed the assignment by determining whether or not forking was associated with release from a period of inhibited height growth.

Confirmation of Released-type Architecture

I determined ages of tree trunks at 0.3 and 1.0 m above ground level from increment cores. I used age at 0.3 m to estimate the year of tree establishment. If a tree had experienced intense browsing that limited its growth to less than 0.3 m for a period of years, a core taken from a height of 0.3 m would underestimate the age of the tree. Such browsing would cause development of multiple primary stems. Because trees at the site did not fork between ground level and 0.3 m, a core at 0.3 m provided a reliable estimate for establishment year of the initial primary stem. Growth to 1.0 m was selected as a benchmark height that corresponded with a browsing intensity that is markedly lower than the present level (Keigley 1997b).

I calculated the number of years required for growth from 0.3 to 1.0 m from the difference in annual-ring numbers between those heights. I termed this number of years the "elongation period," and considered it a measure of the rate of height growth. To identify periods of years with growth inhibition, I regressed elongation period for each plant on year of its establishment. If no inhibition occurred over a period of years, there would be a series of points with short elongation periods (1-3 years) on the ordinate spaced along a series of years on the abscissa. A value of 0 indicated that the stem grew through the 0.3 and 1.0 m levels the same year. If height growth was inhibited for a series of years and then released, the elongation period for each plant would increase by about 1 year for each year it was inhibited.

Consider a hypothetical case where plants were established each year over a period of 9 years and prevented from growing taller than 0.5 m during that period. At 9 years, there would be a group of 0.5-m-tall plants ranging in age from 0 to 9 years old. If in the tenth year all plants were allowed to grow taller than 1 m, the elongation period for plants established in the first year of treatment would be 10 years. Plants established in the second year of treatment would have an elongation period of 9 years, and plants established in the ninth year of treatment an elongation period of 1 year. If establishment years increase from left to right on the X-axis, the hypothetical series would be described with a regression slope of -1.0.

Height growth inhibition could be caused by unfavorable growing conditions (e.g., drought, insect herbivory). It also could be caused by a series of years during which the stems were browsed by ungulates, preventing the trees from growing to 1.0 m. If architectural evidence of ungulate browsing occurred, I assumed this to be the deterrent to plant growth. If there was no architectural evidence of ungulate browsing, I assumed that other factors principally inhibited the growth.

Development of a Browsing History

The architectures described above are produced during the period that the terminal leader grows within the browse zone. A history of browse use can be reconstructed by examining plants of different age (Keigley and Frisina 1998). Dendrochronology can be used to determine when browsing effects occurred.

If a period of intense herbivory followed a period of light-to-moderate browsing, I used the last year in which a tree grew to a height of 1.0 m tall to designate the final year of light-to-moderate herbivory. The presence of retrogressed-type plants established at about the same time offered evidence that browsing caused the latter period of growth inhibition.

Conversely, if a period of light-to-moderate browsing followed a period of intense browsing, the first year in which a tree grew to 1.0 m tall was used to designate the initial year of light-to-moderate herbivory. The presence of released-type individuals established prior to the transition year suggested that browsing influenced the early period of growth inhibition.

RESULTS AND DISCUSSION

Chronologic Distribution of Architectures

All 14 trees in Stand 1 were of uninterrupted-growth-type architecture and of about the same height and dbh. All had heart rot and could not be aged fully. One individual contained 140-150 growth rings in the intact portion of the wood outside the rot. The establishment year for this tree must have preceded the 1840s-1850s. Heart rot in living trees and dead trees of similar stature indicated that trees in Stand 1 were reaching maximum longevity.

All 45 trees in Stand 2 were of uninterrupted-growth-type architecture and of about the same size and dbh. Heart rot also was common in these, and I could successfully age only 4 trees. Their years of establishment were 1877, 1892, 1893, and 1894. Given their similar size, all 45 trees were likely established within this approximate span of years.

All three architectural categories were represented in Stand 3. I successfully cored 51 trees at the 0.3 and 1.0 m heights. These trees were established between 1918-1968: 40 were classified as uninterrupted-growth-type and 11 tentatively as released type.

Approximately 3,000 individuals in Stand 3 ranged in height from ≤ 10 cm to 1.5-m tall. Most of these individuals were classified into the combined arrested- and retrogressed-type category. A few short individuals (≤ 20 cm) were classified into the uninterrupted-growth type category. Browsing by elk occurs primarily during the winter, so I attributed the uninterrupted-growth type architecture of smaller individuals to protection by snowpack. As described above, the youngest individual to grow to tree stature was established in 1968. Therefore, except for plants short enough to be protected by snowpack, all individuals established after 1972 exhibit arrested- or retrogressed-type architecture. One of the largest individuals in the combined arrested- and retrogressed-type category was 1.5 m tall and was determined to have been established in 1972.

Confirmation of Release

I plotted elongation period against establishment year for plants in Stand 3, which I could age at both 0.3 and 1.0 m (Fig. 4). A negative correlation between elongation period and establishment year occurred during two periods, 1924-1947 (Y = 1278 - 0.66X, $R^2 = 0.47$, n = 33) and 1947-1968 (Y = 1965 - 0.74X, $R^2 = 0.55$, n = 17). A period of inhibited growth followed by release from that inhibition produced such a pattern.

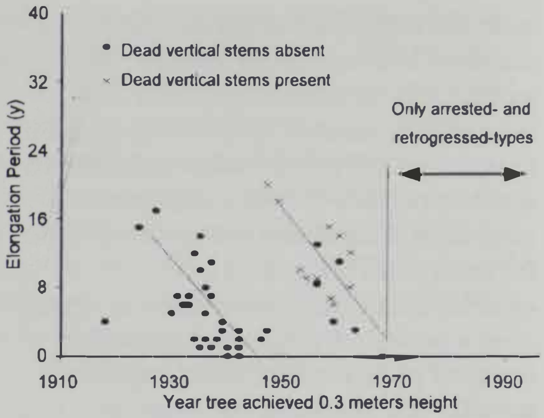

Figure 4. *Relationship between year of establishment and time required to grow from 0.3 m to 1.0 m. The negative slopes mark periods of inhibited growth.*

The lower trunk of trees established from 1924-1947 did not fork, indicating that their terminal leaders were not intensely browsed when the plants were young and short. Other factors, such as drought (Houston 1982), must have played a role in growth inhibition. Although some browsing likely occurred, I attribute the height-growth inhibition that began in 1924 (Fig. 4) primarily to drought. Height growth resumed when the drought ended in the late 1930s (Fig. 4).

Eleven trees (the Xs in Fig. 4) established between 1947-1962 had live stems that forked from dead, near-vertical stems. Some of these dead stems were similar in appearance to heavily-browsed arrested- and retrogressed-type individuals nearby. For example, the dead stem at the base of the tree in Fig. 3 is similar in appearance to the retrogressed-type cottonwood shown in Fig. 2. These dead stems appeared to be the remains of terminal leaders that had been browsed when the plants were young.

The inhibition of growth during 1947-1962 was seemingly browsing-related, which would confirm my tentative assignment of these individuals to the released-type category. Five of the remaining trees established during these years did not show clear evidence of intense browsing, but experienced some degree of inhibition.

History of Browsing at the Site

Stands 1 and 2 (the oldest stands) contained all uninterrupted-growth-type individuals. Stand 3 contained (1) older uninterrupted-growth-types, (2) middle-aged, uninterrupted-growth- and released-type individuals, and (3) younger-aged uninterrupted-growth and arrested- and retrogressed-type individuals. These architectures indicated a four-phased browsing history (Fig. 5).

In phase 1, the older uninterrupted growth individuals in Stands 1, 2, and 3 grew to tree stature during a period of light-to-moderate browsing. However, there are substantial gaps in the phase 1 record from the 1800s to 1924 and the browsing levels that existed during these gaps was not determined from the architectural evidence present at this site. From 1924 to the end of phase 1, the record is nearly continuous and the validity of the reconstructed history is more certain.

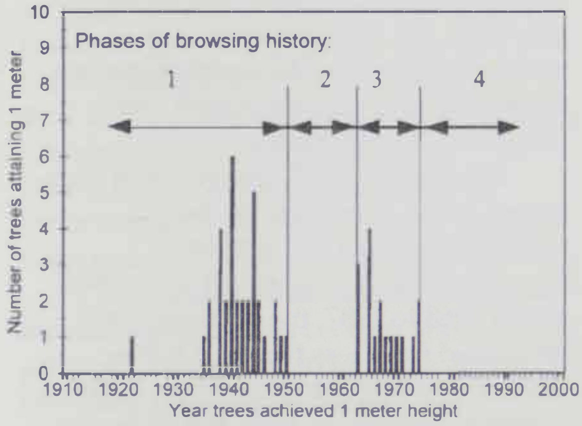

Figure 5. *Frequency diagram describing the number of trees attaining 1.0 m in a given year. Over the past century, cottonwood at the study site experienced a four-phase browsing history, the transition years of which were based on whether or not browsing permitted tree-growth to 1.0 m tall.*

The released-type trees established between 1947 and 1962 are evidence of a period of intense browsing followed by a period of light-to-moderate browsing. The period of intense browsing, phase 2, followed the early period of light-to-moderate browsing, phase 1, identified above. Growth of the released-type plants to tree stature suggests a subsequent period of light-to-moderate browsing (phase 3). The arrest and retrogression of individuals established since 1968 suggests intense browsing at the present time (phase 4).

No cottonwoods attained a height of 1 m during the period 1952 to 1962 (Fig. 5) even though individuals were established during this period (see distribution along the X-axis, Fig. 4). I attributed inhibition of height growth during this period to browsing. The transition between phase 1 (light-to-moderate browsing) and phase 2 (intense browsing) is marked by the final year (1951) that a tree grew to a height of 1 m. Phase 2 occurred between 1952 and 1962, when no trees grew to 1 m tall.In 1963, three individuals grew to a height of 1.0 m (Fig. 5), which marked the beginning of a period of light-to-moderate browsing: phase 3. The arrested- and retrogressed-type plants of stand 3 suggest that current browsing is intense: phase 4. The year of transition between phase 3 and phase 4 is marked by the final year (1974) that a tree grew to a height of 1 m (Fig. 5). Retrogressed-type individuals in stand 3 experienced an early period of light-to-moderate browsing, phase 3, followed by intense browsing: phase 4. The largest, possibly oldest, retrogressed-type individual in stand 3 was established in 1972. The retrogression of this individual a few years after its establishment conforms closely with the 1974 date for transition to intense herbivory as determined by final tree growth to 1.0 m.

I do not imply that browsing levels of cottonwood changed abruptly in the exact years described above. The methods I used provide a consistent way to identify and describe transitions in browsing intensity.

History of Elk

The size of the northern elk herd prior to the establishment of YNP is unknown and the accuracy of early numbers reported after that are subject to question. After a period of market hunting during 1871-1877, Norris (1877) described YNP's northern elk herd as "decimated." After the grey wolf (*Canis lupus*) was reduced and elk were protected from hunting inside the park, the northern herd increased (Norris 1879). By 1886, it was reported that there was more game in the park "than was ever known before" (Wear 1886). In 1915, Smith *et al.* (1915) reported the northern herd to number 27,800 elk. The number of elk wintering in the park was believed to have increased because settlement and hunting along the park's borders blocked the elk's access to an ancestral winter range that extended north of the park (Pitcher 1905, Smith *et al.* 1915, Graves and Nelson 1919).

Wright and Thompson (1935) reported the northern range in "deplorable" condition in 1929 due to overgrazing. From 1935 to 1968, the northern herd was culled to prevent further range deterioration (Houston 1982). By 1968 the northern herd had been reduced to less than 4,000 elk (Coughenour and Singer 1996). But the killing of elk in a national park was controversial (U.S. Senate 1967), and the culling program was halted in 1968. The northern elk herd then increased to more than 23,000 by 1987 (Coughenour and Singer 1996).

Hypotheses Testing

There are two general schools of thought regarding the decline of YNP's woody plants. According to one school, the declines were caused by increased browsing pressure from increased numbers of elk that winter on the northern range (Wright and Thompson 1935, Leopold *et al.* 1963, Kay 1990). According to the other school, the number of elk wintering on the northern range has fluctuated within the natural limits of variability, and decline in woody plants has been influenced by a complex interaction between climate change, fire, mammalian predators, and beaver abundance (Singer and Cates 1995). To date, neither of these hypotheses has been tested, nor have methods of supporting or refuting them been developed.

Here I offer a method to test the hypothesis that the decline in woody plants is primarily due to increased browsing pressure by an increasing elk population. This method is based on the premise that elk prefer some browse species over others.

For example, at a site where aspen is intensely browsed, Douglas fir may be moderately browsed, and spruce may not be browsed at all (pers. obs.). When highly preferred browse species are depleted, elk then consume less preferred species. The onset of intense browsing may occur in a rank order sequence of preference.

In northern YNP, the nature of such a rank order sequence can be determined from the history of browsing that has occurred since 1968. From 1968 to 1987, the northern herd increased from less from 4,000 (the census was 3,172) to more than 23,000 (census, 18,193). In 1974, the browsing intensity of cottonwood at the study site changed from light-to-moderate to intense. The northern herd was censused at 12,607 in that year (Coughenour and Singer 1996). Cottonwood browsing intensity since 1968 has consisted of two phases, an early phase of light-to-moderate browsing, and a later phase of intense browsing. There was no comparable two-phase change in climate. The post-1968 increase in browsing intensity best corresponds to a four-fold increase in elk number.

Architecture-based methods can determine the post-1968 browsing history of aspen, lodgepole pine, Douglas fir, and spruce. Over much of the northern range, these species appear to exhibit a pattern similar to that of cottonwood: older individuals exhibit uninterrupted-growth type architecture, while younger individuals exhibit retrogressed- and arrested-type architectures. Based on the post-1968 browsing histories, the species can be ordered in the sequence in which intense use began. Because elk use varies across the northern range, the actual transition years may vary. However, because the sequence is an expression of current browse preference by elk, the sequence should be identical throughout the northern range.

The cause of the post-1968 increase in browsing intensity is understandable given the six-fold increase in elk number. It is the cause of the pre-1968 increase in browse use that has been controversial. For example, was the increase in cottonwood browsing in 1952 at the study site caused by climate change? By use of the methods I describe, we can determine the rank order sequence in which browse species were intensely used prior to 1968.

I hypothesize that the increase in browse use early this century was primarily caused by an increase in browsing pressure by the elk population. That hypothesis will not be supported if the following are not upheld: 1) the rank order sequence of change in browse use earlier this century will be the same as the rank order sequence of browse use that occurred after 1968, and 2) all sites on the northern range will exhibit a similar pre-1968 rank order sequence.

It seems unlikely that the influences, such as climate-change, fire, and beaver abundance, described by Singer *et al.* (1994) would produce, earlier this century, the same rank order sequence of browse use that occurred after 1968 in response to a six-fold increase in elk number. The influence of such factors should vary with topography and location. I would expect different rank order sequences to occur in different parts of the northern range. The methods and test that I propose provide a way to address a controversial issue on northern YNP elk winter range.

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LITERATURE CITED

Bergström, R. and K. Danell. 1987. Effects of simulated winter browsing by moose on morphology and biomass of two birch species. J. Ecol. 75:533-544.

Bilbrough, C.J. and J.H. Richards. 1993. Growth of sagebrush and bitterbrush following simulated winter browsing: mechanisms of tolerance. Ecol. 74:481-492.

Chase, A. 1987. Playing God in Yellowstone. Harcourt Brace Jovanovich, Publishers. New York, NY.

Cole, G.F. 1958. Range Survey Guide. State of Montana Department of Fish and Game. Helena, MT.

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

Despain, D.G. 1990. Yellowstone Vegetation. Roberts Rinehart Publishers. Boulder, Colorado.

Despain, D.G., D. Houston, M. Meagher, and P. Schullery. 1986. Wildlife in Transition. Roberts Rinehart, Inc. Publishers. Boulder, CO.

Everitt, B.L. 1968. Use of the cottonwood in an investigation of the recent history of a flood plain. Am. J. Sci. 266:417-439.

Ferguson, R.B. and J.V. Basile. 1966. Topping stimulates bitterbrush twig growth. J. Wild. Manage. 30:839-841.

Graves, H.S. and E.W. Nelson. 1919. Our national elk herds: A program for conserving the elk on national forests about the Yellowstone National Park. USDA Circular 51. US Government Printing Office. Washington, D.C. 34 pp.

Harrington, H.D. 1964. Manual of the Plants of Colorado. Swallow Press Inc. Chicago, IL.

Houston, D.B. 1982. The northern Yellowstone elk: ecology and management. MacMillan Publishing Company, Inc., New York, New York. 474 pp.

Kay, C.E. 1990. Yellowstone's northern elk herd: A critical evaluation of the "natural regulation" paradigm. Dissertation, Utah State University, Logan, Utah. 490 pp.

Kay, C.E. 1997. Viewpoint: Ungulate herbivory, willows, and political ecology in Yellowstone. J. Range Manage. 50:139-145.

Keigley, R.B. 1997a. A growth form method for describing browse condition. Rangelands 19:26-29.

Keigley, R.B. 1997b. An increase in herbivory of cottonwood in Yellowstone National Park. Northwest Sci. 71:127-136.

Keigley, R.B. and M.R. Frisina. 1998. Browse evaluation by analysis of growth form. Montana Fish, Wildlife, and Parks. Helena, MT. 149 pp.

Leopold, A.S., S.A. Cain, C.M. Cottam, I.N. Gabrielson, and T.L. Kimball. 1963. Wildlife management in the national parks. Trans. NA Wild. Conf. 24:28-45.

National Park Service. 1988. Management Policies. U.S. Government Printing Office, Washington, D.C.

Norris, P.W. 1877. Annual report of the superintendent, Yellowstone National Park. U.S. Government Printing Office, Washington, D.C.

Norris, P.W. 1879. Annual report of the superintendent, Yellowstone National Park. U.S. Government Printing Office, Washington, D.C.

Pitcher, J. 1905. Annual report of the superintendent, Yellowstone National Park. US Government Printing Office, Washington, D.C.

Riney, T. 1982. Study and management of large mammals. John Wiley and Sons. New York, New York.

Romme, W.H., M.G. Turner, L.L. Wallace, and J.S. Walker. 1996. Aspen, elk, and fire in northern Yellowstone National Park. Ecol. 76:2097-2106.

Singer, F.J. and R.G. Cates. 1995. Response to comment: Ungulate herbivory on willows on Yellowstone's northern winter range. J. Range Manage. 48:563-565.

Singer, F.J., L.C. Mark (sic), and R.C. (sic) Cates. 1994. Ungulate herbivory of willows on Yellowstone's northern winter range. J. Range Manage. 47:435-443.

Singer, F.J. and R.A. Renkin. 1995. Effects of browsing by native ungulates on the shrubs in big sagebrush communities in Yellowstone National Park. Great Basin Nat. 55:201-212.

Smith, C.L., A.A. Simpson, and V. Bailey. 1915. Report on investigations of the elk herds in the Yellowstone region of

Wyoming, Montana, and Idaho. United States Bureau of Biological Survey and United States Department of Agriculture Forest Service. Unpublished report in Yellowstone National Park Archives, Yellowstone National Park, Wyoming. 56 pp.

U.S. Senate. 1967. Hearings before a Subcommittee of the Committee on Appropriations of the United States Senate on Control of Elk Population, Yellowstone National Park. U.S. Government Printing Office, Washington, D.C. 142 pp.

Wear, D.W. 1886. Annual report of the superintendent, Yellowstone National Park. U.S. Government Printing Office, Washington, D.C. 3 pp.

Wright, G.M. and B.H. Thompson. 1935. Wildlife management in the national parks. Fauna of the National Parks No. 2. US Government Printing Office. Washington, D.C. 142 pp.

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EVIDENCE FOR GROUNDWATER SEEPAGE IMPACTS ON THE CENTRAL BITTERROOT RIVER, WESTERN MONTANA

ABSTRACT

Channel instability on the Bitterroot River poses a threat to floodplain property between the towns of Hamilton and Stevensville, Montana. This stretch of river exhibits a complex multi-thread channel pattern characterized by a braided main stem within a network of narrower anastomosing channels covering a floodplain up to 5 km in width. While substantial channel migration and shifting are thought to have occurred in the area, historic changes are undocumented and the processes at work are poorly defined. This investigation employed a comparative analysis of channel features digitized from three sets of aerial photographs spanning a 50-year period to document and quantify historic channel changes of the Bitterroot River. Analysis in a geographic information system indicated that the main braided channel (the braid belt) widened substantially during the first half of the study period. However, lateral channel migration was limited and the positions of bifurcation nodes have remained constant. Evidence is presented suggesting that both the river's multi-channel configuration and tendency for rapid bank erosion are related to groundwater discharge. Groundwater seepage through the channel banks appears to be an important component of bank erosion and channel widening in the study area. Small discontinuous channels on the floodplain appear to be surface expressions of a groundwater discharge network. These observations suggest that groundwater interaction can have large effects on channel and floodplain morphology, and that changes in groundwater flow are among the impacts to be considered when evaluating stream perturbation.

Key Words: stream, anastomosing, braided, channel, morphology, pattern, groundwater, seepage, bank, erosion

INTRODUCTION

The Bitterroot River in Western Montana flows 120 km northward from its mountain headwaters near the Idaho border to its confluence with the Clark Fork River near Missoula, Montana. Through much of its middle course, the river exhibits an unusually complex network of interconnecting braided and anastomosing channels that wander over an extensive valley bottom as wide as 5 km. This portion of the river has also acquired a reputation for channel instability. Local land managers consider a high rate of channel migration and shifting to be a greater hazard to property than flood inundation (Bitterroot Conservation District 1995). State and local government agencies have funded previous investigations into the possible causes for this instability and the feasibility of various bank stabilization options (Cartier and Curry 1980, Simons *et al.* 1981). While substantial channel changes have been observed, previous workers have not systematically

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described the changes or the processes at work. This investigation employed a comparative analysis of channel features digitized from a series of aerial photographs spanning a 50-year period to document and quantify historic channel changes of the Bitterroot River. Mechanisms of channel change and network development were inferred from the relationships between historic changes, field observations, and various physiographic parameters.

PREVIOUS WORK

The Montana Department of Natural Resources and Conservation and the U.S. Natural Resources and Conservation Service published a flood-hazard analysis in which the surface elevations of the Bitterroot River floodwaters were modeled throughout Ravalli County (Bitterroot Conservation District 1993). McMurtrey *et al.* (1972) provided a comprehensive description of the surficial geology, aquifer characteristics, and groundwater budget of the Bitterroot Valley. The multi-channel pattern and associated channel instability has been hypothesized to be a response to aggradation in the central part of the valley related to comparatively recent tectonic movement (Cartier and Alt 1982, Cartier 1984). According to this hypothesis, the multi-channel reach occupies a down-dropped fault block in which valley filling has promoted the development of an extensive braided channel pattern. This idea is based largely on the assumption that the multiple-channel morphology of the central Bitterroot River implies net aggradation. While stream braiding is generally considered to involve processes such as bank erosion, channel widening, and deposition of in-channel bars in a bed-load stream, it is unclear that net aggradation is a necessary prerequisite (Leopold *et al.* 1964). In addition, a wide range of channel morphologies exists within the Bitterroot network, many of which are narrow, sinuous, stable, and well vegetated. Many of these channel branches are better described as anastomosing rather than braided. Anastomosing streams are considered by many authors to be stable multi-channel suspended-load streams of relatively low gradient (Smith and Smith 1980, Harwood and Brown 1993, Rosgen 1994). Anastomosing streams are also described as multiple channels separated by relatively large islands which are excised from the continuous floodplain rather than by bars deposited within the channels (Knighton and Nanson 1992). This process of floodplain dissection is driven by overbank flows that spill on to the floodplain and incise new channels. Carson (1984a, 1984b) described a similar process in certain gravel-bedded streams, which he refers to as "wandering" gravel-bedded streams.

Other authors have addressed stream morphology at the floodplain level, and so accommodate diversity in channel morphology within the framework of a single functioning stream system. In his review of the literature on floodplain morphology, Lewin (1978) distinguished between braid-bar plains with switching zones of active channels, floodplains with stable anastomosing channel networks, and floodplains where a braided main channel with migrating bars is found among multiple meandering accessory channels. This last floodplain type, type F in Lewin's terminology, most closely matches the configuration of the central Bitterroot River.

STUDY AREA

This study investigated the portion of the Bitterroot River between the town of Hamilton in the south to near Stevensville in the north, a distance of about 30 km (Figure 1). The river flows northward in the Bitterroot Valley, an elongate north-trending basin bounded by the Sapphire Mountains on the east

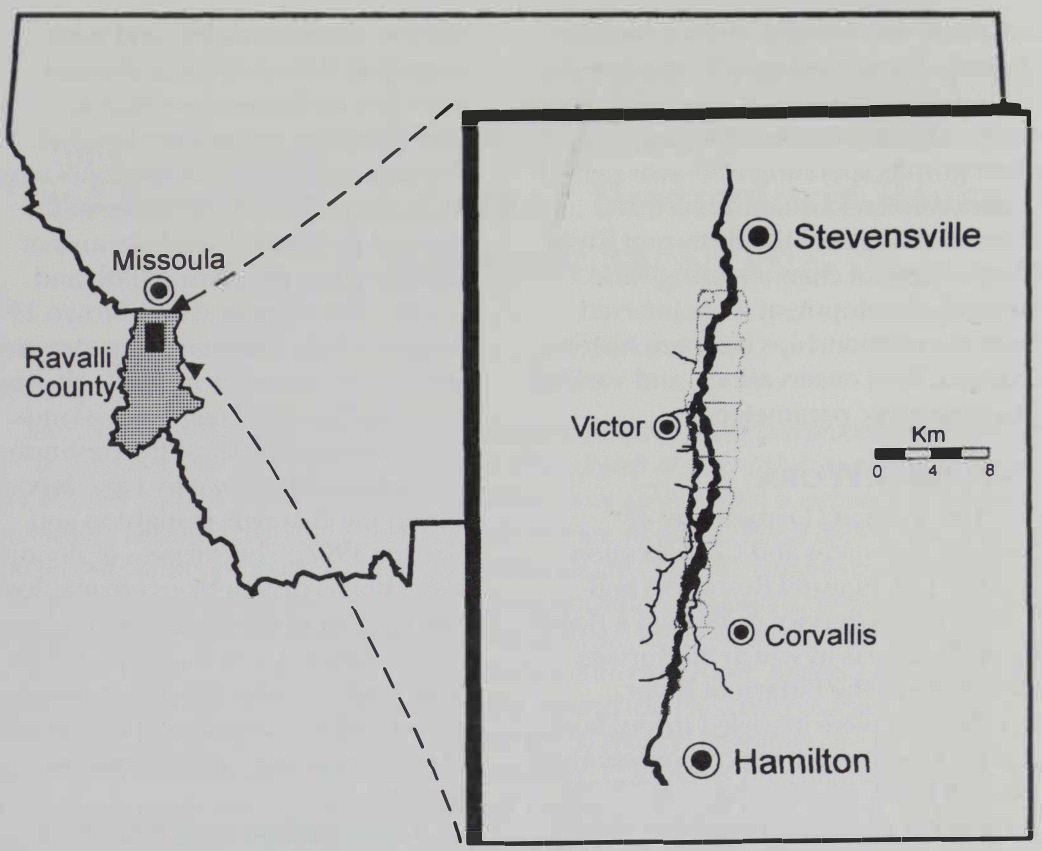

Figure 1: *Study area location.*

and the rugged Bitterroot Mountains on the west. The upper valley south of Hamilton is relatively narrow and the river is generally confined to a single channel. North of Hamilton, the valley widens to an average width of about 11 km and the river divides into numerous channels that spread widely across the bottom land. Channels within this bottom network display great diversity in both morphology and scale. The largest feature is the river's main stem, which can be described as a braided, gravel-bed stream with occasional single-thread reaches. Its bankfull sinuosity is generally 1.2 or less and its average gradient is about 0.0025. At a more detailed level of resolution, numerous active and inactive sinuous channels with fine-grained, well-vegetated banks are seen. Their scale ranges from that of a main-stem channel to that of micro-features observable only in the field. These smaller sinuous channels, as well as some bifurcated branches of the main-stem channel separated by expanses of floodplain, give the river an anastomosing character in many locations. The large Burnt Fork alluvial fan and extensive artificial channelization structures near Stevensville constrict valley bottom width and reduce channel pattern complexity north of the study area.

The Bitterroot River drains a 725,200 hectare (2,800 square miles) watershed and has an estimated bankfull discharge at its confluence with the Clark Fork River of about 410 cubic meters per second (14,450 cfs) (Cartier 1984). Runoff is highest in the spring, with about 55 percent of the river's annual discharge occurring in May and June (McMurtrey *et al.* 1972). Numerous tributaries emerge from the mountain canyons along the valley margins. Except for some westside streams in May and June, the tributaries are mostly dry in their lower courses because of diversions for irrigation and rapid seepage into unconsolidated terrace alluvium along the valley margins (McMurtrey *et al.* 1972).

METHODS

Study Area Partitions

For purposes of comparison, the study area was divided into 15 longitudinal partitions averaging approximately 1.5 km in length (Figures 2A-2B). Partition boundaries were chosen to coincide with changes in valley or river morphology where possible. Morphological parameters for each partition were derived from aerial photographs and used for statistical and spatial analysis.

Aerial Photography

Features visible on aerial photographs from 1937, 1955, and 1987 were digitized for GIS analysis. The 1955 and 1937 photographs have scales of 1:20,000; the scale of the 1987 set is 1:40,000. All visible active and inactive stream channels, areas of bare bed material, vegetated islands and bars, and tributary channels were digitized. Features were classified as follows:

1. Thalweg: The deepest channel of the main river bed, where discharge is maintained at low flow.
2. Braid Belt: A polygonal feature defined as the region occupied by washed bed material and essentially lacking vegetation. This feature ranges from less than 30 meters to more than half a kilometer in width.
3. Overflow channels: Ephemeral light colored gravelly swales that exit the braid belt and arc a short distance over the floodplain before terminating or re-entering the braid belt.
4. Secondary channels: Relatively narrow, stable, often sinuous channels outside the braid belt lacking visible bars or other bed materials. Secondary channels are generally on the order of 10 meters in width, and cut continuously across the floodplain for long distances before intersecting the braid belt.
5. Capillary channels: This end-member class of channels is similar to secondary channels, but is distinguished from them on aerial photographs by frequent and irregular bifurcation, smaller scale, and a lack of continuity. They frequently dissipate into the floodplain before reaching a topological connecting point with the larger channel network.
6. Tributary channels: These occur on terrace surfaces above the floodplain. Upon reaching the valley bottom, tributary channels may enter the braid belt directly or merge with the network of minor floodplain channels.
7. Bars: These are small sparsely vegetated areas lying within the braid belt. They are assumed to be the product of bar deposition within the active channel.
8. Islands: Areas surrounded by braid belt are considered true islands when their large size, irregular shape, and well-established vegetation suggest they are remnants of the floodplain surface that have been circumscribed by channel incision.

Root-mean-square (RMS) errors returned by Tosca digitizing software were less than 10 meters for 22 of 30 photographs digitized. Photographs from the 1937 set were sometimes damaged and contained fewer usable control point features. As a result, three photographs from this set yielded unacceptable RMS errors of 42, 48, and 55 meters that required digital resampling before the separate files could be concatenated into a single coverage. Of the three coverages produced, the 1955 coverage is of the

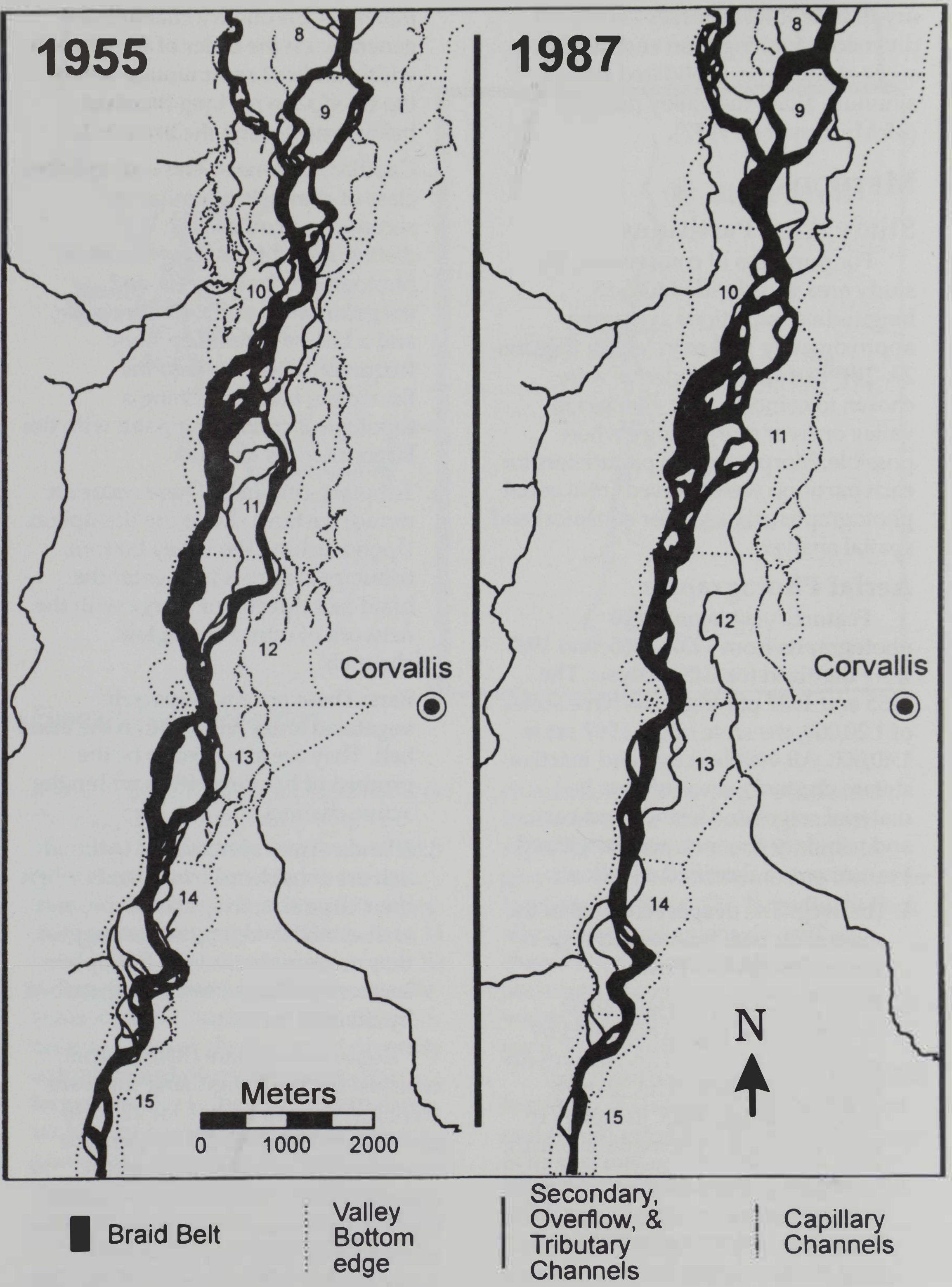

Figure 2A: *Southern half of study area.*

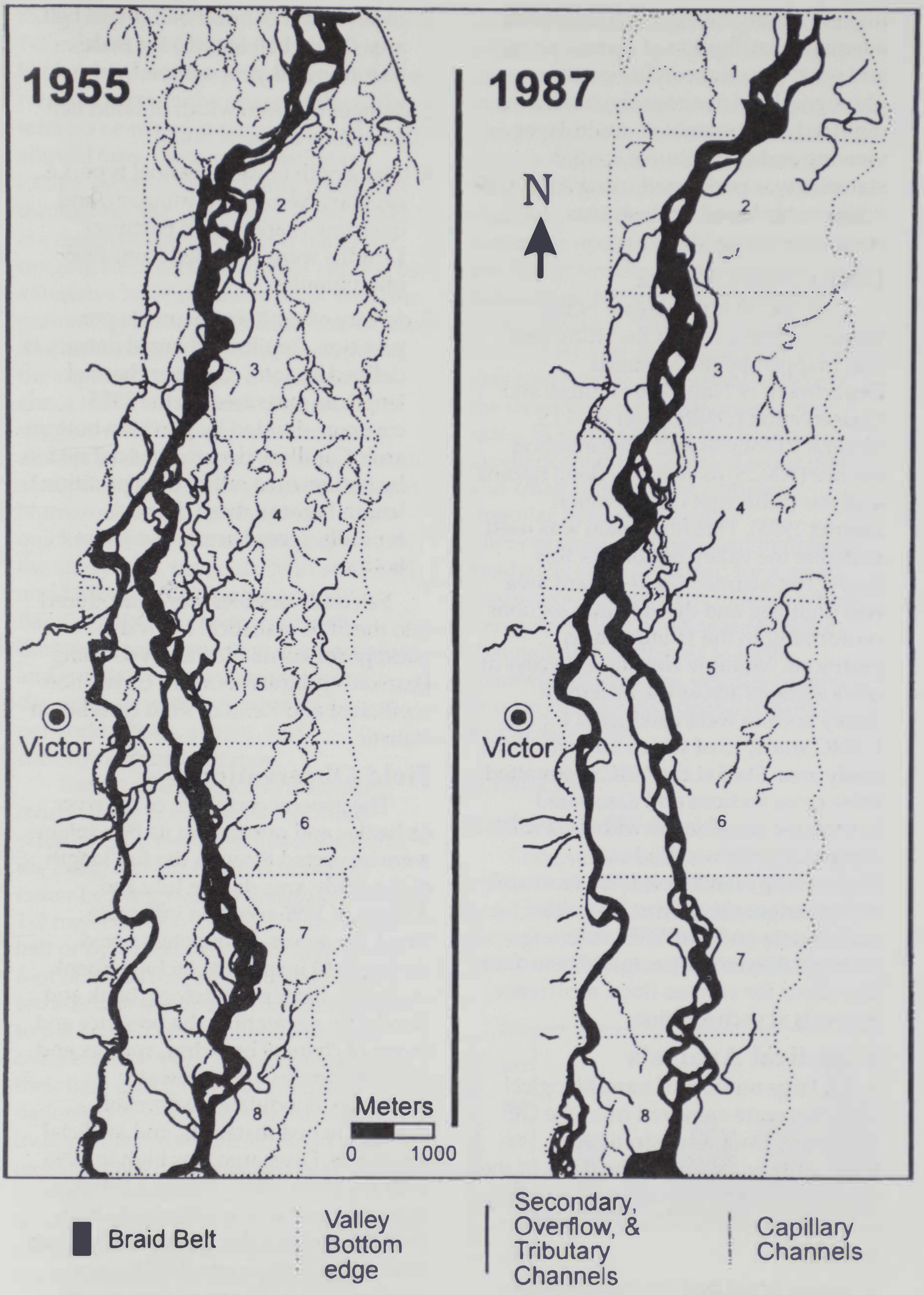

Figure 2B: *Northern half of study area.*

highest quality owing to its large scale, adequate distribution of control points, and good physical condition of the photographs. After coverages were digitized and assembled, multi-layer viewing and extraction of spatial statistics was performed using Atlas GIS while raster-based analysis was conducted using Idrisi.

DNRC/NRCS Data

The 500-year floodplain of the Bitterroot River within the study area was mapped by the Montana Department of Natural Resources and Conservation (DNRC) and the U.S. Natural Resources and Conservation Service (NRCS) as part of a flood hazard analysis (Bitterroot Conservation District 1995). This floodplain was used to define the valley bottom for this study. The mapped flood-hazard area was digitized and divided into sections conforming to the 15 study area partitions. Multiple elevation surveys at cross sections across the Bitterroot Valley bottom were conducted for the DNRC study, 15 of which fall within the study area. Staff at the NRCS formatted these cross sections and associated hydrologic data for use with the WSP2 computer program (National Engineering Handbook 1993) to model water surface elevations. The cross-section data and the WSP2 software were obtained to estimate water surface elevations for various flood recurrence intervals at each location.

Statistical Analysis

A large number of morphological variables were extracted from the GIS coverages. Data were stratified temporally according to the dates of the three sets of aerial photos, and spatially according to partition. These variables included:

1. area of braid belt for each partition and year mapped. Bars are included in braid belt area, islands are excluded;
2. mean width of braid belt (braid belt area/braid belt length) for each partition and year mapped.
3. changes in mean width of braid belt partitions through time;
4. total length of each channel type, i.e., capillary, secondary, tributary, and overflow channels per partition. Lengths were extracted from 1955 photographs;
5. density of capillary channels per partition. Capillary channel density is defined by total capillary channel length as measured on the 1955 coverage divided by partition bottom area. Capillary density was defined by bottom area rather than partition length because these channels typically spread across the entire bottom.

Selected variables were introduced into the SPSS statistical software package for correlation analysis using Pearson's product-moment correlation coefficient and Kendall's tau correlation statistic.

Field Observation

The general condition of the river, its banks, and portions of its floodplain were inspected through the full length of the study area during July and August of 1996 using an inflatable kayak for access. Parameters noted during field inspection included bank materials, bank morphology, bank and floodplain vegetation, the presence and forms of channel branches, springs and other evidence of groundwater discharge, floodplain microrelief, changes in bed materials, and artificial structures. Discharge was high in 1996, with the river rising during a February thaw and sustaining a relatively high level throughout the spring. Daily mean flow at the Darby gage (USGS gage number 12344000) attained its eighth highest level on record with a discharge of 9,320 cfs on June 9.

Bitterroot River banks within the

study area were observed to be typically 1-2 meters high and nearly vertical. Higher banks occur primarily where the river encounters the edges of the valley terraces or where it carves into tributary alluvial fans. Bank composition is locally variable, but broadly consistent throughout the study area. Most banks are composed of coarse bed materials ranging from sand to cobbles capped by a massive layer of loamy fines. This fine-grained layer ranges in thickness from a few centimeters to the full thickness of the exposed bank, but it is normally about half a meter thick. Features suggestive of seepage erosion, such as alcoves in the bank and detached blocks along the channel margins, are common. Numerous seeps, springs, and quicksand were observed in portions of the study area, particularly in sections 9 and 10 between Corvallis and Victor. Bank vegetation varies from well-drained areas supporting sparse grasses and weeds to moist clayey areas of dense brush with extensive root networks. Pines, aspens, and cottonwoods are common.

Details of channel and floodplain morphology not apparent on aerial photography were also documented in the field. The braid belt is bounded either by a vegetated floodplain surface 1-2 meters above the level of the braid belt or by a relatively high scarp at the foot of a Quaternary or Tertiary valley terrace. The floodplain surface adjacent to the braid belt contains numerous overflow channels. Though usually dry, their bare gravelly beds and debris deposited upstream of obstructions indicate they have carried flood waters recently. Overflow channels may become increasingly incised in the downstream direction before re-entering the braid belt or terminate on the floodplain where their discharge is captured by portions of the channel system outside the braid belt.

Secondary channels were observed to often grow in discharge in the downstream direction by ground water additions or by capturing flow from a range of other minor channels. They eventually discharge into the braid belt. Field observation confirmed that a continuous gradation in scale exists from secondary channels to capillary channels, which were observed to often terminate upstream at steep headcuts in the fine-grained vertical accretion deposits of the floodplain. Although many capillary channels were dry during July and August of 1996, water was observed to emerge at the base of the terminal headcuts in many other cases. In some parts of the floodplain, capillary channels, isolated scour pits, and small rills occur in complex irregular networks. Similar discontinuous channels terminating in headwalls were described for a small anastomosing stream in Ireland, where they were called blind anabranching channels and attributed to local channelization of low velocity overbank flood waters around debris (Harwood and Brown 1993).

RESULTS

Braid Belt Widening

Comparison between data from different photo sets indicates that the braid belt width increased considerably throughout most of the study area from 1937 to 1955 (Figure 3). The 1937 braid

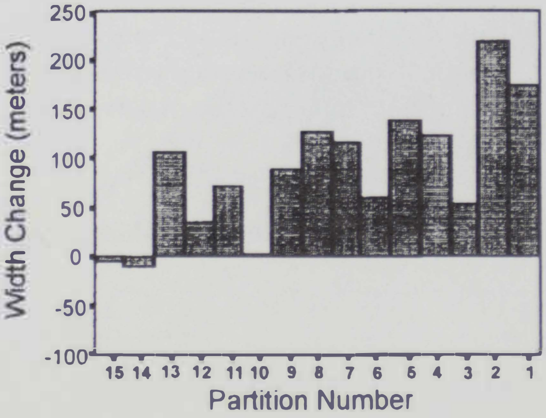

Figure 3: *Change in braid belt width 1937-1955.*

belt covered 493 hectares over all partitions. The average width of the 1937 braid belt was 200 meters. The 1955 and 1987 braid belts covered 685 and 769 hectares for average widths of 278 and 313 meters, respectively. This constitutes a 39 percent increase in width from 1937 to 1955. Following 1955, changes in braid belt width become more erratic. Continuing increases in some areas were balanced by narrowing in others, resulting in a net increase in braid belt width from 1955 to 1987 of 12.6 percent. The total increase in braid belt width between 1937 and 1987 was 56.5 percent. These relationships are summarized in Table 1. After 1955, widening continued in some partitions, although many areas remained stable or narrowed (Figure 4).

Changes in Braid Belt Position

Despite the Bitterroot River's reputation for rapid migration and continual large channel displacements, the positions of the braid belt and extra-braid belt channels have changed little over most of the study area. Lateral migration observed during the 50-year period documented on the aerial photographs is generally small relative to braid belt and floodplain dimensions. The 1901 edition USGS 1:125,000 Missoula and Hamilton quadrangles depict an essentially static channel configuration since the area was surveyed in 1887 and 1888. Despite rapid bank erosion, lateral migration of the braid belt appears to be limited by a tendency for point bars to wash out. Bends in the thalweg were observed to grow in amplitude until development of a cut-off chute restored flow to a former straighter course away from the braid belt margin. Bankfull sinuosities of the main stem channels rarely reach values as great as 1.3 except locally along the river's west branch around an extremely large island (8 km long) near Victor. Portions of this relatively narrow channel are somewhat entrenched at the foot of a valley-side terrace and lack a well-developed braid belt.

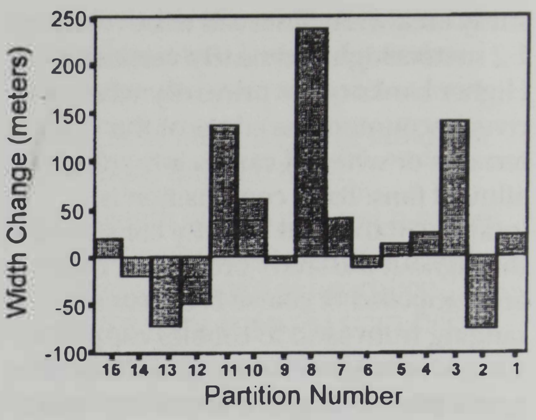

Figure 4: *Change in braid belt width 1955-1987.*

Changes in the magnitudes of existing channels can produce changes in the location of the river's thalweg even though the positions of individual channels and points of bifurcation network are generally stable through time. Where two or more channel branches are separated by islands or expanses of floodplain, one may widen and intercept the bulk of the river's discharge while other channel branches fill. However, incision of new large-scale channels was not observed.

Table 1: *Changes in Braid Belt Width.*

	1937	1955	1987	1937-1955	1955-1987	1937-1987
Mean Braid Belt Width (m)	200	278	313			
Change in Braid Belt Width (m)				78	35	113
Percent Braid Belt Width Increase				39	12.5	56.5
Percent Total Increase 1937-1987				69	31	100

Statistical Analysis

Few interesting relationships emerged from the large number of variables subjected to correlation analysis. In general, only known relationships produced significant correlations. For example, braid belt width correlates strongly with valley bottom width. A very wide braid belt can clearly not exist in a narrow valley. One relatively weak but nonetheless significant correlation lacking obvious explanations was between capillary channel density and braid belt expansion during 1937-1955. Capillary density correlates with 1937-1955 braid belt widening at the 95 percent confidence level (R = 0.594).

DISCUSSION

Widening of the braid belt has been the dominant change observed in the main stem Bitterroot River during the study period, particularly between 1937 and 1955. Braid belt widening on the Bitterroot River can probably be attributed to bank recession and loss of the floodplain surface. Detachment of large blocks of adjacent floodplain was observed to be a major contributor to bank erosion on the Bitterroot River following the 1996 run-off season (Figure 5). These blocks were often observed intact where they fell at the base of the bank, indicating the failures occurred after peak flows had passed. Numerous authors have attributed this type of bank failure to groundwater sapping (Schumm and Lichty 1963, Twildale 1964, Schumm and Phillips 1986, Simon and Hupp 1986, Keller *et al.* 1990). Block detachment commonly occurs during flood recession when water held in the saturated floodplain materials discharges back into the river channel. This return flow into the channel causes erosion of the more permeable layers in the bank profile. After being undermined in this fashion, the upper portion of the bank may break loose and fall into the channel as an

Figure 5: *Example of bank block failure (kayak paddle for scale).*

intact block. The process was described in detail by Keller *et al.* (1990) who identified 4 modes of block failure related to seepage along sand seams or other weak permeable layers in the bank profile on a section of the Ohio River. In addition to the detached blocks themselves, pipes and slit-like cavities at the base of banks and alcove in the banks where seepage is concentrated are described as visual evidence of seepage erosion. Such cavities and alcoves were observed on the Bitterroot River. The hydraulic gradient present where groundwater is seeping into a channel also contributes to bank erosion by lowering the flow and gravitational forces necessary to entrain particles of bank material (Burgi and Karaki 1971, Dunne 1990). In addition to the numerous block failures observed through the study area, bank structure and demonstrated groundwater discharge on the floodplain suggest that bank recession on the Bitterroot River can be attributed in part to seepage processes.

Observation of channel widening on the Cimmaron River of southwestern Kansas suggests that floodplain elimination may be typical of degradation on certain streams in semi-arid environments (Schumm and Lichty 1963). As defined by Schumm and Lichty, the term "degradation" includes any net loss of sediment from a portion of the stream and floodplain system. The authors proposed that channel widening may be an alternative to channel incision as an expression of degradation; the floodplain is eliminated while the bed elevation remains the same. Channel expansion on the Cimmaron was postulated to be initiated by the destruction of bank vegetation during the maximum flood on record. Vegetation loss was then exacerbated by a prolonged dry period that prevented new bank vegetation from becoming established. This does not appear to be the case for widening of the Bitterroot River braid belt. Precipitation records for Hamilton and Stevensville reveal no notable deficits during the 1937-1955 period of pronounced Bitterroot braid belt widening. Nor does this period contain extraordinarily high or frequent large peak flows as measured at the Darby gaging station (the maximum peak flow on record occurred in 1947, but it is not extraordinary compared to other recorded peaks). One possible impact that has been overlooked is the rise of irrigated agriculture in the Bitterroot Valley. Large-scale irrigation works were initiated near the turn of the last century. The Big Ditch, a major project delivering water through the valley from Como Reservoir (south of Hamilton) to Stevensville, was completed in 1909. During the apple boom of the early 1900s, irrigated and cultivated acreage increased substantially, as did agricultural production. For example, apple production in the area increased 20-fold from 20,000 bushels in 1898 to 400,000 bushels by 1919 (Zeisler 1982). Previous researchers have demonstrated that groundwater levels on the valley terraces respond directly to recharge from irrigation ditches (McMurtrey *et al.* 1972, Finstick 1986, Uthman 1988). Static well levels are reported to rise rapidly in May and June, remain high throughout the irrigation season, and decline after irrigation ends. Whether this source of recharge materially affects groundwater flow near the river banks is uncertain. Alternatively, braid belt widening in the central valley may be viewed as a return to the river's normal state following a period of abnormal channel narrowness. A period of low flow beginning about 1930 is reported to have created the impression that the Bitterroot River was a stable meandering stream (Simons et al 1981). However, this claim is difficult to evaluate as stream gaging records for the river begin in 1937 and earlier channel conditions are poorly documented.

The intricate network of small-scale floodplain channels in much of the study area may also be genetically linked to groundwater discharge. The significant correlation between braid belt widening during 1937-1955 and capillary channel density in the anastomosed central part of the valley (R = .594, probability < .05 and tau = .352, probability = .07) suggest that the two processes may be related to a common factor. A theoretical framework for drainage system development through groundwater discharge has been proposed by DeVries (1976), who describes a groundwater outcrop-erosion model (GOEM). In the GOEM model, surface channels are viewed as groundwater "outcrops," and are considered to be components of a groundwater discharge system. The model is described as one end-member in a spectrum of erosion models where the opposite end is occupied by overland flow as defined by Horton (1945). GOEM is applied to relatively flat areas of high subsurface permeability and moderate precipitation rates where water enters into subsurface flow before appearing in the surface channel system (DeVries 1976). The requirements of GOEM seem to match the circumstances of the Bitterroot Valley. Most tributary and irrigation discharge infiltrates into the permeable alluvium of the low valley terraces before discharging on the flat valley bottom. Measurements of static well levels indicate that groundwater circulation in the central valley is predominantly toward the valley center, where flow turns northward and discharges into the Bitterroot River (McMurtrey *et al*. 1972, Finstick 1986, Uthman 1988). Woessner (1998) describes such situations, where subsurface flow entering permeable floodplain materials is refracted parallel to the direction of stream flow, as "fluvial plain" groundwater systems. The fluvial plain is a zone of dynamic groundwater-surface water exchanges, and the stream channel is regarded as one of its components.

Many of the morphological characteristics defining capillary channels of the Bitterroot floodplain are indicative of a significant subsurface connection. Lack of connectivity within the network and large upstream and downstream variations in discharge within individual channels are solid evidence of a substantial subsurface flow component. Many of the minor floodplain channels may be remnants of formerly larger channels that have filled incompletely, perhaps because of the maintenance of a base groundwater flow. In other cases, groundwater discharge may be actively excavating channels by the retreat of headcuts at the end of small channels or in alcoves in the banks of larger channels. The suggested process is analogous to basal sapping at the base of gully headcuts as described by Higgins *et al.* (1990). The capture of overbank flood flow by these incipient channels is probably also an important factor in their growth and network development.

CONCLUSIONS

The main Bitterroot River channel has widened considerably since 1937. Much of the widening occurred between 1937 and 1955. In spite of the rapid bank erosion during this period, channel migration has been modest relative to floodplain and channel dimensions. Channel and floodplain morphology on the central Bitterroot River may be substantially impacted by groundwater discharge on the valley floor. Bank erosion on the main channels is characterized by block failures, which appear to be promoted by groundwater seepage through the banks. Groundwater discharge on the floodplain may also contribute to floodplain dissection and development of anastomosing characteristics of the

Bitterroot channel network. Causes for the dramatic channel widening of the central Bitterroot River after 1937 are uncertain and no doubt complex. Climatic fluctuations, floodplain deforestation, livestock grazing, and upland erosion are sometimes cited. However, changes in the rate of groundwater discharge through the river banks, possibly related to intensive irrigation in the valley, is also a potential impact in this system.

LITURATURE CITED

Bitterroot Conservation District. 1995. *Flood plain management study, Bitterroot River, Ravalli County, Montana.* Bozeman, MT: U.S. Natural Resources Conservation Service.

Burgi, A.M. and S. Karaki. 1971. Seepage effects on channel bank stability: Proceedings of the American Society of Civil Engineers 7968, IR1, *Journal of the Irrigation and Drainage* Division p. 59-72.

Carson, M.A. 1984a. Observations on the meandering-braided river transition, the Canterbury Plains, New Zealand: Part one. *New Zealand Geographer* 40(1):12-19.

--- 1984b. Observations on the meandering-braided river transition, the Canterbury Plains, New Zealand: Part two. *New Zealand Geographer* 40(2):89-99.

Cartier, K.D. and D. Alt. 1982. The bewildering Bitterroot, the river that won't behave. *Montana Magazine* March-April:52-53.

Cartier, K.D. and R.R. Curry. 1980. *Erosion and stream channel stability in the Bitterroot River watershed, Southwestern Montana.* Helena, MT: Water Quality Bureau, Department of Health and Environmental Sciences.

Cartier, K.D. 1984. *Sediment, channel morphology, and streamflow characteristics of the Bitterroot River drainage basin, Southwest Montana.* University of Montana Master's Thesis.

Coleman, J.M. 1969. Brahmaputra River: Channel process and sedimentation. *Sedimentary Geology* 3:129-239.

Dunne, T. 1990. Hydrology, mechanics, and geomorphic implications of erosion by subsurface flow. In: *Groundwater Geomorphology,* Geological Society of America Special Paper 252. ed, Thomas Dunne, pp. 1-28.

De Vries, J.J. 1976. The groundwater outcrop-erosion model; evolution of the stream network in the Netherlands. *Journal of Hydrology* 29:43-50.

Finstick, S.A. 1986. *Hydrogeology of the Victor and Bing quadrangles, Bitterroot Valley, Montana.* University of Montana Master's Thesis.

Harwood, K., and A.G. Brown. 1993. Fluvial processes in a forested anastomosing river: Flood partitioning and changing flow patterns. *Earth Surface Processes and Landforms* 18(8):741-748.

Higgins, C.G., B.R. Hill, and A.K. Lehre. 1990. Gully Development. In: *Groundwater Geomorphology,* Geological Society of America Special Paper 252. ed, Thomas Dunne, pp. 1-28.

Horton, R.E. 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin* 56:275-370.

Keller, E.A., G.M. Kondolf, and D.J. Hagerty. 1990. Groundwater and fluvial processes; selected observations. In: *Groundwater Geomorphology,* Geological Society of America Special Paper 252. ed, Thomas Dunne, pp. 319-340.

Knighton, A.D., and G.C. Nanson. 1993. Anastomosis and the continuum of channel pattern. *Earth Surface Processes and Landforms* 18(7):613-625.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. *Fluvial Processes in Geomorphology*. New York: Dover.

Lewin, J. 1978. Floodplain geomorphology. *Progress in Physical Geography* 2(3):408-37.

McMurtrey, R.G., R.L. Konizeski, M.V. Johnson and J.H. Bartells. 1972. *Geology and water resources of the Bitterroot Valley, Southwestern Montana*. U.S. Geological Survey Water-Supply Paper 1889.

National Engineering Handbook (1993). Part 630, Chapter 31. SCS Central Technical Unit.

Rosgen, D.L. 1994. A classification of natural rivers. *Catena* 22(3):169-199.

Schumm, S.A. and L. Phillips. 1986. Composite channels of the Canterbury Plain, New Zealand: A Martian analog? *Geology*, vol. 14, 326-329.

Schumm, S.A. and R.W. Lichty. 1963. *Channel widening and flood-plain construction along the Cimarron River in southwestern Kansas*. USGS Professional Paper 352-D, pp. 71-88.

Simon, Andrew and C.R. Hupp. 1986. Channel widening characteristics and bank development along a reach of Cane Creek, West Tennessee. In *Selected Papers in the Hydrologic Sciences 1986*, ed. Seymour Subitzky, 113-126. . USGS Water-Supply Paper 2290.

Simons, D.B., R-M. Li, S. Ellis, and J.D. Schall. 1981. *A feasibility study for a streambank stabilization program for the Bitterroot River, Montana*. Helena, MT: Water Resources Division, Montana Department of Natural Resources and Conservation.

Smith, D.G. and N.D. Smith. 1980. Sedimentation in anastomosed river systems: Examples from alluvial valleys near Banff, Alberta. *Journal of Sedimentary Petrology* 50(1):157-164.

Twildale, C.R. 1964. Erosion of an alluvial bank at Bidrwod, South Australia. *Zeitschrift fur Geomorphologie*, vol. 8, 189-211.

Uthman, W. 1988. *Hydrogeology of the Hamilton North and Corvallis quadrangles, Bitterroot Valley, Southwestern Montana.* University of Montana Master's Thesis.

Woessner, W.W. 1998. Changing views of stream-groundwater interaction. In: *Proceedings of the Joint Meeting of the XXVIII Congress of the International Association of Hydrogeologists and the Annual Meeting of the American Institute of Hydrologist: Gambling with Groundwater*, American Institute of Hydrology. Las Vegas, Nevada, Sept 28-Oct. 2, 1998.

Zeisler, Dorothy J. 1982. *The history of irrigation and the orchard industry in the Bitter Root Valley.* University of Montana Master's Thesis.

Keith B. Olson

AN NP-COMPLETE PROBLEM ARISING FROM A BRUTE FORCE SEARCH FOR LIMITS OF SUBSETS OF B^N

ABSTRACT

A brute force search for limits of a subset of $B^n = \{0,1\}^n$ *is shown to be NP-Complete. This is accomplished by demonstrating equivalence to an extension of the known NP-complete problem SATISFACTION. No results are postulated concerning sufficient conditions for the existence of such a limit.*

Key words: NP-Complete, limits, binary vector spaces, computational complexity

MOTIVATION

In a fundamental paper in 1967, E. M. Gold proposes a paradigm for learning processes entitled *Identification In the Limit (IIL)*. This branch of learnability has developed the following model over the years since Gold's work (See, for example, Ben-David (1992)). Suppose there is a finite or countable class of 'concepts' *C* that is known to both a teacher and a student. The teacher chooses a concept *T* from *C*, and then repeatedly passes chunks of information about *T* to the student. The student, based on the information passed to him, successively modifies his conjecture concerning the identity of *T*. The student is successful if the infinite sequence of his conjectures stabilizes on the correct concept *T*. One way to mathematically represent this process is to treat the concepts as elements of the vector space $\{0,1\}^n = B^n$. Information from the teacher is presented in the form of other elements of B^n which are known to agree with *T* for at least *k* of its *n* elements.

Consider the problem of transmitting data to Earth from a very remote spacecraft. If the transmitter is weak, or if there is a lot of interference between the spacecraft and Earth, there will be a great deal of noise that will obscure the correct data. Many error-detecting and error-correcting codes are currently in use, but in severe cases, they can require the transmission of more bits than the data itself. We can consider the spacecraft as the teacher in the first example above, and the Earth station as the student. How many elements of B^n (retransmissions of the raw data) must be sent to guarantee that we can correctly determine the correct data value? If the spacecraft is far away (say at the orbit of Pluto), the time required to request a retransmission of the data and then receive it is on the order of 10.5 hours or more for each request. If 10 retransmissions are needed, this approach would occupy over 100 hours. If, on the other hand, one request can be made for the 10 retransmissions, they could all be received in something on the order of 11 hours. But we must know how many retransmissions would be required to guarantee that we could determine the correct data value.

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These problems give rise to the following definition and the question that follows it. The question was first posed by Shai Ben-David (1992).

> ***Definition:*** *Let B^n be the set of all n-dimensional vectors over {0,1}, and A be a subset of B^n. The element **x** in B^n is said to be a **K-LIMIT** of the set A, $1 \leq k \leq n$, if for any choice of k subscripts, there is an element **y** in A, **y** not equal to **x**, such that **x** and **y** agree on these k subscripts.*
>
> ***Question K-LIMIT:*** *Is there an integer K(k,n), such that for **A** a subset of B^n, $|\mathbf{A}| > K(k,n)$ implies that **A** has a k-limit?*

One approach that can be taken to solving this problem is to look at all subsets of B^n, determine which have limits, and then find the largest subset that does not have a limit. If this is done for a number of different values of *n*, then perhaps a pattern can be determined and a theorem would follow. The difficulty here is that the number of elements in B^n is $m = 2^n$. This means that the number of possible subsets of B^n is 2^m. Even for small values of n, this number is very large. If n = 5, for example, there are 32 elements in B^n, and over 4 *billion* subsets that would have to be considered. A more common value for n in the spacecraft problem is 32, and the number of subsets is in excess of $10^{1,260,000,000}$, an almost unimaginably large number. Problems of this type are said to be of *exponential* complexity, because the time necessary to work through the problem increases exponentially with the size of the problem (n in this case). We would like to find an algorithm that would solve the problem in a time period that is at most a polynomial function of the size of the problem.

BACKGROUND

A problem is said to be of class *NP* if it is only solvable in polynomial time on a non- deterministic computer. A non-deterministic computer is one that has the capability of pursuing all of its possible sequences of action in parallel (See, for example, Gersting 1982:362). Since all contemporary computers are deterministic, this is essentially equivalent to saying that the problem cannot be solved in an amount of time that is polynomial in the size of the problem. In a fundamental paper, Cook (1971) showed that there is one particular problem in the class NP that has the property that every other NP problem can be reduced to it in polynomial time. That problem is referred to as SATISFIABILITY, and is stated by Garey and Johnson in their book *Computers and Intractability* as follows: (The format used here is the traditional one for stating NP-Complete problems. It consists of a statement of the elements of the problem, and a question that is to be answered either yes or no.)

> INSTANCE: Set U of logic variables, collection C of clauses over U.
>
> QUESTION: Is there a satisfying truth assignment for C?

A *logic variable* is one that can assume one of two values: True or False. For a given set $U = \{u_i \mid 1 \leq i \leq n\}$, the set V consisting of all the elements of U and the logical negations of those elements is referred to as the set of *literals* over U. A *clause* is the disjunction of a subset of the set V; i.e., an expression of the form

$$c = v_i + v_j + \ldots + v_k.$$

A *satisfying truth assignment* is an assignment of True or False to each of the logic variables in such a manner that at least one of the terms in each clause is True.

To establish that another problem is NP-Complete, one must show that it is either an *extension* of a known problem, or that it is *equivalent* to a known problem. A problem **X** is equivalent to problem **Y** if a solution to either one gives rise to a solution of the other with a transformation time that is a polynomial in the size of the problem. **X** is an extension of **Y** if a solution of **X** always provides a solution to **Y**, but not vice versa. We will use both methods in the sequel.

In what follows, we will work exclusively with 3-limits. The extension to k-limits for arbitrary k is not conceptually difficult, but it is a notational nightmare. We leave it to the reader to see that the extensions do work.

We begin with an extension of the problem SATISFACTION, proceeding as follows. We begin with a set of logic variables $U = \{u_1, u_2, \ldots u_n\}$. We generate a new set of variables $V = \{v_1, v_2, \ldots v_n\}$ by assigning v_i to be either u_i or $-u_i$, $1 \leq i \leq n$. As will be shown, there is usually a rule to be used in making the choice between u_i and $-u_i$, and once this assignment has been made, it will remain fixed through the remainder of the problem. Now, there are $m = [n(n - 1)(n - 2)]/6$ selections of (i,j,k), with $1 \leq i < j < k \leq n$. Number these 1, 2, 3, . . . m. If the pth such triple is (r,s,t), set $x_p = v_r v_s v_t$ (the juxtaposition of logic variables here implies a logical *and*). This defines a new set of logic variables that we will call X. We are now concerned about the relationship between truth assignments for U and truth assignments for X.

It is clear that any truth assignment for U will generate truth values for each element of X. Once each u_i is assigned to be either True or False, then the values of the v_i's are also determined; if $v_i = u_i$, then the values are the same; otherwise, they are opposites. With the v_i's determined, it is a simple matter to apply the rules of logic to determine the value for each of the x's.

Now, consider the problem of assigning values to the x_i's and determining from those values what would be the appropriate values for the u_i's. If all the x_j's are false, then the problem is straightforward — simply assign all the v_i's to be false also, and from that determine the values for the u_i's. Similarly, if all the x_j's are true, then all the v_i's can be assigned to be true, and then the u_i's are again easily determined.

This leaves us with the case that we have some x_j's being true and some false. For a given x_j to be true, the three v's involved in its definition must also be true. We thus begin by taking all the x_j's that are true, and assign all the v_i's that appear in these terms to be true also. Now consider any x_j that is false. We must find a v in the definition of this x_j that is not in the set already defined to be true, and assign it to be false. If such a v_i cannot be found, there is no truth assignment for the u's to produce the result in the x_j's; otherwise we proceed to the next x_j that is false. The transition from the v_i's to the u_i's is again straightforward. Thus we will either find a satisfying truth assignment or a contradiction as above; in either case the question has been answered in polynomial time.

To summarize, we have the following relationship. A given truth assignment for the u_i's will always produce an assignment for the x_j's, but the converse is not always true. In some cases a truth assignment for the u_i's may be deduced from one for the x_j's, but not always.

For the set X described above, define the expression

$$s = x_1 + x_2 + x_3 + \ldots + x_m$$

to be a ***complete clause*** over the set X. It is complete in the sense that it contains every element of the set X. Note that the nature of the set X, relative to U, depends on the selection of the literals in the set V. If U has *n* elements, then there are 2^n ways that the set V can be chosen, and each such choice gives rise to a corresponding set X. We should properly refer to X as X(V) to clearly express this dependency. If we have a collection of V's, say $\{V_1, V_2, \ldots V_k\}$, then we would also have a corresponding set of X's, $\{X(V_1), X(V_2), \ldots X(V_k)\}$. Let us denote this set by Z. For each set of X's in Z, we can construct a complete clause; the set consisting of these complete clauses will be called S. In the construction of these complete clauses, we will assume that the terms of each are numbered in a consistent manner. By this we mean that if the p^{th} term in $X(V_1)$ is $v_{1,i} v_{1,j} v_{1,m}$, then the p^{th} term in $X(V_r)$ is $v_{r,i} v_{r,j} v_{r,m}$, $2 < r < k$. We are now concerned about satisfying truth assignments for the set S. The problem that we wish to consider is as follows:

> *INSTANCE: A set* ***S*** *of clauses in the logic variables of Z, which are in turn expressions in literals over a set of logic variables U.*
>
> *QUESTION: Is there a truth assignment for U that implies a truth assignment for* ***Z*** *that in turn satisfies S?*

This problem is broken into two steps. First, one must find a satisfying truth assignment for **S** in terms of the logic variables of **Z**. This is essentially the problem SATISFACTION referenced above. To get from there to the variables of U is a polynomial time problem, as described above. This problem is therefore NP-Complete.

We will extend this problem by imposing an additional condition on the satisfying truth assignments. Inasmuch as the terms in each complete clause are numbered in the same manner, it does make sense to compare the i^{th} term of one clause with the i^{th} term of another clause. We will refer to the following problem as SEQUENTIAL SATISFACTION:

> INSTANCE: A set **S** of clauses in the logic variables of **Z**, which are in turn expressions in literals over a set of logic variables U.
>
> QUESTION: Is there a truth assignment for U that satisfies **S**, with the additional condition that for some numbering of the elements of **S** , the i^{th} term of the i^{th} clause is satisfied?

Any solution to SEQUENTIAL SATISFACTION is a solution to the unnamed problem posed above, but the converse is not true. The additional restrictions only make solutions harder to find, and this problem is also NP-Complete.

RESULTS

We are now prepared to treat the fundamental question of the paper as stated in Section II. The elements of B^n are related to logic variables and truth assignments in the following way. For a given element b in B^n, we generate a V_b as follows: if the i^{th} component of b is 1, then $v_{b,i} = u_i$; if the i^{th} component is a 0, then $v_{b,i} = -u_i$. In this manner, we can obtain a one-to-one correspondence between the elements of B^n and the sets of literals V_b. If we have a subset *A* of elements of B^n, then each element will correspond to a V in this manner, and we generate a set V_A. From this we generate the set of logic variables **Z**, and the corresponding set of complete clauses S. Similarly, there is a one-to-one correspondence between elements of B^n and truth assignments for the variables U. Again, if *b* is an arbitrary element of B^n, and if the i^{th} component of B is 1, then set u_i to be *True*; if that component is 0, then set u_i to be *false*. We can also proceed in the other direction: given a truth assignment for U, it can be transformed in a straightforward manner into an element of B^n. We are now prepared to prove the following theorem:

> **Theorem:** If T is a subset of B^n, *b* an element of B^n, then *b* is a limit of T if and only if there is a subset A of T

such that the set V_A and the truth assignments generated by *b* constitute a solution to SEQUENTIAL SATISFACTION.

Proof: Suppose first that *b* is a limit of T. Let A be the subset of T consisting of those elements that are used to establish the limit. Then for any choice of 3 subscripts, there is an element of A that agrees with *b* on those 3 subscripts. Number the possible arrangements of the 3 subscripts from 1 to m. Now, consider the element of A that agrees with *b* on the elements defined by the i^{th} triple. If we label this element *a(i)*, then the i^{th} term in $X(V_{a(i)})$ will be true. Since this is true for any set of three subscripts, it follows that the set V_A and the truth assignments generated by *b* form a solution to the sequential satisfaction problem.

Now, suppose that we have a set V_A which together with the truth assignment of *b* yields a solution to the sequential satisfaction problem. That is, for each i, $1 \leq i \leq m$, there is an element of A, call it *a(i)*, such that the i^{th} term in the complete clause $X(V_{a(i)})$ is true. This says simply that *a(i)* and *b* agree on those three subscripts. Since i was general, there is an element of A that agrees with *b* on any set of 3 subscripts; in other words, *b* is a limit of A. Note that if T is a superset of A, *b* will be a limit of T also.

We now propose the following decision problem, which we will call 3-LIMIT:

INSTANCE: A set A of elements from B^n, $|A| = k$.

QUESTION: Does A have a 3-limit?

Corollary: 3-LIMIT is NP-Complete

Proof: A brute force approach to this problem would involve finding all subsets of B^n that have k elements, and then trying all elements of B^n to find if a limit exists. By the previous theorem, this amounts to finding a solution to SEQUENTIAL SATISFACTION. Hence, this problem is also NP-Complete.

CONCLUSIONS

The establishment of a problem as being NP-Complete does not in itself imply that the problem is insolvable and should be abandoned. Zadeh (1973) and others established in the early 1970's that the Simplex method of solving linear programming problems is in general of exponential complexity, and yet it is one of the most widely used methods in linear programming today. Complexity here only establishes a worst-case scenario. Garey and Johnson (1979) summarize the significance of establishing a result like the one above:

> . . . . the primary application of the theory of NP-Completeness is to assist algorithm designers in directing their problem-solving efforts toward those approaches that have the greatest likelihood of leading to useful algorithms.

In light of this statement, one should note carefully that the original problem *k*-LIMIT is still open: that is, is there a *k* such that $|A| > k$ will guarantee that A has a limit in B^n? However, the search for such a *k* by brute force is not likely to succeed for even moderate values of *n* because of the complexity of such a search. It is possible, however, that some of the work on the All-Nearest-Neighbor problem will yield results that will apply to this problem.

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LITERATURE CITED

Ben-David, S. 1992. Personal communication following presentation of his paper "Can finite samples detect singularities of real-valued functions?" Proc. ACM Symp. on the Theory of Computing, Victoria, B.C., Canada. 24:390-399.

Cook, S. A. 1971. The Complexity of Theorem-Proving Procedures. Proc. ACM Symp. on the Theory of Computing, New York, NY. 3:151-158.

Garey, M. R. and D. S. Johnson. 1979. Computers and Intractability, W. H. Freeman and Co., San Francisco. p. 259.

Gersting, J. L. 1982. Mathematical Structures for Computer Science. W. H. Freeman and Co., San Francisco, CA.

Gold, E. M. 1967. Language Identification in the Limit. Information and Control 10:447-474.

Zadeh, N. 1973. A Bad Network Problem for the Simplex Method and Other Minimum Cost Flow Algorithms. Math Programming 5:255-266.

ABSTRACTS

BIOLOGICAL SCIENCES - AQUATIC

THE STATUS OF AMPHIBIANS ON THE FLATHEAD RESERVATION, MONTANA^{TWS}

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Increasing concern about diminishing populations of amphibians has prompted many agencies, including the Confederated Salish and Kootenai Tribal Wildlife Division, to inventory local species. Between 1993-1997, a total of 398 herpetological surveys were made at 276 sites on the Flathead Reservation. Surveys were conducted by 2 individuals and consisted of a thorough search of the wetland perimeter, netting of near shore aquatic habitats for larvae/tadpoles, and in the case of some streams, electrofishing. Of the eight amphibian species most likely to occur on the reservation, six were present. The long-toed salamander, Pacific treefrog, and spotted frog were found throughout the reservation, but their populations appeared diminished in open agricultural areas of the Mission valley. There is concern about the Western toad that was found breeding at only five sites during the 1993-1994 surveys. The Leopard frog, for which there are six historical sightings in the Mission valley, was absent from all surveys and has probably been extirpated from the area. Populations of the tailed frog were found in seven mountain streams and appear stable. The bullfrog was introduced at several sites in the Lower Flathead River area in the 1970s. It is successfully reproducing at two localities along the Flathead River and along approximately nine miles of Camas Creek. Populations along Camas Creek appear to be the result of range expansion. A monitoring program was set up in 1995 to assess species abundance at approximately 17 sites across the reservation on a 3-5 year cycle.

Title footnote indicates organization, location and date presentation was made:

^{MAS}Montana Academy of Sciences Annual Meeting, Bozeman, MT, April 10-11, 1998
^{TWS} Montana Chapter of the Wildlife Society Annual Meeting, Polson, MT, March 4-6, 1998

BIOLOGICAL SCIENCES - TERRESTRIAL

COYOTE AND WOLF COEXISTENCE IN NORTHWESTERN MONTANA[TWS]

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Recolonizing wolves (*Canis lupus*) may affect congeneric coyotes (*C. latrans*) by altering food habits, social behavior, movements and habitat use. We examined the effects colonizing wolves have on coyote populations in northwestern Montana. Home ranges for eleven coyotes were distributed between the two wolf pack territories and on the edge of the territories, and minimally overlapped with core wolf areas. Although dietary overlap was high between the canids, food partitioning by size and age occurred. Wolf presence may be beneficial to coyotes as a source of additional food through scavenging, but it also appears that the wolves are affecting coyote distribution and survival.

STATISTICAL TESTING IN WILDLIFE RESEARCH[TWS]

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Wildlife researchers overuse statistical hypothesis testing. A test can only help to determine if a difference or effect exists. A test does not provide any information on the importance, size, or direction of the effect. Most of the time, wildlife researchers are not interested in the presence or absence of an effect, but in estimating the size of an effect they know exists. The appropriate statistical tool is the confidence interval.

HIGH ELEVATION MUSHROOM COMMUNITIES[MAS]

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Wild mushrooms are often perceived as appearing randomly or haphazardly in various locales, but like plants and animals, most fungal species have a preference for certain habitats and form recognizable communities. An ongoing survey of Rocky Mountain mushrooms shows that fungal communities of this montane region are unique in many respects, and some appear limited to the western U.S. Communities of high elevation habitats include: alpine mushrooms, snowbank mushrooms (dependent on snow melt-water), mushrooms of boreal conifer forests, burn fungi (which fruit after forest fires), mushrooms of quaking aspen forests, and fungi of disturbed areas (avalanche paths, previous smelter sites, etc). These macromycete communities are discussed in terms of the species involved, the ecological roles of fungal guilds, the global distribution of these types of communities, and the dynamics of how mycofloras change through disturbance and succession. Specific examples of community types from western Montana are emphasized. The preservation of this macromycete biodiversity depends on the conservation of these habitat types and the promotion of uneven age forests.

MAPPING FERRUGINOUS HAWK NEST SITES USING GIS AND GPS - SIMPLE WAYS TO MAP WILDLIFE POINT FEATURES^{TWS}

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New GPS and GIS equipment and software have become affordable to many wildlife professionals, yet barriers to the use of new techniques limit their use by management biologists. One of the barriers is the lack of time to learn how to use complex equipment and software. I will describe how I used an inexpensive Garmin GPS unit and ArcView to map ferruginous hawk nest sites and other wildlife point features. The Garmin GPS 45 unit was used with an external antenna taped to the overhead bar of a Supercub airplane to track the flight path of aerial surveys and mark locations of ferruginous hawk nests. The track and waypoint files, with locations recorded as UTM coordinates, were downloaded into a computer, then imported into dBase III Plus. These files were brought into ArcView and overlaid on base layers that were projected into the UTM coordinate system. The system enabled generation of a map depicting the areas surveyed and the nests located, within 1 hour of the completion of the flight. Flight time near nests was minimized by elimination of the need to circle around the nest area while attempting to locate the nest on a map. Uncorrected GPS locations were accurate to within approximately 100 to 300 meters (depending upon satellite configuration and selective availability), which is sufficient for aerial locations from an airplane. This system is adequate for much of the survey work conducted by wildlife management biologists, yet simple enough to be used without extensive training in GIS software.

BLACK-TAILED PRAIRIE DOG ABUNDANCE AND TRANSLOCATION EFFORTS ON CHARLES M. RUSSELL NATIONAL WILDLIFE REFUGE^{TWS}

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Prairie dogs (*Cynomys spp.)* continue to decline from historic times as a result of agricultural cultivation, eradication programs and sylvatic plague (*Yersinia gesfis*). In 1997 the US Fish and Wildlife Service began a translocation program to re-establish black-tailed prairie dogs (*C. ludovicianus*) on previously "plagued-out" colonies

located on the Charles M. Russell National Wildlife Refuge (CMR) in southern Phillips County, north-central Montana. Successful translocations should speed prairie dog re-colonization and provide habitat for endangered black-footed ferrets (*Mustela nigripes*) and species of concern such as mountain plovers (*Charadrius montanus*), burrowing owls (*Speotyto cunicularia*) and ferruginous hawks *(Buteo regalis)*. Seven release techniques involving various cages and holding pens and 1 passive technique using augured holes were evaluated during initial trials and 2 were selected for 1997 translocation efforts; 1) a chicken wire pen containing augured holes, and 2) augured holes without any containment. A total of 330 prairie dogs were translocated, 281 from other CMR colonies and 49 from a dog colony at Fort Harrison, Helena, Montana. The CMR prairie dogs were released at 4 sites, 2 with the chicken wire pen method and 2 at augured hole only sites on the Manning Corral prairie dog colony where no old burrow openings were present. The Fort Harrison prairie dogs were released at one site on the Big Snowy prairie dog colony where old burrow openings were still present. Prairie dogs were observed on all 5 sites 60 days post release and some are assumed to still be there based on presence of active burrows and fresh diggings. All releases appear successful, but observations this spring and subsequent reproduction and colony growth will help determine the most efficient techniques.

BIGHORN SHEEP POPULATION DYNAMICS ON THE BEARTOOTH WILDLIFE MANAGEMENT AREA, MONTANA[TWS]

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The dilemma of bighorn sheep (*Ovis canadensis)* die-offs has plagued wildlife biologists and managers for decades. Many states have established augmentation programs in an effort to counteract such die-offs and maintain viable sheep populations. I studied the population dynamics of a reintroduced bighorn sheep herd on the Beartooth Wildlife Management Area in west-central Montana. After a decade rapid growth, this herd experienced a major disease-mediated die-off in 1984 and has subsequently been unable to recover to pre die-off densities. Primary study objectives included evaluation of sheep reproduction and mortality, habitat use, and disease. Particular emphasis was placed on determining the role of predation in sheep population dynamics. Additionally, transplanted individuals were monitored to evaluate the effectiveness of two augmentation projects (N=39 sheep). Results from this study will provide insight into the post die-off population dynamics of small sheep herds and improve our understanding of augmentations and the degree to which they actually assist in population recovery.

USING CLIMATIC DATA TO DEVELOP AN INDEX OF WINTER SEVERITY AND RESPONSES BY LARGE MAMMALS^TWS

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Daily climatic data are obtained by Natural Resources and Conservation Service (NRCS), SNOTEL stations and National Weather Service (NWS), and climatological (CLIM) stations. SNOTEL sites are usually in mountain locations in western US and provide near-real time, year around, daily data on snow water equivalent (SWE), precipitation, maximum, minimum and average air temperatures (TMAX, TMIN, TAVG). CLIM sites are usually at valley locations and provide daily precipitation, TMAX, TMIN, TAVG and snow depth (SNWD). After all missing data are estimated by correlation with nearby sites, daily SWE and snow density are estimated at CLIM sites using precipitation, SNWD and TAVG. The Keetch/Byram drought index (KBDI), a soil moisture deficit model, and accumulated growing degree days are also computed. The Index of Winter Severity (IWS) for each winter range is calculated using SWE for the snow index, minimum temperatures below the effective critical temperature for each species for temperature index, and KBDI and growing degree-days for the winter forage index. The snow, temperature and forage indexes are weighted and combined to provide an IWS on a scale from +4 for the mildest of historic conditions to -4 for the most severe conditions. The IWS is one of the factors relating to mortality, reproduction and predation of big game animals. Accumulation of SWE on summer and transitional ranges is related to migration to winter ranges. Winter temperature, forage and SWE are related to declines in fat reserves and winter mortality.

EVALUATION OF THE "PEEPER" VIDEO PROBE TO EXAMINE BURROWS AND SUBSURFACE ACTIVITY OF BURROWING MAMMALS[TWS]

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We used the "Peeper" video probe (Christensen Designs, Manteca, CA) to examine burrow structure, complexity and use by pygmy rabbits (*Brachylagus idahoensis*) and black-tailed prairie dogs (*Cynomys ludovicianus*) in southwestern Montana. The probe proved useful on pygmy rabbit burrows but of little use on prairie dog burrows. Utility of the probe on different burrow types is described. Advantages and disadvantages of the current technology are recorded. We attempted to locate pygmy rabbit maternity burrows or nests, and determine occupancy rate but were unsuccessful. However, the probe was useful for pygmy rabbits and we' learned a great deal about burrow structure and complexity without excavation. Fifteen rabbits (both *B. idahoensis* and *Sylvilagus nuttallii*) were observed in burrows and behavioral response to burrow intrusion recorded. No other vertebrate species were observed. Due to limited mobility, not every burrow could be completely examined. Prairie dog burrows were deep, steep and penetrated rocky soils. Thus, mobility of the probe and cable length were not suitable for examining prairie dog burrows.

RECENT STUDIES OF SNOW-URINE SAMPLES FOR EVALUATION OF ELK NUTRITION[TWS]

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Over the past 7 years a group of collaborators have been investigating the possible utility of using urinary allantoin:creatinine ratios as an index of nutrition in Rocky Mountain elk. Research has included both controlled experiments with captive elk at the Starkey research facility in Oregon as well as studies of free-ranging, radio-collared elk in the Madison-Firehole herd of Yellowstone National Park. The captive animal studies have demonstrated a strong linear relationship between dietary intake of metabolizable energy and urinary allantoin:creatinine ratios. The relationship appears to be quite robust to different nutritional regimes and responds quickly to changes in dietary intake. Intensive sampling of free-ranging, radio-collared cow elk in Yellowstone over a 6-year period indicate that the urinary ratio exhibits pronounced seasonal and annual variation that can be correlated to changes in forage quality, due to plant senescence and green up, and quantity, due to changes in snowpack. Annual differences in mean overwinter allantoin:creatinine ratios were also correlated with overwinter calf survival. These data suggest that allantoin:creatinine ratios derived from snow-urine samples may be useful as a research tool for studying overwinter nutrition when the identity of the animals depositing the urine is known. We found significant differences in urinary

allantoin:creatinine profliles. among sex–age classes that could limit practical management applications that would require collection of anonymous snow-urine samples. A sampling and analysis protocol to alleviate these problems was developed and tested on 6 elk herds in Wyoming and Montana during the winter of 1996-97. Results of this study suggest that the urinary ratio may have promise as a management tool as well, however, additional research will be needed.

DEMOGRAPHIC CONSEQUENCES OF BROWN-HEADED COWBIRD PARASITISM ON LAZULI BUNTINGS[TWS]

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Lazuli buntings (*Passerina amoena*) breed throughout the western United States and southwestern Canada in a wide variety of habitat types. Although previous studies have suggested that Lazuli buntings are not experiencing problems on the breeding grounds, my research indicates that 80 - 100% of Lazuli bunting nests are parasitized in many habitats throughout the west. I investigated the demographic consequences of parasitism for Lazuli bunting populations with age structured Lefkovitch matrix models. Current estimates of survivorship and fertility indicate that, in the absence of parasitism, Lazuli bunting populations have lambda values (geometric rate of population growth) just slightly greater than 1 (the break-even point). These models suggest that parasitism rates of about 15% or higher decrease the growth rate of bunting populations below 1. Hence, it is unlikely that many bunting populations are self-sustaining. Metapopulation models using GIS models are used to investigate the conservation implications of different management options.

A SOURCE SINK MODEL OF LAZULI BUNTINGS IN MONTANA[TWS]

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Although Lazuli buntings (*Passerina amoena*) are currently widely distributed in the western US and southwestern Canada, parasitism by brown-headed cowbirds (*Molothrus ater*) is extremely high in many populations. Such populations do not appear to be self-sustaining. To examine spatial structures of potential source and sink populations of Lazuli buntings, we developed GIS models of Lazuli bunting and brown-headed cowbird distributions for the state of Montana. These models suggest that Lazuli buntings may be more vulnerable to cowbirds than currently appreciated. Of the 4,375, 746 ha identified as potential Lazuli bunting breeding habitat, 97% falls within areas with a high risk of cowbird presence (possible sink habitats), and <1% occurs in areas with no cowbirds (possible source habitats). Furthermore, Lazuli buntings breed in habitats that occur in configurations that make them especially vulnerable to cowbirds: patches tend to be small (>90% of patches are <I 0 ha) with

high edge to interior ratios, and are generally surrounded by habitats that could support livestock and thus cowbirds.

ABUNDANCE OF SNAGS IN WESTERN MONTANA FORESTS^{TWS}

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Standards for snag retention and recruitment in managed forests are often based on models of species specific habitat requirements. If maintenance of the entire biota is the goal, an ecosystem approach, using historic patterns as a guide, may be more appropriate. I used plot data from the USFS continuous forest inventory program to characterize the abundance of snags from western Montana forests. I classified plots by whether or not they had a history of timber harvest, as well as by dominant species and habitat types. I characterized snag abundance by dbh class and species. On unharvested plots, total snag (9"+) density varied from under 3/acre on dry Ponderosa pine (*Pinus ponderosa*) types to approximately 24/acre on mesic spruce and fir types as well as warmer sites supporting grand fir (*Abies grandis*) and western red cedar (*Thuja plicata*). Abundance of large (21"+) snags was much lower but showed similar trends, varying from as low as 0.45/acre on dry Ponderosa pine sites and 0.19/acre on lodgepole pine (*Pinus contorta*) dominated sites, to 2.07/acre on warm, mesic sites. Snag abundance on young, recently disturbed stands was lower than on older, sawtimber stands. However, snag dynamics differed from those of live trees during the process of stand aging. Unharvested stands had higher mean snag abundance than those with a history of timber harvest. I interpret the generally higher snag abundances in uncut stands to reflect not only an unharvested condition, but also a lack of fire, and probably an attendant excess of mortality from insects and disease. Such influences would be manifested more strongly in smaller, than larger dbh classes. Thus, snag abundances in the larger dbh classes of these uncut stands should closely resemble those that would generally occur on the landscape in the absence of intervention by mechanized mankind, if accounting for a small upward bias caused by fire suppression. These latter figures can be used as rough targets for landscapes where managing for biodiversity or emulating natural disturbance patterns is an important objective. I also offer suggestions for snag retention/ recruitment guidance in regeneration harvest units.

CAVITY NESTING BIRDS IN SALVAGE LOGGED AND UNLOGGED POST-FIRE FORESTS^{TWS}

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Practices of wildfire suppression and salvage logging of burned forests have prompted concern among biologists for fire-associated bird species in the northern Rocky Mountains. Therefore, in May 1997, we initiated a five-year study to examine the responses of cavity birds to salvage logging of recently burned forests. Here, we present an overview of the study and some highlights from the first field season. Three of our four study areas burned in 1994 and portions of each were subsequently salvage logged. The fourth area, which was not logged, burned in 1996. We systematically searched all study areas for nests and then monitored nests to determine reproductive success. We also measured habitat characteristics of nest sites and random sites. Nest searching efforts in all areas identified 140 occupied nests of 13 cavity nesting species. Of all cavity-nesting species in our study, Black-backed and Three-toed woodpeckers and brown creepers had the strongest affinity for nesting in unlogged forests; >80% of nests were found in unlogged portions of burned forests. The nests of hairy woodpeckers, Northern flickers, and mountain bluebirds were found in equal numbers in logged and unlogged areas of burned forests. Small numbers of Lewis' woodpecker, Williamson's sapsucker, and American kestrel nests primarily were found in the logged areas. Preliminary data suggest that post-fire forests, which are salvage-logged, provide nesting habitat for some cavity-nesting species. However, the suitability of nesting habitat may be markedly decreased for the two fire-associated species, the black-backed and three-toed woodpecker.

IN HEAT ON THE RANGE—THOSE SEXY MONTANA ELK!^{TWS}

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Elk breeding behavior and time of mating have received increasing attention. Photoperiod, physiological condition, and age of cows, age structure and availability of bulls and human disturbance are factors believed to influence the timing of conception. Late breeding is believed to result in lowered calf survival and consequent management implications. Crown-rump measurements of elk embryos from cow elk harvested during late season hunts provided data about the timing of breeding and other aspects of reproduction. Sixteen samples (n=11- 248) of elk uteri were collected from 6 locations in Montana between 1982 and 1994. A total of 1324 embryos were examined to determine breeding date distributions, fetal sex ratios, and twinning rates. Comparative data from 2 earlier Montana samples were also examined. Conception dates ranged from August 27 to November 11. The mean conception date for all Montana embryos was September 26. Of adult cows 250 conceived by September 20 and 95% by October 12. Sample means ranged from September 19 through October 4. Conception date distributions were positively skewed and leptokurtic and did not indicate late or disrupted breeding patterns. Conception date distribution for yearling cows was significantly later than for other age classes. Only 0.52% of the uteri contained twin embryos. The overall the sex ratio was 115 males:100 females, but varied between samples.

ABUNDANCE AND NESTING SUCCESS OF CAVITY-NESTING BIRDS IN UNLOGGED AND SALVAGE-LOGGED BURNED FOREST PATCHES^TWS

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Three years of post-fire censusing for cavity-nesting bird (CNB) nests was conducted in a northwestern Montana forest which had been partially salvage-logged. Over all three years, nest density was consistently higher in unlogged patches (27.18 - 48.33 nests/40ha) vs. salvage-logged patches (7.74 - 21.43 nests/40 ha). Diversity of CNB species was higher in unlogged patches with 19 species nesting there compared to only seven nesting in salvage-logged patches. Cavity trees were marked and re-checked each year. Cavity re-use rates were higher in salvage-logged vs. unlogged patches. Habitat characteristics thought to be important in determining suitable nest trees were measured at active nests and at random trees. Tree species, tree size (DBH and height), tree status, and tree density were all important habitat characteristics for most species. Nesting success was monitored in unlogged and salvage-logged patches for one breeding season for the three most common species (Northern flicker (*Colaptes auratus*), Mountain bluebird (*Sialia currocoides*), and house wren (*Troglodytes aedon*). Northern flickers had significantly higher daily survival rates in unlogged vs. salvage-logged patches. The trend was similar for Mountain bluebirds, but the difference was not significant. House Wrens did equally well in either treatment type. Surprisingly, none of the habitat variables measured correlated with either successful or failed nests. Other factors were likely responsible for lowered nesting success in salvage-logged patches. Identifying, ideal nesting habitat for cavity-nesting birds may help mitigate future salvage logging activities.

THE STATUS OF ELK HABITAT PROJECT^{TWS}

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The Status of Elk Habitat Project began with the 1996 publication of Status of Elk in North America, 1975- 1995 by the Rocky Mountain Elk Foundation (RMEF). While this publication depicted elk populations, it did not assess elk habitat. In the spring of 1997, the RMEF and Geodata Services, Inc. initiated the Status of Elk Habitat Project. The objective of the project is to develop eight base layers that display the status of elk habitat across North America. The process involves using existing maps and habitat data when possible, instead of creating new data. The RMEF and Geodata are working with professional state, federal, and tribal wildlife specialists in a collaborative effort to map general summer and winter range, crucial summer and winter range, migratory corridors, parturition areas, and other important habitat features. The wildlife managers will also assign key limiting factors to each of the habitat polygons. Other data layers, such as land ownership, major roads, census geography, administrative stewardship, RMEF projects and management plans can also be added. Upon completion, the data will be available to Project cooperators throughout the United States and Canada.

PRODUCTION AND SURVIVAL OF ELK CALVES IN RESPONSE TO HABITAT IMPROVEMENT IN NORTHWEST MONTANA^{TWS}

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The purpose of this study was to determine elk pregnancy rates and calf survival from habitat enhancement. Habitat mitigation was completed in the area on elk winter range in the spring of 1996. I followed approximately 25 collared cow elk and their calves per year over a 2-year period to gather baseline data on pregnancy rates and calf survival. Pregnancy was determined through fecal analysis, and calf survival through observations and capture. Forty-year harvest trends show a possible decline in elk population in the Southfork of the Flathead River around Firefighter Mountain. We speculate that there are lower pregnancy rates in the Southfork as compared to other Rocky Mountain ecosystems. This may be because of alternate year breeding, summer or winter habitat quality, weather conditions. Over the two years of my study, we did see a difference in calf production and survival, however, weather conditions may have been a factor.

COMMON LOON MANAGEMENT IN MONTANA—AN UPDATE^{TWS}

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Common loons (*Gavia immer*) have been monitored in northwestern Montana since the early 1980's. The number of summer residents has remained relatively constant through this period, at about 200. Approximately 60 pairs attempt to nest with 24-26 pair successfully raising 1-2 chicks each year. Beginning in 1988, nest sites on lakes prone to high human recreational activity were protected by floating signs, which formed voluntary closures to help the public stay an adequate distance from the nest. The use of these signs resulted in a significant increase in the number of 2 chick broods produced and their use continues to present. Extensive public education occurs in the area of the lakes with signs so that the public understands the reason for the closure. This has resulted in high levels of compliance. In 1996 a banding program began in which loons were uniquely color-marked in hopes of determining the frequency of territory/partner changes, survival rates of 3 year olds returning to natal lakes, distance of dispersal from natal lakes, and the location of wintering sites. Blood and feather samples were taken to examine the extent of mercury bioaccumulation. Use of these samples has been incorporated into continent-wide genetics and physiologic investigations. The latter has determined that loons are extremely sensitive to environmental loads of methylmercury and are excellent biosentinels for this heavy metal.

RELOCATION OF THE FORT HARRISON PRAIRIE DOG COLONY^{TWS}

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A 10 ha black-tailed prairie dog (*Cynomys ludovicianus*) colony at Fort William Henry Harrison in the Helena Valley was relocated to two new sites during the fall of 1997. Prairie dogs were relocated because of a multi-million dollar construction project planned for the Fort Harrison cantonment area which included the existing prairie dog colony. Prairie dogs were live-trapped and moved 1 km to a 1 ha disturbed grassland site located outside the development zone near the northeastern corner of Fort Harrison. Prairie dogs were also transported 500 km by vehicle to the Charles M. Russell National Wildlife Refuge (CMRNWR) and released at a prairie dog colony extirpated by a sylvatic plague epidemic during 1996. The Fort Harrison relocation site was mowed and fenced with 5x5 cm mesh wire fencing. The fencing was buried 45 cm below the soil surface and extended 90 cm above the soil. A total of 79 prairie dogs was captured and moved to the Fort Harrison relocation site during September 1997. Prairie dogs apparently were able to climb the enclosure fence or squeeze through the wire mesh. Prairie dogs were observed on several occasions traveling on a gravel road back to the original colony. The greatest number of prairie dogs observed within the enclosure was 17, and five remained at the relocation site by December 1997. Groups of 33 and 16 prairie dogs were released at the abandoned CMRNWR colony during early and mid-October. Prairie dogs readily used abandoned prairie dog burrows and showed little tendency to move from the release site.

DYNAMICS OF RUSSIAN OLIVE INVASION AND COTTONWOOD FORESTS ON THE LOWER MARIAS RIVER^{MAS}

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Russian olive is an exotic tree used for wildlife and windbreak plantings in western North America. There is concern that Russian olive will replace native riparian forests resulting in a loss of biological diversity. We mapped the occurrence of Russian olive along the entire lower Marias River below Tiber Dam. We measured the size, density and age of Russian olive and cottonwood in sample plots in sandbar, low terrace and high terrace habitats at 19 randomly chosen sites along the lower river. Cottonwood establishment was restricted to lower terrace Sites, usually within 30 m of the river channel. Russian olive in all size classes occurs along the entire lower Marias River but is much more abundant in proximity to domesticated plantings. Russian olive establishes in moist, lower terrace habitat as well as under mature cottonwood on high terraces but was never observed in fresh sandbars with cottonwood seedlings. Seventy-seven percent of cottonwood trees in all size classes were damaged by beavers in low terrace habitat, while only 22% of Russian olives showed damage. Most beaver- damaged cottonwood were cut at the base, while damage to Russian olive was usually confined to one or two basal limbs. Beavers returned to harvest cottonwood in low terrace habitats at least every 2-3 years on average. Beaver use was lower in high terrace habitat with 41% and 2% of cottonwood and Russian olive respectively showing damage. The lower Marias River had large annual flow fluctuations and frequent flooding prior to construction of Tiber Dam in 1956. Since then flooding has been attenuated, and flows remain relatively constant throughout the year. Cottonwood recruitment that used to occur over large areas of the floodplain is now confined to a narrow zone along the channel. Beaver populations may have been enhanced by flow regulation that increases the number of potential den sites safe from flooding and severe drawdown. Beaver effectively prevent cottonwood from developing a mature canopy close to the river while having little effect on the continued invasion of Russian olive. Riparian cottonwood forests will eventually be replaced by Russian olive as old cottonwood die on upper terraces and young plants on low terraces are removed by beaver or shaded by the less palatable species. The decline of riparian cottonwood forests can be ameliorated by a return to more natural flow regimes, management of beaver populations, and not planting Russian olive near riparian areas.

Bearproofing Solid Waste Containers for Grizzly and Black Bears in Lake and Cascade Counties, Montana$^{\text{TWS}}$

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Abstract: Grizzly bear (*Ursus arctos*) and black bear (*Ursus americanus*) access to garbage at solid waste transfer sites is a serious problem for wildlife managers, county officials, local residents, and bears. We present the design, installation, costs/ operation, and politics associated with bearproofing two solid waste transfer sites. Between 1982 and 1992, we documented the removal of four black bears from the Porcupine disposal site in Lake County. During 1993, we documented five black bears and one grizzly bear using the Porcupine site. In 1994, we designed and installed an automatic, hydraulic lid system for the 42 cubic yard dumpsters. Since the system was installed in September 1994, bears have not gained access to garbage, and evidence of bears visiting the site has declined every year. In 1996, Cascade County designed a similar system and installed it at a site we identified as a major problem for black bears. We worked with county officials and attended local public meetings to discuss the advantages of bearproofing the transfer site. The modifications have resulted in cleaner and safer sites, and a large reduction in bears accessing garbage. We plan on expanding the program to include additional transfer sites throughout Montana.

Black-footed Ferret Update$^{\text{TWS}}$

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A minimum of 26 black-footed ferret (*Mustela nigripes)* kits from 12 litters were born in the wild during 1997 on the UL Bend National Wildlife Refuge, north-central Montana. The confirmed spring breeding population was 23 (11 males, 12 females). Twenty captive-reared ferrets were released during October, 1997 to augment this growing population and was the fourth year of reintroductions. These ferrets were released among a subset of residents to investigate how ferret density may impact movements, distribution and survival. Resident and newly released ferrets were monitored with telemetry from September through mid-November, 1997 on treatment and control areas. Ferret density on the treatment area was 3.5 times that of the control area. No significant differences in survival were detected between or within areas before or after captive-reared ferret releases. Investigations of the ultimate capacity of the UL Bend area to support ferrets are continuing along with efforts to determine when this population will become self-sustaining and be capable of producing wildborn kits for translocation to other sites.

A WILDLIFE MORTALITY SAMPLE AND MARROW FAT ASSESSMENT DURING A RECORD SNOWFALL WINTER, NORTHWESTERN MONTANA^{TWS}

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Carcasses (n = 114) killed during winter 1996-97 in the lower Clark Fork River drainage of western Montana were examined and assessed for condition by bone marrow fat index using visual rating and percent fat (dry/wet weight) rating methods. Species examined were bighorn sheep (*Ovis canadensis*) (n = 11), elk (*Cervus elanhas*) (n = 33), mule deer *Odocoileus hemionus*) (n = 3), and white-tailed deer *Odocoileus virginianus*) (n = 97). Sex, age, femur length, diastema, mortality agent, and parasites were recorded when available. Percent marrow-fat was analyzed on 53 specimens. Most (93%, n = 29) white-tailed deer that died before 15 February had > 20% marrow-fat, while 33% (n = 15) of those that died after 15 February had < 20% marrow-fat. There was a significant difference between percent marrow-fat for those deer that died during the first half of winter and those that died in the last half (p = 0.003, t-test). A majority (59%, n = 22) of white-tailed deer carcasses from mid-late winter had an inadequate marrow-fat visual rating. A total of 41 (36%) animals were < I year old (I elk, 2 bighorn sheep, 3 8 white-tailed deer) and 14 (12%) were estimated at > 10 years old (1 elk, 13 white-tailed deer). Females (77%, n = 85) markedly outnumbered males (n = 26) in this sample (3 were unknown). Mortality agents were categorized as hunter wasted (1 %), predator (7%), road kill (87%), train-kill (4%), and unknown (1%). These data document the seasonal physical stress on a sample of wildlife in northwestern Montana during a record snowfall event and support the contention that weather conditions can have a dramatic impact on wildlife populations. Since this type of data have not been collected in this area prior to 1997, no comparisons can be made regarding physical health during less severe winter conditions. Efforts to collect such data in the future will be made when time and resources allow.

DYNAMICS OF A ROUGH-LEGGED HAWK (*BUTEO LAGOPUS*) COMMUNAL ROOST IN THE MISSION VALLEY, MONTANA^{TWS}

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During the winters of 1994 -1998, I investigated the roosting ecology of Rough-legged Hawks (*Buteo lagopus*) in the Mission Valley of northwestern Montana. Nineteen hawks were radio-tagged during the winters of 1995- 96 and 1996 -97 from which I recorded a total of 320 day and 326 night locations. Radioed birds frequently used two major communal roosts, flying up to 20 km daily to and from foraging areas. The primary roost (Ronan roost) is located in contiguous Douglas fir (*Pseudotsuga menzziesii*) l ponderosa pine (*Pinus ponderosa*) forest near the foothills of

the Mission Mountains, and according to radio telemetry, encompasses approximately 238 ha (n = 133; adaptive kernel 70% polygon). The high-use area (adaptive kernel 40% polygon) within the roost consists of moderately dense forest (canopy closure >75 %) and contains many interspersed houses. A maximum of 225 Rough-legged hawks were counted departing the Ronan roost (Feb 1995), and multiple counts of >150 birds occurred in three of the four years. A maximum of only 44 hawks were counted during 1995- 96. Among- and between-year diffe rences in the number of hawks attending the roost appear to reflect changes in microtine numbers. Preliminary data on the age and sex composition of hawks departing the roost are similar to those recorded on daytime surveys throughout the valley; however proportionately fewer juveniles were observed departing the roost than were recorded in the valley. Current research will test several hypotheses concerning the adaptive significance of rough-legged Hawk winter communal roosting behavior.

EFFECT OF STREAMSIDE DEVELOPMENT ON DISTRIBUTION AND PRODUCTIVITY OF AMERICAN DIPPERS (*CINCLUS MEXICANUS*) IN WESTERN MONTANA^{TWS}

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Human development may play an important role in determining the distribution and success of organisms. Habitat specialists such as the American Dipper (*Cinclus mexicanus*), are particularly likely to be affected by alterations to their habitat. During 1996 and 1997, I examined the effect of streamside development on the distribution and productivity of dippers in the Bitterroot Valley of Western Montana. I surveyed 23 creeks, located and monitored 49 nests, and conducted extensive habitat analyses of dipper territories and non-use areas. Average dipper densities were 0.3 3 +/- 0.12 pairs/km of stream during the breeding season. Dipper breeding territories were more likely to occur in less developed portions of streams. However, there was no significant difference between number of young fledged in developed vs. undeveloped territories (P=0.264). Water depth in dipper territories was significantly greater at the end of the breeding season than in non-use areas (P=0.001) suggesting dipper distributions may be affected by intensive de-watering of creeks for irrigation. The presence of bridges, which provide nest sites for dippers, have allowed dippers to colonize the lower reaches of creeks and nest in areas that may be more vulnerable to flooding and predation. However, there was no significant difference between number of young fledging from bridge vs. natural nest sites (P=0.463). Indeed, bridges at lower elevations allowed dippers to breed earlier and in some cases, to double brood. Overall, the most important factor in determining dipper distributions and productivity in the Bitterroot appears to be the availability of nest sites.

Nest Defense Behavior in Snowy Owls (*Nyctea scandiaca*)^{TWS}

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In 1995 and 1996 at Barrow, Alaska, we studied the nest defense behavior of snowy owls at 73 nests. We recorded female flushing distance from the nest, and vocalizations, attacks, distraction displays, and perching distances of both males and females. Females exhibited an unusual decoying behavior during incubation and brooding, flushing from their nests as researchers approached (mean = 393 m, n = 304, range = 57 - 780 m, SD = 137 m). Median flushing distances differed significantly among individual females; X' = 146.9, df = 46, $p < 0.0005$. Barks, hoots, screams, attacks, and distraction displays differed significantly between the sexes. Males barked often, hooted little, and almost never screamed, while females barked and screamed frequently, but rarely hooted. Males exhibited more aggression than females, attacking during 237 nest visits (n = 2075) while females attacked only 52 times. However, females exhibited more distraction displays, performing on 204 visits (n= 2066), nearly 3 times as often as males. Perching distance differed significantly between the sexes with males perching an average of 40 m closer to researchers; t = 6. 1, df = 828, $p < 0.005$.

Foraging by Hairy, Black-backed, and Three-toed Woodpeckers in Post-fire Forests of the Northern Rocky Mountains^{TWS}

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Woodpecker species occur in differing abundances across the landscape, but populations of several species typically are more dense in early post-fire forests than in green forests. We studied foraging behavior of 3 woodpecker species during year one of a five-year study on cavity-nesting birds in salvage-logged and unlogged post-fire forests in western Montana and eastern Idaho. Three of our four sites burned in 1994 and subsequently were partially salvage-logged; the fourth site burned in 1996 and was not logged. Here we summarize 202 observations of foraging hairy, three-toed, and black-backed woodpeckers from the 1997 breeding season. We observed single instances of foraging birds and recorded pertinent data including bird species, foraging, maneuver, foraging height, and tree species and dbh. We compared foraging variables among, species and to measures of available vegetation taken systematically across the sites. The three species used Douglas fir in 48%, ponderosa pine in 23%, and lodgepole pine in 20% of the foraging instances, with the remaining 9% of observations occurring, in subalpine fir, western larch, and Engelmann spruce. Black-backed woodpeckers used Douglas fir more often than either hairy or three-toed woodpeckers, while three-toed woodpeckers foraged on lodgepole pines to a greater extent than did the other two species. Also, average dbh of trees used for foraging was greater than average dbh of both nest trees and available trees. In subsequent years we expect to expand our analyses to detect differences in foraging between logged and unlogged treatments, and to examine woodpecker diets and prey densities.

STATUS AND DISTRIBUTION OF THE PYGMY RABBIT IN MONTANA^{TWS}

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Pygmy rabbits (*Brachylagus idahoensis*) were first documented in southwestern Montana in 1918. Historical distribution records are sparse at best, and concern over the status of the pygmy rabbit lead to a evaluation of its current distribution in Montana. The present distribution of the pygmy rabbit is defined and reflects historical distribution maps. Pygmy rabbits were present in all historical locations except one. Some evidence suggests a slight contraction in pygmy rabbit distribution. Habitat parameters are similar to occupied areas in other states. Big sagebrush (*Artemesia tridentata*) was slightly shorter in occupied sites in Montana and averaged 21.3 % coverage by line intercept method. In Montana, pygmy rabbits appear to prefer gently sloping or level floodplains where adequate sagebrush 'and soils exist. However, many different occupied sites have been located. Loss of preferred habitat through sagebrush removal is probably the greatest threat to the species. One calculated density in good habitat in Montana of 3.03 rabbits/ha is higher than reports from Washington and Oregon. Morphologically, pygmy rabbits are similar to those in other states with females weighing slightly more than males. Continued monitoring of the pygmy rabbit's distribution is recommended.

DISTRIBUTION AND DEMOGRAPHICS OF BIRD COMMUNITIES IN THE GREATER YELLOWSTONE AREAS^{TWS}

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During 1995-97, we estimated the composition and distribution of neotropical migratory bird communities on a 9,000 km^2 study area in the western portion of the Greater Yellowstone. The study area contains a wide diversity of habitat types and elevations. Our findings indicate that diversity and density of birds are much higher in aspen and cottonwood sites than they are in other habitats (e.g., Douglas fir, lodgepole pine, and others). However, our data also indicate that brood parasites such as brown-headed cowbirds (*Molothrus ater*) and egg predators such as black-billed magpies (*Pica pica*) are not evenly distributed among habitats. Rather, we found that cowbirds, magpies, jays, etc. were much more abundant in cottonwood stands than in aspen and other stand types. Therefore, we also measured reproductive success in hot spots for diversity and density, i.e., aspen and cottonwood stands, to determine if these habitats are beneficial to breeding birds. Preliminary data from both artificial (1994) and natural nests (1995) indicate that nest success is significantly lower ($P < 0.05$) in cottonwood stands than it is in aspen stands or in mature stands of lodgepole pine. Furthermore, preliminary population modeling indicates that cottonwood stands are population sinks for open-cup nesters that are susceptible to brood parasitism (e.g., warblers, sparrows, vireos, etc.)· Management implications will be discussed.

Acute Nutritional Stress in White-tailed Deer During the 1996/97 Winter in Northwest Montana^{TWS}

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Once every 200-300 years, maximum snow depth at Kalispell Airport reaches that recorded during, the 1996/97 winter. Once every 33 years, an equal number of consecutive snow cover days would be recorded. Ungulate overwinter survival depends on many factors, including winter severity and possessing the necessary fat reserves to meet increased thermoregulatory demands and offset nutritional stress caused by low quality forage. To assess the timing and degree of acute nutritional stress in white-tailed deer (*Odocoileus virginianus*), the percent (%) marrow fat content was determined using the oven-drying; technique for femurs collected from carcasses encountered during field work and along roadways from December 1996 to June 1997. We recorded sex and age, location, cause of death, and death date estimated to julian week. Cause of death was categorized as vehicle, predation, unknown, or natural (accidents and winter-kill). Percent marrow fat in adult females declined significantly through the winter for vehicle-kills (p = 0.000 1) but did not decline for those adult females dying of natural causes (p = 0. 19). In fawns, % marrow fat declined significantly through time for vehicle kills (P = 0.008) but not for natural deaths (p = 0.66). Fawn natural mortality commenced in late January whereas adult female natural mortality commenced in mid-February. Of those deer which died of natural causes, the marrow fat content averaged 72.4% (95% C.I. 65.7 - 79. 1) for fawns and 66.9% (95% C.I. 58.1 - 75.8) for adult females. Mean % marrow fat for fawns dying of natural causes was significantly less than for predator-kills (p = 0.02), but the difference was insignificant for adult females (p = 0. 10 8).

The Winter of 1996/97: What Did it Mean to Northwest Montana White-tailed Deer Populations?^{TWS}

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The most notable attributes of the 1996/97 winter were its duration and the record snow depths at all elevations. The collective success of individual ungulates in surviving the winter has important implications for population dynamics and herd management. We assess the role that winter 1996/97 played in shaping population dynamics for white-tailed deer (*Odocoileus virginianus*) using data from an ongoing research project in the Salish Mountains. Fawns began dying of natural, winter-related causes in late January. The monthly observed fawn: 100 adult ratio declined significantly from. December to March (p = 0.02). The predicted fawn: 100 adult ratio in May was 1: 100 (S.E. 7.4). The number of fawns per 100 adults estimated from remote camera surveys declined 44% in the same period, likely declining, further because deer remained on winter range for another 7 weeks post survey. Adult female natural mortality began in mid-February. Of the radio-collared adult females which survived the hunting season and entered the winter, 26% died by June 1, 1997. Fifty nine percent of the adult female mortality occurred in animals cementum-aged 6.5 or younger. Migrant radio-collared deer confined themselves to winter range an average of 159 days (range 126-185), or 8 weeks longer than the average of all previous years. Most deer entered winter range on November 23, 1996 and some stayed until May 27, 1997. Additional results and observations are discussed. Under the most ideal future conditions, it could take 3-5 years for populations in the Salish Mountains to rebound to levels prior to the severe winter event, even longer in areas which experienced harsher winter conditions.

HCP Basics^{TWS}

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Habitat Conservation Plans (HCPs) are coming to the Rockies. HCPs are plans that support the issuance of Permits by the Fish and Wildlife Service and/or National Marine Fisheries Service (together referred to as the services) that allow incidental take of species listed under the Endangered Species Act. This presentation will describe the components of an HCP and permit, describe the application and development processes, and applicable criteria. Most importantly, this presentation will focus on biologists that work for tribes, state agencies, or other federal agencies giving them enough information about how HCPs are put together and when opportunities for public participation arise to make them effective participants in a negotiated process which is primarily conducted between the applicant and the services. The discussion will include specific examples from the HCPs being developed in the "coastal" Northwest and ample time will be allowed for questions and answers so as to tailor the session to the needs of the participants.

SURVIVAL RATES AND MORTALITY FACTORS OF ELK IN THE SOUTH FORK OF THE FLATHEAD RIVER, MONTANA^{TWS}

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We investigated survival rates and mortality factors of elk >1 year old on 2 project areas in the South Fork of the Flathead River, Montana from 1989 through 1997. On the Firefighter project area mean annual survival of cows (n=84) was

0.85±0.13. On the Spotted Bear project area (n=23) it was 0.84 ±0.16 and did not differ from that at Firefighter (p=.23). At Firefighter, survival of cows during the latter half of the study (6/15/93 - 6/15/97) was greater than during the first half (6/15/89 - 6/15/93) (mean annual survival=.89 and .82 respectively, p=.04). Possible reasons are discussed. Sample size precluded a similar test at Spotted Bear. Fifty-seven percent of deaths among cows (n=39) were somehow human-related. Causes of death were: 41 % hunting, 28% winterkill/natural causes, 13%-wounding loss, 10% predation, 5% unknown, and 3% poaching. Survival among bulls from both project areas combined (n=20) was 0.69±0.22 and differed from that of cows on either project area (p<.02). Among, 17 bull deaths, 15 (88%) were by hunting, 1 (6%) by wounding loss, and 1(6%) by winterkill. The management implications of this level of human-caused deaths among both sexes of elk in habitat generally considered secure are discussed.

MONITORING BREWER'S SPARROWS (*SPIZELLA BREWERI*) USING SONG RECORDINGS^TWS^

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Formerly extensive sagebrush-shrub steppe areas of Washington have been substantially reduced and fragmented by conversion to agricultural uses. Thus, conservation of species found only in sagebrush habitats are a major concern for wildlife managers. As part of an ongoing study on the effects of shrub steppe fragmentation on nesting birds in eastern Washington, we color-banded individual male Brewer's sparrows, recorded their songs and tracked their nesting success throughout the breeding season. Recordings indicate that each individual male Brewer's sparrow possesses two different types of songs, termed simple and extended songs. Simple songs are individually distinctive and extremely variable among males within local populations. Thus, recordings of simple song act as acoustic fingerprints for identifying individual males. They are also produced repetitively from late April through the end of May. Recording simple songs during this period may provide a non-intrusive, cost-efficient method for monitoring adult survivorship of Brewer's sparrows and possibly other shrub steppe species.

EXOTIC PLANTS, WILDLIFE, AND ECOSYSTEM MANAGEMENT^TWS^

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Public awareness of exotic, invasive plant problems is increasing and even though momentum has been increasing, there are still people who do not understand or are unaware of the impact on the environment. What is your understanding of the issue? Can you take newcomers through the issue step-by-step so they learn and grasp the significance? If not, please take the time to listen. Nearly every plant

referred to as a weed is not indigenous to this continent. Many have an unfair advantage in the environment because the biological controls on them were removed when the plant migrated here. No insects, fungus, or disease to keep them in check. There are over 2000 non-indigenous plant species in the United States but only about 200 that are invasive. However, there is new bio matter (seeds, stems or tubers) hitting our shores each year and many that are already here are evolving into the next potential spotted knapweed or leafy spurge. Presently weeds cover over 5% of the US, an area larger than the state of California. The Bureau of Land Management has estimated that weeds are increasing at a rate of 4,600 acres per day or 3 million acres per year. Weeds are spread by animals, people, equipment, wind, water, fire and hay. Activities that disturb the soil or plant community or reduce ground cover increase the likelihood of a weed-invasion. Some weed species are so invasive that they are taking over otherwise healthy ecosystems. Impacts of weeds on the environment include replacement of native vegetation, loss of wildlife habitat, loss of wildlife species diversity (60 - 80%) and monocultures on whole landscapes. Montana has over 8 million acres of spotted knapweed alone. Weeds like yellow starthistle will cause loss of recreational opportunities, livestock forage production is reduced ($4.5 million in Montana). Areas infested with spotted knapweed are shown to experience 56 to 192% higher runoff and erosion. What can be done? Pass the word. Until people are concerned they are not going to be interested in solutions.

NATIONAL BISON RANGE COMPLEX COMPREHENSIVE CONSERVATION PLANNING^TWS

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The National Bison Range Complex of the U. S. Fish and Wildlife Service (FWS) is comprised of the National Bison Range, Swan River National Wildlife Refuge (NWR), Ninepipe NWR, Pablo NWR, and the Northwest Montana Wetland Management District. The Complex is currently engaged in developing a comprehensive conservation plan for all units of the complex in addition to a decision document for acquisition for Lost Trail NWR. The who, what, where, when, and why of this public and internal planning process is presented. Ramifications of this process for individual stations and other National Wildlife Refuges in Montana are also discussed.

AUTUMN AND SPRING RAPTOR MIGRATION THROUGH GLACIER NATIONAL PARK^{TWS}

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A raptor migration corridor used by bald eagles (*Haliagetus leucocephalus*) travelling through Glacier National Park (GNP) was first documented in 1939. In October 1987, we also documented large numbers of golden eagles (*Aquila chrysaetos*) migrating through the park. Intermittent observations of migrating raptors using the Livingston and Lewis Mountain Ranges in GNP continued until, 1994, when more intensive observation began. Volunteer observers using binoculars and spotting scopes, recorded migrating raptors when weather conditions allowed visibility of a main migration route that crossed the McDonald Valley. Observations were standardized to record numbers of birds each minute from 1100 hr to 1800 hr. Raptors traveled between 1,830 m and 3,050 m above sea level using thermals and orographic lift. The entire park appears to be part of a migration corridor that is analogous to a large, braided river of birds flowing in main channels with connecting side channels. Between 1994 and 1996, golden eagles comprised over 80% of all raptors and 92% of all eagles documented in autumns at the McDonald observation point. Peak golden eagle migration in autumn was observed during early to mid-October and in spring, during the third week of March. In October 1996, 137 eagles were counted in a single hour. Total eagles counted in autumn during three years were: (1994) 2,242 in 91 hrs of observation; (1995) 1,991 in 109 hrs; (1996) 2,664 in 162 hrs. Spring totals were: (1995) 870 in 79 hrs and (1996) 904 in 86 hrs. Weather conditions appeared to influence numbers of eagles observed on a given day. Threats to migrating eagles in GNP include numerous unrestricted scenic overflights within travel corridors.

STATUS OF SWIFT FOX *(VULPES VELOX)* SURVEYS AND STUDIES IN NORTH CENTRAL MONTANA^{TWS}

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Canadian wildlife agencies began a swift fox reintroduction program in southern Alberta and Saskatchewan, Canada in 1983. Over the next decade, these reintroduction efforts led to a strong possibility of individuals dispersing into north-

central Montana and creating a resident population. This study began in the fall of 1996 in northern Blaine County, Montana to confirm the presence of a resident swift fox population. The study involved systematic block live-trapping by township and radio collaring any swift foxes captured. In the spring of 1997, radio collared swift fox were used to locate possible natal den sites and to confirm a resident population. A total of 16 swift foxes were trapped in the fall of 1996 and late summer of 1997. Five captures were juveniles and 11 were adults. Three litters were monitored in the summer of 1997. A study of home range, food habits, and survival is also incorporated into the study.

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