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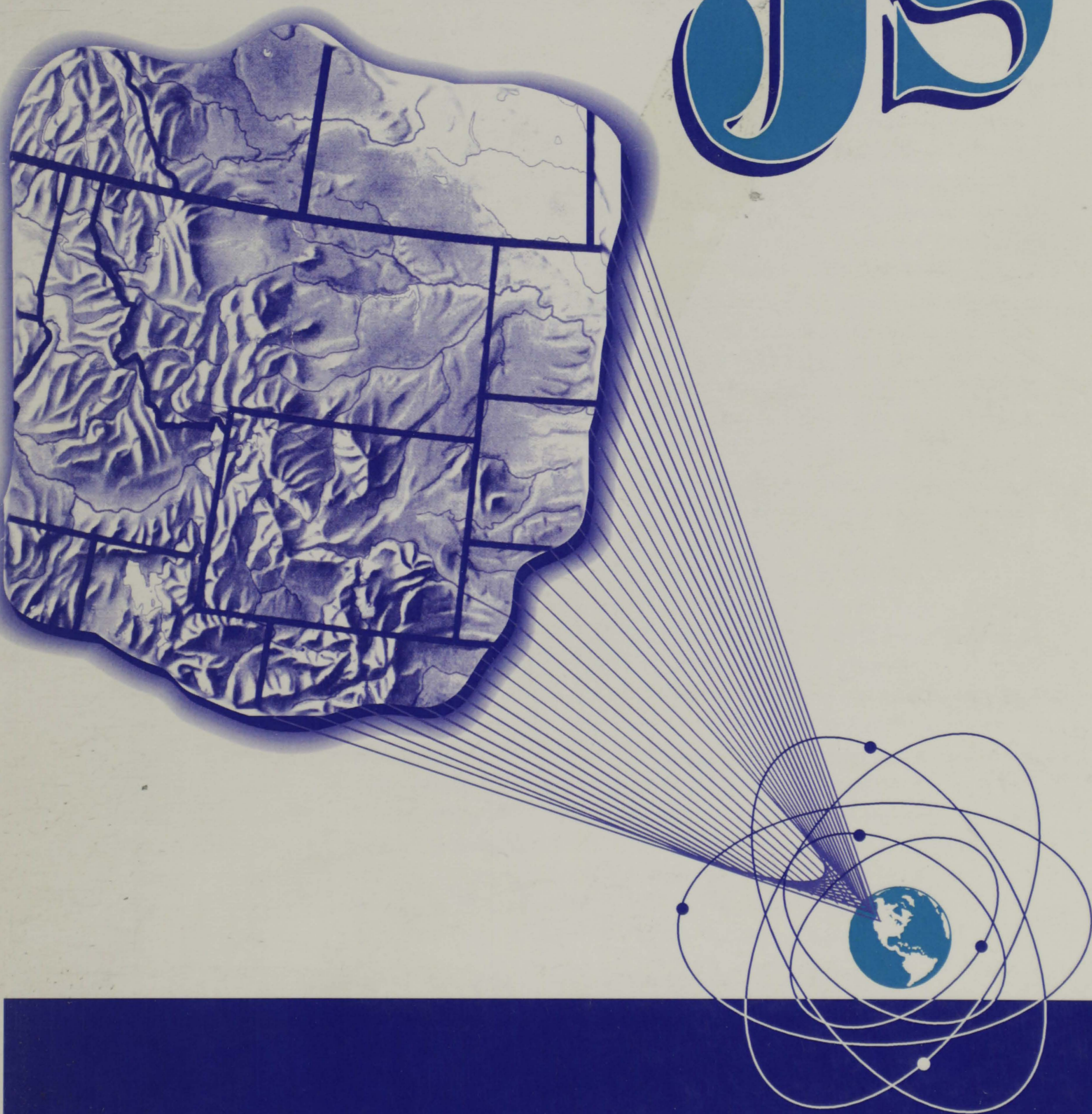
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ANNEX

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IJS



INTERMOUNTAIN JOURNAL OF SCIENCES

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

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

Initial funding was provided by the co-sponsor organizations. Long-term funding will be derived from page charges assessed authors, sponsoring organizations or agencies at \$45 per printed page upon acceptance of each manuscript and from annual subscriptions: student \$6; regular member \$15; patron member \$25; library \$25; life member \$150; and, sustaining subscriber \$2,500.

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

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

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

*For detailed information about IJS, please go to our website at:
www.montanatws.org/ijsindex.html

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EDITORIAL REVIEW POLICY

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

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

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

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

ACCEPTANCE

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

REJECTION

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

REVIEWER ANONYMITY

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

MANUSCRIPTS SUBMITTED BY EDITORS

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

ABSTRACTS

Only abstracts from the annual meetings of the sponsoring organizations will be published in IJS. Other submissions of abstracts shall be considered on a case-by-case basis by the Editorial Board. Sponsoring organizations shall collect abstracts, review them for subject accuracy, key or scan them onto a 3.5" diskette, and submit the diskette and hard copy of each abstract to the EIC on or before November 1. Each abstract shall be reviewed by the

EIC to assure proper grammar, compliance with IJS "Guidelines for Abstracts Only" and for assignment to the appropriate discipline section. All abstracts will be published in the December issue only.

COMMENTARY

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

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

LITERATURE CITED

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

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STRATEGIES FOR UNGULATE-VEHICLE COLLISION MITIGATION

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ABSTRACT

Wildlife mortality caused by vehicles presents a serious conservation and economic problem, as collisions with large mammals are global, pervasive, and increasing. The combination of increasing ungulate populations combined with increasing vehicle-miles traveled has heightened the significance of this problem. We reviewed the U.S. and, secondarily, European scientific literature pertinent to mitigating the effects of ungulate-vehicle collisions. This review presents an analysis of ungulate movement and behavior in relation to roads to further develop general conclusions about accurately locating high frequency collision areas. Some successes in reducing ungulate-vehicle collisions have been documented with fencing, modified fencing, and grade separation via crossing structures, although traditional solutions often are expensive, e.g., fencing, overpasses, have limited effectiveness, e.g., reflectors, static warning signs, or may further habitat fragmentation or create barriers to movement, e.g., ungulate-proof fencing, vegetation clear-zones. We also present several case studies illustrating animal-detection driver-warning systems, technology based deployments, applied to the problem of ungulate-vehicle collisions. Although there is significant interest and potential in animal-detection driver-warning systems, many technical issues must be addressed before they are ready for general use. We emphasize the need for more sound statistical design in determining efficacy of treatments.

Key words: accident, crossing structures, deer, highway, intelligent transportation systems, mammalia, mitigation, mortality, roadkill, transportation, wildlife.

INTRODUCTION

Roads affect biological systems, communities, and species in numerous ways. Some conservation scientists have identified road construction and maintenance in the U.S. as one of the most widespread forms of modification to natural ecosystems over the past 100 years (Noss and Cooperrider 1994, Trombulak and Frissell 2000). Many wildlife species depend on the preservation of large tracts of intact land, but roads often fragment these tracts. Foreman (2000) estimated that 22 percent of the contiguous U.S. has been altered by the nation's road network. Trombulak and Frissell (2000) provide an

excellent review of the ecological effects of roads at the taxonomic level (but also see Foreman and Alexander 1998). Collisions with large mammals are an increasing problem on the roadways of the U.S., Europe, and Japan (Groot Bruinderink and Hazebroek 1996).

Results from a survey of the nation's natural resource agencies ($n = 35$ reporting mortality) indicated that deer (*Odocoileus spp.*) conservatively accounted for 538,000 collisions in the U.S. in 1991 (Romin 1994, Romin and Bissonette 1996). Conover et al. (1995) extrapolated these findings for the remaining states and estimated that ungulates account for 726,000 to 1.5 million

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collisions in the U.S. annually. Groot Bruinderink and Hazebroek (1996) estimated the annual number of collisions with ungulates in Europe to number 507,000. Population density is a principal factor affecting ungulate presence along roads, and increased populations have been correlated with increased ungulate-vehicle collisions (Puglisi et al. 1974, Sage et al. 1983). During the last century, many ungulate populations in the U.S. have recovered due to protection from overexploitation, land-use changes, and application of scientific management (Messmer 2000). For example, the nation's white-tailed deer (*O. virginianus*) population is burgeoning, from about 500,000 animals at the turn of the century to more than 20 million today (Cook and Daggett 1995, Hughes et al. 1996). The combination of increasing ungulate populations and increasing vehicle-miles traveled has heightened the significance of this problem. From 1985 to 1991, deer-vehicle collisions increased an average of 69 percent in the states of California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington (Hughes et al. 1996).

Estimates of the magnitude of damage caused by wildlife are acknowledged to be conservative and inadequate to develop accurate conclusions concerning the scale and socio-economic consequences of ungulate-vehicle collisions (Groot Bruinderink and Hazebroek 1996, Messmer 2000). Such collisions can involve safety and economic impacts that include injuries, fatalities, property damage, increased insurance premiums, lost hunting revenue, and carcass removal expenses (Conover et al. 1995, Conover 1997). Approximately 230 fatalities and 29,000 human injuries occur annually in the U.S. although in Europe an estimated 300 fatalities and 30,000 injuries occur annually from ungulate-vehicle collisions (Conover et al. 1995, Groot Bruinderink and Hazebroek 1996). Conover et al. (1995) and Cook and Daggett (1995) estimated the total cost in

property damage due to ungulate collisions in the U.S. to exceed \$1.1 billion annually. Estimates for Europe are similar (Groot Bruinderink and Hazebroek 1996).

Many factors affect the spatial and temporal distribution of ungulate-vehicle collisions, particularly ungulate movement, behavior, habitat, and topography. Ungulate-vehicle collisions are not randomly distributed but frequently occur in predictable locations, often in relation to habitat or topographical configurations, which concentrate crossings along particular sections of a roadway (Table 1). Collisions between large mammals and vehicles increase when roadways are constructed through prime habitat or intersect ungulate migration routes (Reed and Woodard 1981). Vegetation and topography can work synergistically to funnel deer to predictable crossing areas. Foreman and Hersperger (1996) outlined three (of six) major types of flows across landscapes that prove pertinent to highway mortality. They include surface water in streams, wildlife in major corridors, and vehicles on roads. Indeed, Hubbard et al. (2000) found that bridges in Iowa "always indicate points where major edge-creating landscape features intersect roadways" and thus provided the best indicator of high incidence areas of white-tailed deer-vehicle accidents.

Roads change habitat complexes. Ungulates can be attracted to the road right-of-way because of palatable roadside plantings or increased production of understory vegetation (Case 1978, Feldhamer et al. 1986, Waring et al. 1991). Bellis and Graves (1971) found that the number of white-tailed deer killed/month on Interstate 80 in central Pennsylvania was strongly correlated with numbers of deer observed grazing along the right-of-way. For white-tailed deer, the highway right-of-way is an "increasingly common, if not 'natural,' aspect of their environment" (Carbaugh et al. 1975). Early green-up of right-of-way vegetation was a primary cause of sika (*Cervus nippon*) deer-vehicle accidents in

Table 1. Published research regarding ecological relationships associated with ungulate mortality on roads, predominately for the United States.¹

Reference	Species	Location	Habitat Type
Peek and Bellis 1969	<i>O. virginianus</i>	PA	Mixed hardwood
Carbaugh 1970	<i>O. virginianus</i>	PA	Mixed hardwood
Vaughn 1970	<i>O. virginianus</i>	PA	Mixed hardwood
Bellis and Graves 1971	<i>O. virginianus</i>	PA	Mixed hardwood
Puglisi et al. 1974	<i>O. virginianus</i>	PA	Mixed hardwood
Reilly and Green 1974	<i>O. virginianus</i>	MI	Mixed hardwood
Carbaugh et al. 1975	<i>O. virginianus</i>	PA	Mixed hardwood
Mansfield and Miller 1975	<i>O. hemionus</i>	CA	Varied
Allen and McCullough 1976	<i>O. virginianus</i>	MI	Mixed hardwood
Goodwin and Ward 1976	<i>O. hemionus</i>	WY	Prairie
Kasul 1976	<i>O. virginianus</i>	MI	Mixed hardwood
Rost and Bailey 1979	<i>O.hem/C.e.can</i>	CO	Pine/Juniper/Shrub
Sicuranza 1979	<i>O. virginianus</i>	MI	Mixed hardwood
Kress 1980	<i>O. virginianus</i>	PA	Mixed hardwood
Sage et al. 1983	<i>O. virginianus</i>	NY	Mixed Hardwood/ Conifer
Bashore et al. 1985	<i>O. virginianus</i>	PA	Mixed hardwood
Waring et al. 1991	<i>O. virginianus</i>	IL	Mixed hardwood/Ag.
Groot Bruinderink and Hazebroek 1996	Various	Europe	Varied
Calvo and Silvy 1996	<i>O.vir.clavium</i>	FL	Varied
Pafko and Kovach 1996	<i>O. virginianus</i>	MN	Mixed Hard./Conifer/Ag.
Gunther et al. 1998	Various	Yellowstone N.P.	Varied
Finder et al. 1999	<i>O. virginianus</i>	IL	Varied (GPS)
Iverson and Iverson 1999	<i>O. virginianus</i>	OH	Varied
Hubbard et al. 2000	<i>O. virginianus</i>	IA	Varied (GPS)
Rowland et al. 2000	<i>C. elaphus</i>	OR	Pine/Bunchgrass Forest

¹ After Romin and Bissonette 1996.

Japan (Kaji 1996). For the U.S. as a whole, elk (*Cervus elaphus*) and mule deer (*O. hemionus*) are most vulnerable to highway collisions in winter when driven to lower elevations by snow accumulation (Leedy 1975). Moose (*Alces alces*) tolerate snow, but great depths can encumber movement and encourage moose to use plowed roads for travel (Garrett and Conway 1999). Moose also are particularly vulnerable to collisions in spring and early summer when leeching highway salts attract them to roadside pools (Fraser 1979, Fraser and Thomas 1982).

Ungulate presence, activity, movement, and behavior contribute greatly to high-incident collision locations. Generally, ungulate activity levels tend to be highest in early morning and evening, times of typically decreased visibility and increased commuter traffic (Putman 1997). Peek and

Bellis (1969) correlated dawn and dusk peaks in collision numbers to increased deer movement during those times. Leedy (1975) noted that elk mortality due to vehicles occurred primarily at night. Haikonen and Summala (2001) found that the crash rate for moose and white-tailed deer in Finland was highest 1 hr after sunset. Although no ungulate is strictly diurnal, crepuscular, or nocturnal, all have proven sensitive to human disturbance and tend to avoid open areas during the day (Putman 1997). Ungulates can habituate to roadways and will regularly cross minor roadways during daily movements within their home ranges to reach favored foraging (Waring et al. 1991, Putman 1997) and resting areas (Carbaugh et al. 1975).

Vehicle collisions with ungulates also have been linked with breeding and dispersal activities (Jahn 1959, Case 1978,

Feldhamer et al. 1986, Groot Bruinderink and Hazebroek 1996). Studies in Pennsylvania and Michigan suggested collisions with white-tailed deer peak during the autumn breeding season (rut), when both females and males are more peripatetic (Puglisi et al. 1974, Allen and McCullough 1976). There is usually another small peak in spring corresponding to parturition and dispersal of young (Reilly and Green 1974). In Pennsylvania, Feldhamer et al. (1986) documented that of 44 seasonal home range estimates for white-tailed deer, 16 (36.4%) included segments of I-84 or a secondary roadway during one or more seasons.

The importance of accurately identifying high crash areas cannot be understated, as the success of many mitigation measures depends on the accurate location of high incidence crash areas and the understanding of all factors that contribute to them (Table 1). As Putman (1997) states, "selection of the appropriate deterrent measures in any given situation is itself dependent upon proper understanding of the actual pattern of such accidents.... Without such biological understanding, we cannot really determine where preventative measures should be concentrated, or suggest *a priori* which of a variety of deterrent options is likely to be most effective in given circumstances." The remainder of this paper reviews the many research efforts, both past and present, which have attempted to reduce ungulate-vehicle collisions.

REVIEW OF TRADITIONAL MITIGATION METHODS

There have been numerous attempts to reduce large mammal mortality due to vehicles over the past few decades (Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Putman 1997). Most researchers attempt to evaluate a single mitigation technique, which makes comparisons among techniques difficult (Table 2). Most of the literature suggests that many mitigation techniques have

limited utility. Researchers applying traditional countermeasures have generally approached the problem of ungulate collisions with one or more of the following goals (1) reduce ungulate density in problem areas, (2) prevent or deter animal access to the road, (3) improve the motorist's ability to avoid a collision by elevating the motorist's awareness of the hazard.

Decreasing Ungulate Density

Local population density is one of the primary drivers of wildlife-traffic mortality (Finder et al. 1999, Joyce and Mahoney 2001). Allen and McCullough (1976) suggested controlling ungulate population numbers through harvest as one of the most effective means of reducing ungulate-vehicle accidents. Hunting has proven to be a fundamental and effective tool for managing ungulate populations. Sage et al. (1983) noted that hunting negatively influenced observation rates of white-tailed deer along forest roads in New York, largely because of reduced deer density. Spatial distribution of moose-vehicle collisions in Newfoundland depended on both traffic volume and local population density (Joyce and Mahoney 2001). Both Michigan and Illinois have used harvest in an attempt to reduce local populations and decrease ungulate-vehicle collisions (Romin and Bissonette 1996). Michigan indicated that hunting was successful (Romin and Bissonette 1996), whereas despite local population declines in Illinois, white-tailed deer-vehicle collisions did not subsequently decrease (Waring et al. 1991). Inconsistencies such as these suggested that frequency of ungulate-vehicle collisions is not simply density dependent. Similarly, utility of highway mortality as an index of species population trends has been debated (Jahn 1959, McCaffery 1973, Loughry and McDonough 1995). According to Case (1978), ungulate-vehicle collisions are the function of the following parameters: population densities, seasonal behavior, traffic speed, traffic volume, and roadside vegetation.

Table 2. Examples of published literature assessing the efficacy of various traditional mitigation techniques in reducing ungulate-vehicle collisions (categories are not mutually exclusive).

Reference	Location	Mitigation Technique
Effective		
Reed et al. 1975	CO	Highway Underpasses
Ward 1982	WY	Highway Fencing and Underpasses
Ludwig and Bremicker 1983	MN	Highway Fencing and One-way Gates
Schafer and Penland 1985	WA	Swareflex Reflectors
Wood and Wolfe 1988	UT	Intercept Feeding
Jaren et al. 1991 ¹	Norway	Vegetation Removal
Lavsund and Sandegren 1991	Sweden	Highway Fencing, Vegetation Removal
Foster and Humphrey 1995	FL	Highway Underpasses
Messmer et al. 1999	UT	Temporary, Seasonal Signage
Clevenger et al. 2001	Alberta, Canada	Highway Fencing
Ineffective		
Woodward et al. 1973	CO	Swareflex Reflectors
Pojar et al. 1975	CO	Lighted, Animated Deer Crossing Signage
Falk et al. 1978	PA	Highway Fencing
Reed and Woodard 1981	CO	Highway Lighting
Feldhamer et al. 1986	PA	Highway Fencing
Lavsund and Sandegren 1991	Sweden	Repellents (light, sound, and scent)
Ford and Villa 1993	CA	Swareflex Reflectors
Reeve and Anderson 1993	WY	Swareflex Reflectors
Ujvári et al. 1998	Denmark	WEGU Reflectors
Inconclusive		
Bellis and Graves 1971	PA	Highway Fencing
Puglisi et al. 1974	PA	Highway Fencing
Gilbert 1982	ME	Deer Mirrors
Pafko and Kovach 1996	MN	Deer Reflectors
Lehnert and Bissonette 1997	UT	Highway Crosswalk Structures

¹ Assessed efficacy on reducing moose–train collisions.

Limiting Ungulate Access

Management of ungulates on roads often consists of countermeasures designed to reduce crossing or change the pattern of crossing activity (Putman 1997). The goals of many countermeasures include altering, limiting, or preventing animal access to the roadway in areas exhibiting frequent collisions. Traditional countermeasures attempting to accomplish these goals include: (1) fencing, modified fencing, and grade separation through overpasses and underpasses to prevent animals from entering the roadway; (2) reflectors, scent repellents or sonic signals that temporarily arrest ungulate movement; and (3) vegetative plantings to alter ungulate

movement patterns or the relative attractiveness of right-of-way versus non right-of-way vegetation.

Fencing, modified fencing, grade separation.—Building barriers, such as fences, is the most common approach to prevent ungulate-vehicle collisions (Cook and Daggett 1995). A variety of fences exist to address the problem and they vary in cost and effectiveness (Clevenger et al. 2001). Most of the fencing used to limit human access to high capacity freeways is 1.22 m woven or barbed wire (Cook and Daggett 1995). However, ungulates can readily jump such fences making ungulate-proof fencing necessary. Ungulate-proof fencing, generally 2.2 to 2.7 m high, is

considered an effective restraint and is typically used to channel ungulates to crossing structures (Falk et al. 1978, Ward 1982, Cook and Daggett 1995). Although the literature offers no clear guidance on the length of ungulate-proof fencing (Foster and Humphrey 1995), fencing must be of sufficient length so as not to encourage end-runs (Ward 1982, Feldhamer et al. 1986). End runs occur when ungulates travel to the end of the fence and become trapped in the road corridor, often re-concentrating collisions. Because of this phenomenon, ungulate fencing is sometimes modified by additional one-way gates, which allow ungulates caught within the paved area to escape through the gate (Reed et al. 1974). Fencing is only effective when designs take local topography, snow accumulation, and need for maintenance into account (Ward 1982). Falk et al. (1978) documented white-tailed deer crawling through fence openings <23 cm wide. When considering fencing projects, engineers and biologists should realize that barrier fencing profoundly affects animal movement and is not always feasible or acceptable (Clevenger and Waltho 2000, Hourdequin 2000).

Overpasses, underpasses, and crosswalks are sometimes used in combination with fences to increase permeability across, over, or under the roadway. Grade separation is the process of channeling ungulate movement toward crossing structures, mainly through fencing, so that they pass over or under the highway rather than walking across it at grade (Cook and Daggett 1995). Several studies demonstrated that grade separation, through the use of overpasses and underpasses, effectively increased permeability of roads for many species of wildlife (Foster and Humphrey 1995, Yanes et al. 1995, Clevenger 1998, Clevenger and Waltho 2000, Gloyne and Clevenger 2001). However, target species might initially be reluctant to use crossing structures, e.g. mule deer (Reed et al. 1975); therefore, it is important to determine the design features of crossing structures that increase efficacy

(Rodriguez et al. 1996).

Several studies demonstrated that structure dimension and location, nearby cover, and human activities influence use of any crossing structure by large mammals (Reed et al. 1975, Singer and Doherty 1985, Clevenger and Waltho 2000, Gloyne and Clevenger 2001). Generally, the larger and more open crossing structures are the most effective. Reed et al. (1975) recommend a height and width of 4.3 m or larger for ungulate underpasses with the shortest practical length. Reed et al. (1975) found that neither artificial lighting nor skylights increased the use of underpasses by mule deer in Colorado. A relatively inexpensive alternative to grade separation are crosswalks, which consist of a break in fencing (at grade), accompanied by signs that warn motorists of crossing animals. Lehnert and Bissonette (1997) estimated the cost of crosswalks for a 2 and 4-lane highway to be \$15,000 and \$28,000, respectively, as compared to retrofitting underpasses on those same highways to be \$92,000 and \$173,000.

Reflectors and repellents.—Wildlife reflectors do not physically block animals entering the roadway, but they purport to discourage animals from entering the road by creating a visual barrier via incident light reflected by headlights until vehicles have passed (Gilbert 1982). Typical systems consist of a series of reflectors mounted on posts installed at regular intervals along the roadside. Reflector systems are relatively inexpensive, estimated to cost \$8,000 \$10,000/mile (Gilbert 1982). Several states have experimented with reflective devices though results were often mixed (Romin and Bissonette 1996, Putman 1997). Three types of reflectors exist: polished metal mirrors and WEGU reflectors (Walter Dräbing KG, Kassel, Germany) that reflect incident light from headlights (e.g. Gilbert 1982 and Ujvári et al. 1998, respectively), and Swareflex reflectors (D. Swarovski and Company, Tirol, Austria), which transmits incident light as a continuous visual barrier of red or blue-green light (e.g. Schafer and Penland 1985).

Gilbert (1982) noted that polished metal mirrors were ineffective in reducing deer-vehicle collisions in Maine, even though small sample size limited any formal conclusions. Swareflex reflectors reduced deer mortalities in Iowa (Gladfelter 1984) and Washington (Schafer and Penland 1985) but were unsuccessful in Colorado (Woodard et al. 1973), Illinois (Waring et al. 1991), California (Ford and Villa 1993), and Wyoming (Reeve and Ander on 1993). Fallow deer (*Cervus dama*) in Denmark exhibited increasing indifference to WEGU reflectors, which suggested that they too are ineffective at reducing ungulate-vehicle accidents (Ujvári et al. 1998). Furthermore, Zacks (1986) questioned the notion that ungulates avoid the color red when the results from his experiment provided no evidence that white-tailed deer responded any differently to the presence of red Swareflex reflectors, white reflectors of the same geometry, or a headlight beam without reflectors. Ujvári et al. (1998) noted that reflectors are not a reliable method of reducing ungulate-vehicle collisions on a long-term basis due to technical limitations and ungulate propensity to habituate to reflectors.

Wildlife repellents exist in many forms and with many different repelling principles, but most applied to ungulate-vehicle crashes utilize high frequency sound waves or odors that are either unpleasant to the animal or frighten them. Sound repellents may be stationary or installed as ultrasonic whistles on vehicles (Romin and Dalton 1992). When motorists reach certain speeds, the whistles produce frequencies of 16 to 20 kHz, and in theory the tone warns animals of approaching traffic (Romin and Dalton 1992). However, Romin and Dalton (1992) failed to detect behavioral response differences in 150 groups of mule deer that were exposed to whistles in Utah. In Sweden stationary sounds of 70 dB and frequencies up to 50 kHz were employed, yet moose failed to respond to sounds <21 kHz (Lavsund and Sandegren 1991). Bomford and O'Brien (1990), in a comprehensive review of sonic deterrents in

animal damage management, state "devices producing sounds other than communicative signals (alarm or distress) have no persistent effect on animals' space use or food intake." There also is evidence of habituation to sonic repellents with prolonged or frequent exposure (Bomford and O'Brien 1990, Lavsund and Sandegren 1991).

Scent appears to be a better deterrent for animals than sound, but Lavsund and Sandegren (1991) noted that scents have had limited effectiveness in reducing moose-vehicle collisions in Sweden. A research team at the University of Umea (Sweden) synthetically produced a substance that resembled the component smells in wolf urine. The motivating principal behind this development is that all ungulates possess a natural instinctive fear of predators (Koehne 1991). Fraser and Hristienko (1982) demonstrated that putrescent material (putrescent egg and cattle manure) and certain volatile compounds (isobutyric acid and creosote) were effective in repelling moose from salty roadside pools in Ontario. However, some researchers question the long-term utility of scent deterrents because the substances tend to deteriorate over time (Fraser and Hristienko 1982).

Intercept feeding.—In some areas lack of quality forage in roadside forests caused deer to use the right-of-way as a food source (Feldhamer et al. 1986, Waring et al. 1991). Planting unpalatable species within the right-of-way or creating alternate feeding areas away from the roadway can discourage ungulate use of roadside habitat or intercept ungulates moving toward the road. Indeed, Fraser and Thompson (1982) showed that alternative salt sources could be established to lure moose away from the highway. Wood and Wolf (1988) showed intercept feeding of mule deer to be useful at reducing ungulate-vehicle crashes in Utah. They further suggested that intercept feeding might reduce ungulate-vehicle collisions by <50 percent over the short term. However, Wood and Wolfe (1988) do not recommend intercept feeding for long-term reductions as it is labor intensive, and

Gilbert (1982) noted that polished metal mirrors were ineffective in reducing deer-vehicle collisions in Maine, even though small sample size limited any formal conclusions. Swareflex reflectors reduced deer mortalities in Iowa (Gladfelter 1984) and Washington (Schafer and Penland 1985) but were unsuccessful in Colorado (Woodard et al. 1973), Illinois (Waring et al. 1991), California (Ford and Villa 1993), and Wyoming (Reeve and Anderson 1993). Fallow deer (*Cervus dama*) in Denmark exhibited increasing indifference to WEGU reflectors, which suggested that they too are ineffective at reducing ungulate-vehicle accidents (Ujvári et al. 1998). Furthermore, Zacks (1986) questioned the notion that ungulates avoid the color red when the results from his experiment provided no evidence that white-tailed deer responded any differently to the presence of red Swareflex reflectors, white reflectors of the same geometry, or a headlight beam without reflectors. Ujvári et al. (1998) noted that reflectors are not a reliable method of reducing ungulate-vehicle collisions on a long-term basis due to technical limitations and ungulate propensity to habituate to reflectors.

Wildlife repellents exist in many forms and with many different repelling principles, but most applied to ungulate-vehicle crashes utilize high frequency sound waves or odors that are either unpleasant to the animal or frighten them. Sound repellents may be stationary or installed as ultrasonic whistles on vehicles (Romin and Dalton 1992). When motorists reach certain speeds, the whistles produce frequencies of 16 to 20 kHz, and in theory the tone warns animals of approaching traffic (Romin and Dalton 1992). However, Romin and Dalton (1992) failed to detect behavioral response differences in 150 groups of mule deer that were exposed to whistles in Utah. In Sweden stationary sounds of 70 dB and frequencies up to 50 kHz were employed, yet moose failed to respond to sounds <21 kHz (Lavsund and Sandegren 1991). Bomford and O'Brien (1990), in a comprehensive review of sonic deterrents in

animal damage management, state "devices producing sounds other than communicative signals (alarm or distress) have no persistent effect on animals' space use or food intake." There also is evidence of habituation to sonic repellents with prolonged or frequent exposure (Bomford and O'Brien 1990, Lavsund and Sandegren 1991).

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vehicles to recover or stop, appropriate width is determined by the design speed of the roadway and the average daily traffic (ADT). For example, the U.S. Roadside Design Guide recommends a roadside clear-zone of 9 m for roadways with an ADT of 6000 vehicles/day and a design speed of 100 km/h (AASHTO 1996; 3-3).

Researchers have suggested that extending the clear-zone out even further improves visibility for motorists and allows a measure of advanced warning, giving the driver a greater scanning area and more time to reduce speed or avoid a crash (Lavsund and Sandegren 1991). For example, Jaren et al. (1991) found that spraying vegetation with the herbicide glyphosate (Roundup®) in a 20- to 30-m section on each side of two railway lines caused a 56 percent ($\pm 16\%$) reduction in the number of moose-train collisions. However, vegetation clear-zones also may attract animals to the roadside where early successional vegetation is exposed, and the method is expensive and must be well maintained due to regrowth (Lavsund and Sandegren 1991).

Highway Lighting.—Because the preponderance of ungulate-vehicle collisions occur during hours from sunset to sunrise, Reed and Woodard (1981) thought that installation of roadway lighting would improve motorist visual acuity. They hypothesized that with increased roadside lighting, animals can be more easily sighted prior to entering the roadway, thus reducing the probability of an ungulate-vehicle collision. Reed and Woodard (1981) noted that highway lighting was successful at reducing serious vehicular accidents in urban settings. However increased highway lighting did not affect motorist speeds, deer crossings, or crossings-per-accident ratios in Colorado, and thus was not effective at reducing mule deer-vehicle collisions (Reed and Woodard 1981).

Signage and Public Education.—Conventional warning signs have been widely used to alert both frequent and infrequent motorists of dangers along the roadway (Pojar et al. 1975). Forty of 43 states (93%) surveyed by Romin and

Bissonette (1996) used static deer-warning signs. However, static deer-warning signs have been shown to have a limited effect on driver behavior but may be useful for public relations and liability considerations (Pojar et al. 1975). Warning signs could be effective if they required reduced speeds. However, signs are common and do not necessarily predict ungulate presence; thus motorists become complacent to the warning (Romin and Bissonette 1996, Putman 1997). Messmer et al. (1999) show flashing seasonal warning signs to be effective in reducing motorist speeds on Highway 89 in Utah, but cautions “drivers may initially slow down because of the flashing lights and signs, but if they do not encounter deer, their speeds may increase.” Studies have shown that drivers base their behavior on what they see on the road in front of them and not necessarily on the signing (e.g., Aberg 1981). Even seasonally lighted, animated deer-crossing signs failed to elicit enough of a motorist response to reduce the number of mule deer killed attempting to cross State Highway 82 in Colorado (Pojar et al. 1975). Similarly, Lehnert and Bissonette (1997) found a lack of motorist response to crosswalk warning signs and surmised that they may have been mistaken for conventional ungulate-warning signs.

Public education programs inform motorists of potential dangers in the roadway environment. The intent is to alter driving behavior and improve alertness levels. Public awareness programs were used by 22 of 43 states (51%; Romin and Bissonette 1996). Although, 24 percent believed the programs successful (62% inconclusive) these programs have not been rigorously evaluated (Romin and Bissonette 1996). Potential information distributed through a local public education effort should include statistics showing magnitude and severity of the problem, high crash locations, the times at which the risk is highest, what a driver can do to minimize risk, and what a driver should do if a crash does occur. In spite of inconclusive results, educating motorists of the risks of ungulate-

vehicle collisions remains a fundamental recommendation of several authors (Pojar et al. 1975, Lavsund and Sandegren 1991, Groot Bruinderink and Hazebroek 1996).

REVIEW OF NEW MITIGATION OPPORTUNITES

In a search for more sophisticated ways to reduce ungulate-vehicle collisions, transportation agencies have turned to advanced technology solutions, such as animal-detection driver-warning systems (Hughes et al. 1996). Such systems detect large mammal presence on the roadside and provide an active, dynamic warning to the motorist. These systems focus on two aspects of the problem: (1) ability to detect ungulate presence on or approaching the roadway, and (2) the driver's response to dynamic warning signs. Animal detection can be accomplished through a single method or a combination of methods. Currently, vendors are promoting microwave radar, passive and active infrared, fiber-optic grating, seismic sensors, or thermal imaging technologies to detect large mammals. Image recognition software can be used to identify animal presence in video or infrared images. Buried seismic sensors may detect ground vibrations caused by animal presence. A beam may be broken such as microwave radar, laser, or other light-wave sent between a transmitter and a receiver. Microwave radar detection systems have the highest potential for success because the systems are capable of reducing false detections caused by blowing vegetation or other small animal intrusions (Taskula 1997). A disadvantage of complex systems of this type is the need to use advanced software packages, which require the ability to process many algorithms.

Once animals have been detected in the right-of-way, drivers are warned of ungulate presence via dynamic signing, flashing beacons, or audible warnings. Given the limited effectiveness of conventional, static signing to elicit a motorist response, dynamic signing is perceived as more

appropriate and can range from a static sign with a flashing beacon to a full matrix variable message sign (Pojar et al. 1975, Cook and Daggett 1995). Recently, several pilot animal-detection, driver-warning systems have been installed, including: (1) Moose Warning System, Finland; (2) FLASH System, Wyoming; (3) Laser Detection System, Washington; and (4) Dynamic Elk Crossing, Washington. We reviewed each of these systems.

Moose Warning System, Uusimaa, Finland

In Finland, moose account for about 1300 collisions annually, costing about \$10 million in human injury and property damage (Taskula 1997). In 1995 on all public roads in the Uusimaa region, 435 moose collisions were reported to police. On Highway 7, a moose-detection driver-warning system was installed to increase motorist awareness of the hazard and to alleviate vehicle damage. Here, moose were funneled by 1650 m of fence into a designated 220-m opening that allowed moose to cross the road (Taskula 1997). A motion-detecting system, using microwave radar sensors (two/pole, 50 m apart) spanned the 220-m crossing in the right-of-way. Positive detections triggered fiber-optic moose-warning signs located approximately 150-200 m upstream of the crossing/detection zone on both sides of the road (4 in all). Minor adjustments concerning moose movement rates were necessary to avoid false detections due to blowing grass and small birds (Taskula 1997). To reduce false detections caused by rain and air pressure fluctuations, passive infrared detectors and a rain detector were also built into the system. Driver reaction, in the form of reduced speed, was measured during periods of sign activation using inductive loop traffic detectors. When encountering the activated signs (versus control periods), motorists decreased speed in rainy conditions (14.0-15.6 km/hr) and at night (1.6-2.6 km/hr), yet there was little impact on motorist speed during daylight periods with good visibility (increase of

0.4-0.5 km/hr; Sabik Oy, unpublished report).

FLASH System, Nugget Canyon, Wyoming

On U.S. Highway 30 in Wyoming between Kemmerer and Cokeville, collisions kill hundreds of mule deer annually during seasonal migrations (Gordon and Anderson 2002). The extensive road crossings, along with occasional crossings by elk, pronghorn (*Antilocapra americana*), and moose prompted officials to install 11.3 km of ungulate-proof fencing in 1989 (see Reeve and Anderson 1993) with one opening for ungulate crossings. Additionally, an ungulate-detection driver-warning system was installed at each side of the fence openings. The detection system consisted of two passive infrared radar sensors detecting deer body heat and a backup system of 10 buried geophone sensors detecting ground vibrations caused by ungulates. The infrared detection system coupled with flashing beacons and signing to form the driver-warning system, while the geophone system served as a partial backup and gathered data on crossing frequency. Conventional signing was modified to read “Deer on Road when Lights are Flashing.” The infrared system turned the lights on only when an animal is detected in the crossing zone. Additionally, highway advisory radio played a 30-second informative message about the crossing zones and why drivers should reduce speed. Initially, technical issues such as detection zone layout, sensor alignment, and optimal positioning of signs hampered the evaluation of the effectiveness of this system. Researchers found that more than 50 percent of the detections registered by the FLASH system were false detections although the backup geophone system functioned nearly perfect (Gordon and Anderson 2002). Data collected to gauge driver reaction to the system revealed that passenger vehicles and tractor-trailers significantly reduced their speed by 18.7 and 10.1 km/h, respectively, when signs

were animated and a mule deer decoy was deployed in the crossing (Gordon and Anderson 2002). Other treatments resulted in decreases in vehicle speeds ≤ 8 km/hr (< 5 mph) that we deemed insufficient to reduce the likelihood of an ungulate-vehicle collision. These results showed that speed reduction was generally higher for passenger cars than tractor-trailers. Very few large trucks responded with any reduction in speed.

Laser Detection System, Colville, Washington

The Washington Department of Transportation identified MP 290 on US Highway 395, south of Colville near Chewelah, Washington, as a high ungulate-vehicle collision area (J. Schafer, Washington Department of Transportation, personal communication). The highway segment is 402 m in length with the necessary clear line-of-sight along the right-of-way to support a simple broken-beam detection system. The system consisted of two lasers (one on each side of the road); two conventional deer warning signs with supplemental plaques, which read “When Flashing” and red beacons. The system was partially solar-powered and activated the warning beacons when the detection beam was broken. Unfortunately, the system experienced numerous technical and maintenance problems. Sighting the laser proved difficult, as proper alignment at threshold distances (400 m for most beam technologies) can be difficult to obtain and sustain. Distortion of the laser via direct solar radiation disrupted sensor alignment and lead to detection failures and false detections without shade hoods. Theft of solar power units also has been a problem.

Dynamic Elk Crossing, Sequim, Washington

On the Olympic Peninsula near the city of Sequim Washington, approximately 10,000 vehicles pass through on Highway 101 per day. From 1994 to 2000 despite standard crossing signing installed in 1996, vehicles killed 12 resident Roosevelt elk (*C. elaphus roosevelti*) whose home range was

bisected by the road. Collisions between vehicles and elk presented a safety concern for the region, which likely would increase when the new Sequim Bypass, completed during fall 2000, produced increased traffic volumes and road density. To address the problem, local officials installed an ungulate-detection driver-warning system in December 2001. Eight adults were radio collared from a herd of 81 elk. The VHF signal transmitted from their collars triggered warning signs located along 4.8 km of highway the elk frequently cross to reach the northern portion of their range. The six signs were standard elk crossing signs (with "ELK X-ING" supplemental plaques) modified with flashing beacons. When the collared elk moved within 402 m of the highway right-of-way, the 360-degree whip antenna detected their proximity and the radio-activated signs began flashing to warn motorists to reduce speed. Since installation, one traffic-related elk mortality was documented. The limited data available suggest that the system decreased mortality from 1.7 to 0.5 elk/yr.

DISCUSSION

To date, the problem of large mammal-vehicle collisions has been underestimated (Groot Bruinderink and Hazebroek 1996). Some successes in reducing ungulate-vehicle collisions have been documented with traditional countermeasures such as fencing, modified fencing, and grade separation via crossing structures (Table 2). However, traditional solutions to ungulate-vehicle collisions are often expensive, e.g., fencing, overpasses, have limited effectiveness, e.g., reflectors, static warning signs, or may damage the environment by furthering habitat fragmentation or creating barriers to movement, e.g., ungulate-proof fencing, vegetation clear-zones.

Although there is significant interest and potential in ungulate-detection driver-warning systems, our review of the literature indicated a paucity of clear information on accuracy and reliability for different ungulate detection sensors currently available. Critical parameters that

affect feasibility of ungulate-detection driver-warning systems include: detection zone layout, differentiation of large mammals from smaller objects, duration of warning signal, motorist reaction time, and local climatic conditions (Taskula 1997). Other problems include inherent range limitations, coverage limitation within detection zones, and impacts of background influencing animal-detection efficiency. False detections pose a common problem among most of the systems reviewed. One of the leading theories is that multiple detection systems, where two or more detectors must be triggered to verify animal presence, would reduce or eliminate false detections (Taskula 1997). Any dynamic warning system carries substantial development costs; have the potential for considerable maintenance costs, e.g., aligning and replacing sensors, and costs will compound with multiple systems. Until costs are reduced, ungulate-detection driver-warning systems should only be placed in discrete areas of high crash occurrence. Even if detection technologies work flawlessly, motorists may not respond enough to dynamic signing to significantly reduce the probability of ungulate-vehicle collisions (e.g., Gordon and Anderson 2002).

Effective testing of ungulate-vehicle collision mitigation measures has not kept pace with development of alternative methodologies. Many evaluations have been short-term tests of commercially developed and marketed products, e.g., Swareflex reflectors. Evaluations that compared ungulate mortality before and after installation yielded confounded results of efficacy (e.g., Pafko and Kovach 1996) because many studies recognized that the ungulate-vehicle collisions vary temporally with respect to topography, habitat, behavior, local population concentrations, time, and traffic volume. Some early evaluations lacked experimental controls, which precluded robust conclusions about expected collision numbers in the absence of countermeasures (Gilbert 1982). Where experimental controls have been used, they

often are merely adjacent roadway sections (e.g. Lehnert and Bissonette 1997). Independence can be compromised by control sections proximity to treatment sections (see Bomford and O'Brien 1990). In such cases, countermeasures in treatment sections may displace ungulates onto control sections, potentially enhancing the treatment's effect. We recommend systematic, well-designed tests of different countermeasures. Emphasis also should be placed on increasing motorist response to animal-detection driver-warning systems. If motorists do not respond by reducing speed or increasing vigilance, the best detection system will be ineffective.

Engineers should consider highway design in an ecological context to reduce interactions between ungulates and vehicles. New road designs and reconstruction plans should include wildlife passage at critical locations. This is fundamental to any attempt to mitigate the problem and may itself require a major effort, as broad scale studies of landscape features contributing to ungulate-vehicle collisions are generally lacking (Hubbard et al. 2000). Finder et al. (1999) demonstrated that deer-vehicle accident statistics, along with remotely sensed habitat and highway data might be used to predict high incidence deer-vehicle collision locations.

An example of the potential for agency cooperation is the improvement of U.S. Highway 93 on the Flathead Reservation from Evaro to Polson (90.6 km) in northwest Montana. Recently, a memorandum of agreement was signed by the Confederated Salish and Kootenai Tribes, Montana Department of Transportation, and Federal Highway Administration allowing for expansion of the highway from 2-lanes to a combination of 2-lanes, 4-lanes, and passing sections. This document further mandated retrofitting the highway with 42 fish and wildlife crossing structures and 23.7 km of ungulate-proof fencing for a total estimated cost of just over \$9 million (CSKT et al. 2000).

Although costs of many preventive measures likely are high, benefits resulting from a reduction in accidents to the motoring public and wildlife need to be adequately addressed via cost-benefit analysis (Reed et al. 1982). High mitigation costs may only be justified for major roadways or interstates (Putman 1997). For primary roads that combine high speed and high traffic volumes across important wildlife habitat, the most effective approach to ungulate-vehicle mitigation is to combine barrier fencing with wildlife crossing structures to provide large mammal permeability (Groot Bruinderink and Hazebroek 1996). In instances in which fencing costs or effects are prohibitive, as on secondary roadways, Groot Bruinderink and Hazebroek (1996) recommend animal detection-driver warning systems in which the goal of mitigation may be to delay rather than prevent crossings (Putman 1997). A monitoring program using track counts or infrared detection technologies to assess large mammal use and mitigation efficacy is critical to the long-term success of any management action (Groot Bruinderink and Hazebroek 1996).

CONCLUSION

Clearly, there is no quick fix to the problem of ungulate-vehicle collisions, but potential solutions do exist. With development of new technologies, acknowledgement by transportation agencies of ecological problems caused by roads, and new funding initiatives such as the Transportation Equity Act for the 21st Century, there is potential for increased implementation of rigorous testing of techniques for reducing ungulate-vehicle collisions. There also is a greater awareness that countermeasures should be applied within the context of a large-scale strategy to reduce problems within road corridors.

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SMALL MAMMAL COMMUNITY IN A JUNIPER-WOODLAND SAGEBRUSH-GRASSLAND MOSAIC IN SOUTHWESTERN WYOMING

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ABSTRACT

We sampled small mammal species in four distinct habitat types in a pinyon-juniper woodland and sagebrush-grassland mosaic in southwestern Wyoming. The sagebrush-grassland, pinyon-juniper woodland, pinyon-juniper rocky slope, and pinyon-juniper cliff habitats were identified as common components of the landscape. We used sherman live-traps to capture small mammals in the sagebrush-grasslands ($n = 10$ sites), pinyon-juniper woodlands ($n = 10$ sites), pinyon-juniper rocky slopes ($n = 7$ sites), pinyon-juniper cliffs ($n = 7$ sites) habitat types to identify the small mammal community and determine macrohabitat associations of the more abundant species. We measured six habitat variables at random points throughout each site to determine a habitat complexity index (HCI) for each habitat type based on structural diversity. The small mammal community of the combined four habitats was composed of 11 species with deer mice (*Peromyscus maniculatus*) being the most abundant species in all four habitats. Next to deer mice, the least chipmunk (*Tamias minimus*) was the most abundant species in three of four habitat types. The least chipmunk and cliff chipmunk (*T. dorsalis*) exhibited similar abundances in the cliff habitat type. The pinyon-juniper woodland, the most complex habitat (HCI = 1.74), had the second lowest small mammal diversity (0.583); only sagebrush had lower diversity. The cliff habitat type had the highest species richness ($S = 8$), highest diversity ($H' = 1.011$) and evenness ($J' = 0.49$). We did not find a correlation between habitat complexity and small mammal diversity although we did find a significant relationship ($P \leq 0.01$) between small mammal diversity and the percentage of ground covered by rock. Our findings suggest the importance of cliff habitat in maintaining small mammal diversity in the pinyon-juniper and sagebrush-grassland mosaic in southwestern Wyoming.

Key Words: community structure, diversity, habitat complexity, juniper woodland, rock cover, sagebrush-grassland, small mammals

INTRODUCTION

Small mammals are important components of ecosystems, and as such they must be considered in land management decisions. However, little is known about small mammal communities in most habitats, which may hamper effective decision-making. Small mammals serve as prey items for many avian and terrestrial predators and also are important seed dispersal agents. Gibson (1988) offers

several reasons for giving small mammals special consideration with regard to management decisions of which one in particular includes a lack of basic ecological and life history information for many species.

Small mammal communities have been studied in a wide range of habitats all over the world. Much research has focused on the influence of interspecific competition

and habitat structure on species diversity and community composition. The role of competition in structuring small mammal communities is not clear (compare Whitaker 1966 and Grant et al. 1985). However, there is evidence that small mammal species diversity is correlated with vegetation diversity and habitat structure (Rosenzweig and Winakur 1969, Germano and Lawhead 1986, O'Farrell and Clark 1986). By surveying four unique habitats we identified the small mammal community in a pinyon-juniper and sagebrush-grassland in southwestern Wyoming and compared their diversity with plant community diversity and structure.

The pinyon-juniper (*Pinus* spp. *Juniperus* spp.) habitat type is one of the most extensive plant communities in the United States (Sedgwick 1987). Estimates indicate that these pigmy woodlands, as they are called because of the small size of the trees (Clary et al. 1974), occupy up to 60 million ha in the southwest and Great Basin (Hurst 1977, West 1984, Evans 1988, Skousen et al. 1989). Clendenen (1977) estimated that these woodlands comprise approximately 32 percent of the forested land in the Rocky Mountains.

The states with the most extensive cover of pinyon-juniper woodlands include New Mexico, Utah, Arizona, Colorado, and Nevada. In these states the woodlands are an important multiple-use resource. Approximately 80 percent of the land area occupied by pinyon-juniper woodlands is used for livestock grazing (Evans 1988). Pinyon-juniper woodlands also are very important habitat for a variety of wildlife species. Although a few pinyon-juniper woodland obligate species exist, many species use them seasonally (Swenson 1977). Not only do they provide important winter habitat for mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) (Evans 1988, Gottfried and Severson 1994, Skousen et al. 1989, Swenson 1977), at least 75 bird species are associated with pinyon-juniper woodlands at various times throughout the year (Swenson 1977;

Sedgwick 1987). In addition, pinyon-juniper woodlands also provide firewood, posts, Christmas trees, and pinyon nuts (Hurst 1977).

A significant increase in tree density and distribution of the pinyon-juniper habitat type throughout the western United States over the last 100-150 years has been well developed (Austin 1987). A common belief is that historical uses of this system, including overgrazing by livestock and fire suppression, have led to these changes. Overall, encroachment of pinyon-juniper woodlands on adjacent grasslands and shrublands leads to reduced production of understory vegetation. Since the 1970s encroachment and loss of understory has led to an ongoing debate over whether these woodlands should be managed for livestock forage production through overstory removal, or managed for production of multiple resource products (Gottfried and Severson 1994). Wyoming represents the northeastern extent of the pinyon-juniper woodland's distribution as the only true pinyon-juniper woodlands occur in the southwestern portion of the state near the Utah border (Knight 1994). Our objectives are to determine the composition of small mammals in this woodland. Understanding the small mammal component of the system can lead to a better understanding of the ecology of the pinyon pine community and therefore provide a better basis for management decisions.

STUDY AREA

We live-trapped small mammals throughout a 1300-km² area around Flaming Gorge Reservoir south of Rock Springs, Wyoming, in south-central Sweetwater County. Study area boundaries included Interstate 80 on the north and the Utah state line to the south. In addition to Flaming Gorge Reservoir, Little Mountain, Pine Mountain, and The Glades were dominant geographical features of the area.

A "naturally patchy" pinyon-juniper and sagebrush-grassland mosaic characterized the study area. The

woodlands were dominated by Utah juniper (*Juniperus osteosperma*) and Rocky Mountain juniper (*J. scopulorum*) with pinyon pine (*Pinus edulis*) occurring at very low densities in the extreme southern portion of the study area. Big sagebrush (*Artemisia tridentata*) dominated the lower elevations (<1860 m near Flaming Gorge Reservoir) with juniper woodlands occupying the ridges and slopes. At the highest elevations of Little Mountain and Pine Mountain (~ 2745 m), quaking aspen (*Populus tremuloides*) and Douglas-fir (*Pseudotsuga menziesii*) were the dominant cover types. True mountain mahogany (*Cercocarpus montanus*) was another common shrub species.

We identified four distinct habitat types that occurred throughout the pinyon-juniper woodland and sagebrush-grassland mosaic: sagebrush-grassland, pinyon-juniper woodlands, pinyon-juniper rock-slopes, and pinyon-juniper cliffs. The sagebrush-grassland habitat type was most common in areas in which the pinyon-juniper woodlands did not occur. Big sagebrush and various cool season and warm season grasses and forbes dominated this habitat type. The pinyon-juniper woodland habitat occurred on very low-gradient slopes with a moderate-to-high juniper canopy cover and variable amounts of understory vegetation. The pinyon-juniper rocky slopes occurred on moderate-gradient slopes with moderate-to-high juniper tree canopy cover and generally low understory cover. The rocky slope habitat type contained interspersed rock outcrops that potentially provide important structural diversity for small mammals. The cliff habitat type was characterized by high-gradient slopes and low juniper canopy cover. Shrubs, grasses, and forbs were common in the understory but occurred at very low densities.

METHODS

Small Mammal Trapping

We conducted small mammal surveys from mid-May through mid-August in 1998

and 1999. We sampled the sagebrush-grassland and juniper woodland habitat types in 1998 and the rocky slopes and cliffs in 1999.

In 1998 and 1999 the field season was divided into two trapping periods: the early period from 16 May in 1998 and 18 May in 1999 through 30 June during both years; the late period from 7 July through 12 August in both years. Ten sagebrush-grassland and 10 juniper woodland sites were sampled in 1998, and seven rocky slope and seven cliff sites were each sampled in 1999. We surveyed all sites once during the early trapping period and a second time in the late trapping period to compare relative abundance of each mammal species between early and late summer.

Small mammals were captured using 7-cm x 9-cm x 23-cm Sherman live traps. Traps were arranged in variable shaped grids of 50 traps in the sagebrush-grassland and pinyon-juniper woodlands, and 49 traps in the rocky slope and cliff habitat types, with 15-m spacing between traps. The exact configuration of the trapping grid depended on the shape of the habitat patch being sampled. For instance, cliff sites were often long and narrow requiring a rectangular grid. The area encompassed by each ranged from 0.74 to 0.81 ha.

Traps were baited with a combination of rolled oats and peanut butter and polyester bedding was added to each trap. Each trapping session consisted of four consecutive nights; traps were set in the evening at about 1900 hrs and checked and closed at about 0800 hrs. Traps remained closed during the day to eliminate small mammal mortality as a result of being captured during periods of extreme temperatures despite the fact that this could limit the capture of chipmunks and ground squirrels. Individuals were identified to species, sexed, and weighed.

Habitat Sampling

The habitat sampling procedure was similar to that used by Dueser and Shugart (1978). We measured 6 habitat variables at

21 randomly located, 0.02-ha circular sampling plots within each trapping grid to quantitatively compare the horizontal habitat complexity index (HCI) of each habitat type. The index was a measure of the horizontal diversity in each habitat, expressed by the equation:

$$\text{HCI} = - \sum p_i (\ln p_i)$$

where p_i represents the portion of the total ground cover of element i . Habitats that are dominated by a couple of elements are much less complex than those characterized by several elements.

We used criteria described by Dueser and Shugart (1978) to select the habitat variables that were measured. Each variable had to: 1) provide a measure of the structure of the environment that was either known or reasonably suspected to influence distribution and local abundance of small mammals; 2) be quickly and precisely measurable with nondestructive sampling procedures; 3) have small intra-seasonal variation relative to inter-seasonal variation; and 4) describe the environment in the immediate vicinity. Variables that we measured included tree canopy cover, shrub density, and percent cover of grass, forbs, shrubs, litter, bareground, and rock. Tree canopy cover was included because juniper overstory influences the understory and associated ground cover (Skousen et al. 1989, Vaitkus 1991). The variables selected occurred in 3 strata: overstory, understory, and ground level.

Data Analysis

We estimated relative abundance of each species by calculating the number captured/100 trap nights and used one-way ANOVA to determine differences in species abundance between years. Because trapping techniques in 1999 differed from those used in 1998, data were analyzed separately for each year. Two-way ANOVA was used to compare the abundance of each species within each habitat type between the first and second trapping periods. Small mammal data from both trapping periods

were combined for each habitat. We used correlation analysis to determine relationships between habitat complexity (HCI) and species richness (S), diversity (H'), and evenness (J') (Peet 1974). Correlation analysis was also used to examine relationships between each habitat component used to calculate the HCI and S, H' , and J' . Statistical significance was inferred at $P < 0.05$ for all tests.

RESULTS

Small Mammal Trapping

Eleven small mammal species were captured (Table 1) in 1998 and 1999. Including recaptures, we obtained 3593 captures of these species over 13,295 trap nights for an overall trap success of 27 captures/100 trap nights. We obtained 1467 and 2126 total captures in 1998 and 1999, respectively. The deer mouse (*Peromyscus maniculatus*) was the species captured most often, accounting for 78 percent of the total captures. The least chipmunk (*Tamias minimus*) and the cliff chipmunk (*T. dorsalis*) were the species captured the next most frequently, but accounted for 16 percent of the total combined captures.

A higher capture rate in 1999 might have indicated that small mammals were more abundant in rocky slopes and cliffs than the sagebrush-grasslands and juniper-woodlands sampled in 1998. Because we did not trap all four types during the same year, we were unable to determine if the higher capture rate was due to habitat effect. Therefore, statistical comparisons were only made between habitats sampled the same year and not between habitat types sampled in different years.

To understand a change in seasonal abundance, we used ANOVA to compare captures/100 trap nights of each species between trapping periods during early and late summer for each habitat type. In the sagebrush-grassland type, the mean relative abundance of deer mice increased from 10/100 trap nights to 23/100 trap nights ($n = 20$, $F = 29.58$, $P < 0.05$); mean abundance of least chipmunks increased from 0.5 to

Table 1. Total number of small mammal captures , species richness (S), diversity (H'), and evenness (J') in each of four habitat types sampled in 1998 and 1999 in southwestern Wyoming.

Species	Habitat Type			
	Sagebrush- Grassland 1998	Juniper Woodland 1998	Juniper Rocky Slope 1999	Juniper Cliff 1999
Deer mouse (<i>Peromyscus maniculatus</i>)	643	614	851	755
Least chipmunk (<i>Tamias minimus</i>)	65	93	108	107
Cliff chipmunk (<i>Tamias dorsalis</i>)	0	23	68	114
Pinon mouse (<i>Peromyscus truei</i>)	0	0	31	13
Canyon mouse (<i>Peromyscus crinitus</i>)*	0	0		18
Great-Basing pocket mouse (<i>Perognathus parvus</i>)	0	0	5	22
Golden-mantled ground squirrel (<i>Citellus lateralis</i>)	0	0	9	7
Bushytail woodrat (<i>Neotoma cinerea</i>)*	0	0		6
Sagebrush vole (<i>Lagurus curtatus</i>)*	15		0	0
Longtail vole (<i>Microtus longicaudus</i>)	12	0	0	0
Northern pocket gopher (<i>Thomomys talpoides</i>)*	0		0	0
Total captures	735	732	1074	1052
Species richness (S)	4	3	6	8
Species diversity (H')	0.48	0.53	0.76	1.01
Evenness (J')	0.34	0.48	0.42	0.49

* indicates species was captured <5 times in at least one habitat type and was not included as a component of the small mammal community in that type. S, H, and J reflect these exclusions.

3.0/100 trap nights ($n = 20$, $F = 6.23$, $P < 0.05$). In the juniper woodland habitat type, deer mouse abundance increased from 10 to 22 captures/100 trap nights ($n = 20$, $F = 15.18$, $P < 0.05$). We did not find any significant differences in relative abundance between trapping periods for any species in the rocky slope or cliff habitats that we sampled during 1999.

While most species increased from early to late summer, only increases among deer mice and least chipmunks were significant (Table 2). The longtail vole (*Microtus longicaudis*) was the only species

to exhibit a decrease in relative abundance from early to late summer. We would expect abundance of small mammals to increase from early to late summer as young are born and recruited into the population.

In 1998 species richness (S) was the same for the sagebrush-grassland and juniper woodland habitat types. However, diversity (H') and evenness (J') were both higher in the juniper woodlands (Table 1). Deer mice and the least chipmunks were the most frequently captured species in both habitats. Sagebrush voles (*Lagurus curtatus*) and longtail voles were also t

Table 2. Trapping results by session 1 (May-June) and session 2 (July-August). Sagebrush-grassland trapped in 1998 and Rocky hill and cliff trapped in 1999.

	PEMA			TAMI			TADO		
	Session 1	Session 2	P value	Session 1	Session 2	P value	Session 1	Session 2	P value
Sagebrush-grassland	10.34	23.37	0.0000	0.46	2.88	0.0220			
Juniper-woodland	9.60	21.55	0.0010	1.02	3.70	0.0570	0.46	0.71	0.42
Rocky hill	27.99	34.84	0.2570	5.82	2.15	0.1010	1.86	3.18	0.34
Cliff	26.97	29.97	0.4870	3.04	5.20	0.3660	4.41	4.30	0.95

	LACU			MILO			THAT		
	Session 1	Session 2	P value	Session 1	Session 2	P value	Session 1	Session 2	P value
Sagebrush-grassland	0.46	0.63	0.6300	0.51	0.10	0.0400			
Juniper-woodland	0.05	0.00	0.3310	0.00	0.05	0.3310	0.00	0.05	0.3310
Rocky hill									
Cliff									

	PETR			PEPA			CILA		
	Session 1	Session 2	P value	Session 1	Session 2	P value	Session 1	Session 2	P value
Sagebrush-grassland									
Juniper-woodland	0.05	0.00	0.3310						
Rocky hill	0.73	1.54	0.4600	0.08	0.30	0.4850	0.07	0.37	0.2700
Cliff	0.58	0.37	0.7200	1.14	0.52	0.5090	0.53	0.00	0.0870

	NECI			PECR		
	Session 1	Session 2	P value	Session 1	Session 2	P value
Sagebrush-grassland						
Juniper-woodland						
Rocky hill	0.00	0.07	0.3370			
Cliff	0.30	0.89	0.1970			

PEMA=Deer Mouse
TAMI=Least Chipmunk
TADO=Cliff Chipmunk
LACU=Sagebrush Vole
MILO=Long-Tailed Vole

THAT=Northern Pocket Gopher
PETR=Pinyon Mouse
CILA=Golden-Mantled Ground Squirrel
NECI=Bushy-Tailed Woodrat
PECR=Canyon Mouse

equally represented among captures in sagebrush-grasslands. Only one sagebrush vole was captured in the juniper woodland habitat, whereas the cliff chipmunks were not captured in the sagebrush-grassland habitat type. They were found in the

juniper woodlands. Additionally, a northern pocket gopher (*Thomomys talpoides*) was captured in the juniper woodlands, which was most likely an incidental capture. This species may be present in each of the

habitat types, but is not frequently captured in live trap (Szaro, et al. 1988).

In 1999 diversity and evenness were higher in the cliff habitat (Table 1). The deer mouse and the pinyon mouse (*P. truei*) were captured more often in the rocky slopes than in the cliffs. The cliff chipmunk, canyon mouse (*P. crinitus*), great basin pocket mouse (*Perognathus parvus*), and bushytail woodrat (*Neotoma cinerrea*) were captured more often in the cliffs than in the rocky slopes. The deer mouse and the least chipmunk were the most frequently captured species in the rocky slopes although the cliff chipmunk and the pinyon mouse also were commonly captured in this habitat type. In the cliffs, deer mice were the most frequently captured species but cliff chipmunks were captured more often than least chipmunks.

Habitat Structure

Juniper woodlands had the highest HCI value, whereas the sagebrush grasslands had the lowest (Table 3). Bareground accounted for the largest proportion horizontal ground cover in each of the habitat types. However, the juniper woodlands had the highest HCI value as a result of also having tree canopy cover and litter cover as important components of the horizontal diversity. Sagebrush-grasslands had the lowest HCI value because it lacked presence of a tree canopy cover and had very low rock cover. Tree canopy cover was highest in the juniper-woodland type and gradually declined in the rocky slopes and cliffs. Grass and shrub cover was highest in the sagebrush-grasslands and much lower in the other habitat types. Forb and litter cover was similar in all habitats, whereas rock cover was much higher in the cliffs.

Regression analysis did not indicate a significant relationship between HCI and small mammal species richness, diversity, or evenness within either year of the study. However, there was a trend of small mammal diversity and evenness being higher in the juniper woodlands and cliffs, which had the highest HCI values in the years in which they were sampled.

Once we recognized that there was not a relationship between small mammal species richness, diversity, or evenness and habitat type, we tested for relationships between these parameters and specific habitat variables. Regression analysis indicated a relationship between small mammal diversity and percent rock cover ($R^2\text{-sq} = 62.6\%$, $P < 0.01$) in the rocky slopes and cliffs (Fig. 1). These results could be complicated by the fact that habitats were sampled in different years.

DISCUSSION

Thirty species of small mammals have been identified in juniper-associated habitats throughout Wyoming (Wyoming Game and Fish Department 1993). We found an assemblage in the sagebrush-grassland and juniper-woodland mosaic in southwestern Wyoming consisted of 11 species of small mammals compared to 14 species actually found by the Wyoming Game and Fish Department (1993) in juniper-associated habitats statewide. However, it is fewer than the 17 small mammals species captured by Belitsky (1981) over an area that encompassed our study area. The difference in number of species that we identified and the latter may be that Belitsky (1981) used four different trap types compared to our use of one. Some small mammal species are more susceptible to being captured in one trap type compared to another. Small mammal numbers also change with time.

The species that we captured exhibit a range of habitat specialization. Deer mice and least chipmunks were relatively abundant in all habitat types sampled. These two species form the core of the small mammal community, as they were the most abundant species in the sagebrush-grassland, juniper woodland, and rocky slope habitat types. Cliff and least chipmunks occurred in similar abundance in the cliff habitat type.

The cliff chipmunk, piñon mouse, great-basin pocket mouse, and golden-mantled ground squirrel were intermediate habitat specialists, occurring in two or three

Table 3. Average values for each of the six habitat variables measured to determine the habitat complexity index (HCI) for the sagebrush-grassland, juniper woodland, rocky slope, and cliff habitat types.

Habitat Variable	Habitat Type			
	Sagebrush Grassland	Juniper Woodland	Juniper Rocky Slope	Juniper Cliff
	1998	1998	1999	1999
Tree Canopy Cover		28.3	18.9	15.1
Grass	21.6	9.9	6.4	4.8
Forbs	5.0	2.8	2.4	1.9
Shrubs	18.3	6.3	4.3	4.9
Litter	15.5	29.0	20.4	17.8
Bareground	45.6	49.2	59.0	53.6
Rock	0.5	7.9	7.9	18.2
HCI	1.47	1.74	1.54	1.59

of the four habitat types surveyed. The canyon mouse, bushytail woodrat, sagebrush vole, and longtail vole were most abundant in a single habitat type, which suggested the most habitat specialization of all species captured.

Along with our study, others also have found that small mammal communities commonly include habitat specialists and habitat generalists (Ribble and Samson 1987, Mares et al. 1995). Morris (1996) suggested this as a common structure of “most natural assemblages.” By using habitat at a larger spatial scale, generalists may exploit habitat that is unused or underused by specialist species (Morris 1996, Grant and Birney 1979).

We provide some evidence of a relationship between horizontal habitat complexity and small mammal species diversity and evenness. With few exceptions (Kirkland et al. 1997), other studies (Rozenzweig and Winakur 1969, Tomoff 1974, Yahner 1983, Germano and Lawhead 1986, Koehler and Anderson 1991, Els and Kerley 1996) have found strong positive relationships between small mammal diversity and habitat structure.

We found that the cliff habitat type had the greatest small mammal species richness and diversity. Ward and Anderson (1988) found that cliffs in southcentral Wyoming had more small mammal species than sites

without cliffs. Maser et al. (1979) suggested that cliffs are important habitat for many species of wildlife for providing thermal shelter in addition to nesting and denning sites, and cliffs also may influence surrounding vegetation structure and density. Cliff sites may be important to small mammals for several reasons. In spring and early summer crevices between rocks are used as areas for rearing young by offering protection from predators and severe temperatures. Finally, several species of small mammals cache winter food stores in the cliffs. Further interpretation of our results could be confounded by the fact that we sampled sagebrush/grassland and juniper woodland in 1998 and rocky slopes and cliffs in 1999 in taking into account that year-to-year variation in small mammal abundance could occur.

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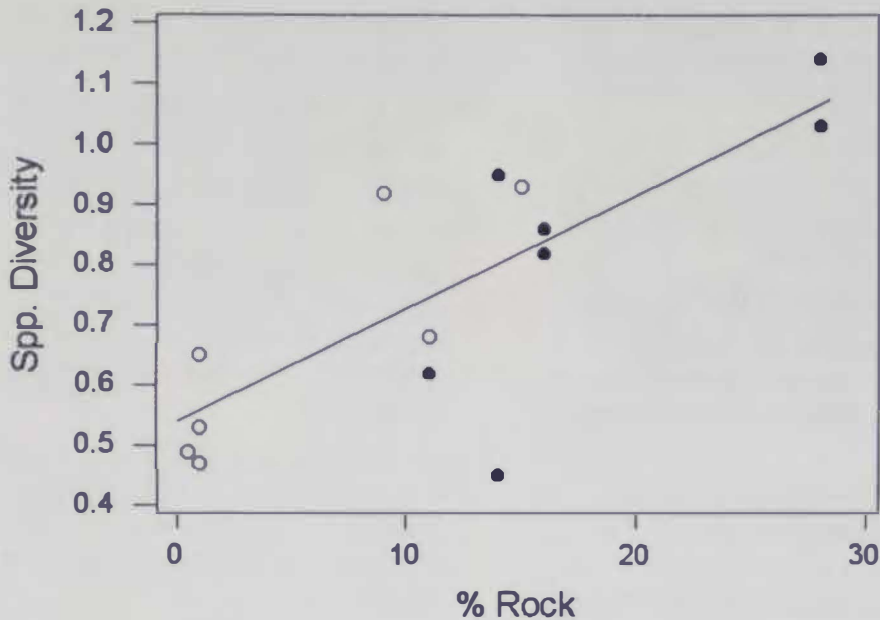


Figure 1. Relationship between small mammal species diversity and percent rock cover in the rocky slope (open circles) and the cliff (dark circles) habitat types.

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USING REMOTELY SENSED DATA IN URBAN SPRAWL AND GREEN SPACE ANALYSES

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ABSTRACT

Using two cities in southeast Idaho we developed a simple and widely applicable methodology for incorporating remotely sensed data into urban sprawl and green space analyses. We used land cover change data and Normalized Difference Vegetation Index (NDVI) data to assess: 1) location, amount, and direction of urban growth, 2) concentration and distribution of green space, and 3) fragmentation of green space areas. Our results document distinct patterns of growth for Pocatello, Idaho, compared to Idaho Falls, Idaho, over the past 15 years. Pocatello grew primarily to the north, while Idaho Falls grew more quickly and in a radial pattern from its urban center. These different growth patterns were influenced by topographic and land-ownership patterns of the region, as well as different zoning regulations. The simplicity of our methods and the minimal investment of time and money make incorporation of remotely sensed data into urban growth and green space analyses a potentially powerful tool for the urban planner/manager.

Key words: urban sprawl, GIS, green space, urban growth, urban planning

INTRODUCTION

Urban sprawl can be described as low-density development occurring on the edge or outside of a municipal area that does not follow a specific growth pattern (Tallinn 2002). Environmental impacts of urban sprawl include: 1) decreased watershed permeability resulting in an increased risk of flooding and groundwater contamination, 2) elevated air and noise pollution, and 3) loss of arable land to development (Knight et al. 1995, Auld 2001). Urban sprawl also can have substantial economic impacts on communities through increased cost of services such as emergency response, infrastructure, or public works and utilities (Chen 2000, Speir and Stephenson 2002).

Green space is an important feature of an urban environment that provides opportunities for outdoor recreation, wildlife habitat, groundwater recharge, pollutant filtering, urban beautification, and improved environmental health (Stephenson 1999, Stoel 1999). Urban sprawl leads to

loss and increased fragmentation of green space areas, thereby diminishing the positive functions of green space (Wang and Moskovits 2001). Fragmentation has a particularly negative impact on wildlife in and around the urban area (Marzluff and Ewing 2001). Determining degree of fragmentation may prove useful to evaluation of urban green space.

Various methods exist for tracking urban sprawl such as recording the location and number of building permits or simple visual assessments. However, these data are often difficult to incorporate, e.g., compiling paper building permits into useful statistics, are frequently subjective, e.g., visual assessments, and may not accurately capture temporal patterns of urban growth and changes in green space. The use of remotely-sensed data to analyze urban growth and green space distribution allows land use planners to perform large-scale temporal analyses with minimal

investment of time and money. Additionally, remotely-sensed data are easily incorporated into a geographic information system (GIS) along with other data such as zoning regions, topography, hydrography, geology, and political boundaries, allowing for urban managers to consider the effect these factors may have on observed growth patterns. This ancillary information is invaluable in determining the intrinsic suitability of regions (McHarg 1969) and aids in development of holistic land-use/urban planning.

We used the cities of Pocatello and Idaho Falls, Idaho, as case studies of how remotely sensed data can be used to quantify urban growth, the concentration and distribution of green space, and fragmentation of green space areas. These cities have experienced markedly different growth patterns over the past 15 years, with a high proportion of the new growth occurring in the past five years. Additionally, due to topographic and land ownership characteristics, the type and direction of growth in these two cities also are quite different. Although specific growth patterns of Pocatello and Idaho Falls are important to planners in the region, in this paper we seek to address the potential for applications of remotely sensed data for urban planning.

MATERIALS AND METHODS

For our analyses we used phenologically synchronized LANDSAT Thematic Mapper 5 (TM5) multispectral satellite imagery (path 39, row 30) from 1987, 1997, and 2000. Phenologic synchronization is a process by which calculations of growing degree day and accumulated precipitation are used to select imagery dates to ensure that detected changes are not due to phenological differences (Weber 2001). TM5 imagery, which has a 30 x 30 m pixel size, provides adequate spatial resolution to analyze trends within the urban environment without excessive processing time that data of finer spatial resolution would require. TM5

imagery also is widely available and can be obtained free of charge or at relatively low cost.

To compare changes within the city versus sprawl development, we partitioned the cities of Pocatello and Idaho Falls into two zones. The “urban zone” (UZ) consisted of the urban extent of each city (as defined by the 2000 U.S. Census). The “sprawl zone” (SZ) was an area equal in size to the UZ and immediately surrounding the UZ (Figs. 1a and 1b). We compared measures of urban sprawl and green spaces distribution/fragmentation between the zones and between cities.

Land Cover Change Data and Urban Sprawl Analysis

We used a principle components analysis (PCA) to determine correlation between bands of the TM5 image to create a weighted composite image that would best represent unique data contained within multiple bands. Using the covariance matrix of the PCA we created a composite image using bands 5, 3, and 4 (with weightings of 89, 8, and 4%, respectively) that described >95 percent of the unique data in the imagery for each year (1987, 1997, 2000). We used the 5:3:4 composites to generate land-cover change (LCC) data for two time periods (1987-1997, 1997-2000) by performing image differencing change detection with LUCCAS software (Lunetta and Elvidge 1998, Pacific Meridian 1996). To exclude detected LCC that was non-anthropogenic, only those changes occurring ≤ 50 m from a road were included in the analyses. To delineate these areas, we created a 50-m buffer around all roads, and intersected this buffer with the LCC data. We determined buffer size based on the pixel size of the imagery. The 50-m buffer allowed at least one, but no greater than two pixels to be included on each side of each road.

NDVI Green Space Analysis

We quantified the abundance of vegetation by creating Normalized Difference Vegetation Index (NDVI) images

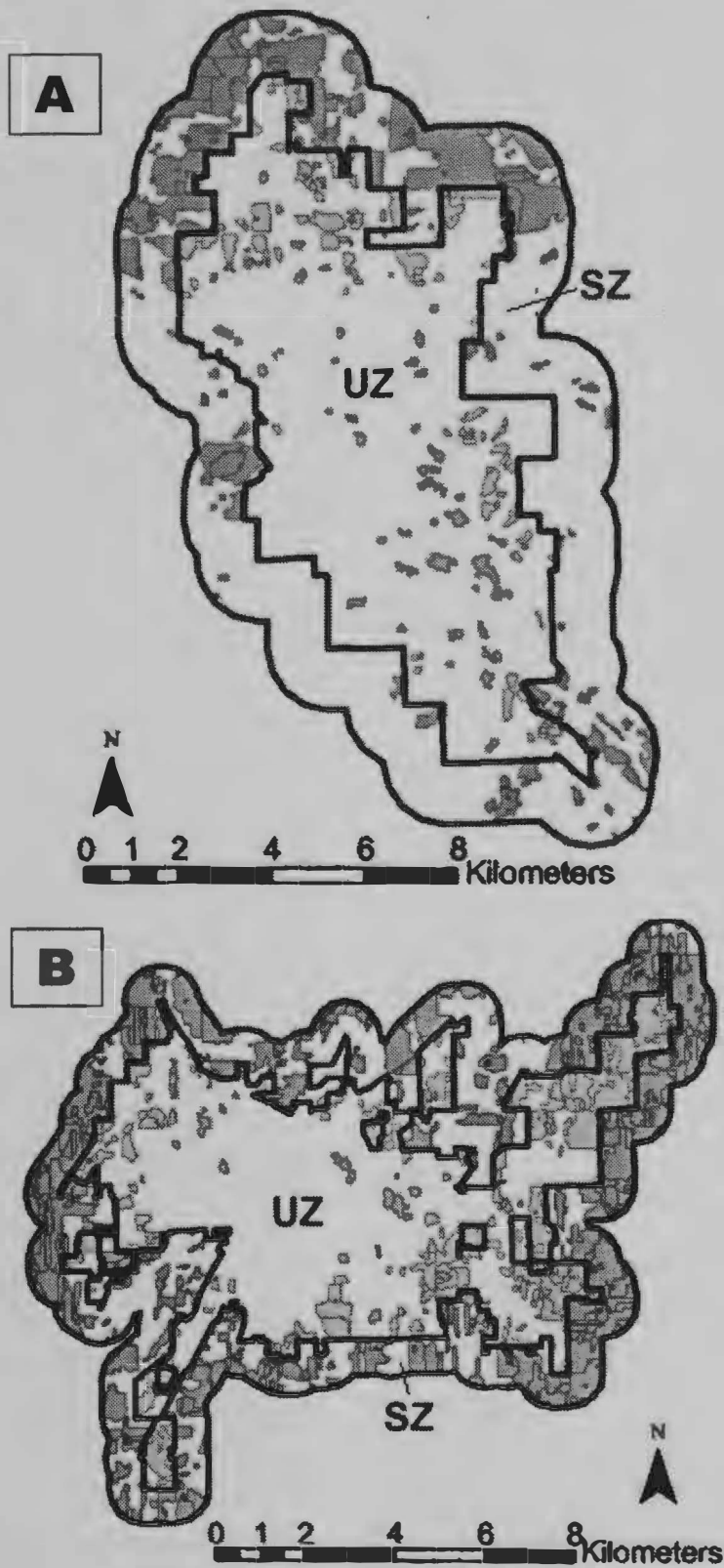


Figure 1. The total growth (UZ + SZ) in Pocatello, Idaho (A) was approximately 1/2 that of Idaho Falls, Idaho (B). Land Cover Change areas are shown in light gray (UZ) and dark gray (SZ).

(Lillesand and Kiefer 2000) for each year of our analysis (1987, 1997, and 2000). Resulting values ranged between -1 and 1, where non-vegetative areas, e.g., bare rock, water, etc., have a negative value, and areas of green vegetation have a positive value. To better correlate NDVI values to green space areas, we overlaid the NDVI image onto digital orthophotographs to identify the NDVI values for known or visually apparent green space areas, e.g., city parks, green ways, golf courses, etc. We also correlated the image values to known non-green space areas, e.g., parking lots, light industry, etc. Using these NDVI values, we reclassified the NDVI images into more useful categories representing non-vegetative, moderate quality green space, and high quality green space (Table 1). Using the classified NDVI images and UZ/SZ perimeters, we determined the amount of “highly vegetative” green space present in each zone for both cities. When expressed as a percent of the total area of each zone, these calculations allowed us to perform various comparative analyses between zones and between cities.

We analyzed the contiguity of green space using two methods. First, we created a standardized city block dataset (200 x 200m polygons) to determine the amount of “highly vegetative” green space/city block for the UZ and SZ. We used these data to better visualize the concentration and distribution of green space. Second, we used FRAGSTATS landscape metrics software (McGarigal 1995) to calculate “core area” of green space, i.e., the area of green space $\geq 30m$ from an edge, within each zone (UZ and SZ) and within the total area (UZ + SZ) of each city.

RESULTS

Urban sprawl analysis using land cover change data for 1987-1997 showed total growth (UZ+SZ) in Idaho Falls to be approximately twice that of Pocatello. From 1997 to 2000, growth in Idaho Falls was approximately three times that of Pocatello. Additional visual analysis of the detected change areas revealed that Idaho Falls grew radially from its urban center, whereas growth in Pocatello was predominantly north of the urban center (Fig. 1). Within the two cities, growth in the SZ was approximately twice (2:1) that of the UZ for all intervals (1987-1997, 1997-2000) except for Idaho Falls (1997-2000) where SZ growth was slightly less than UZ growth (0.8:1) (Fig. 2).

Green space analysis using classified NDVI images revealed that the area of “highly vegetative” green space was approximately 2x greater in Idaho Falls than in Pocatello, even though the area of Idaho Falls is smaller than that of Pocatello (113.8 and 133.6 km², respectively). The area of “highly vegetative” green space in Pocatello averaged 1.3x greater in the SZ than in the UZ. In Idaho Falls, the area of “highly vegetative” green space averaged 1.7x greater in the SZ than in the UZ. (Figs.3a, 3b).

The results of the standardized city block analysis illustrated the distribution of green space in Pocatello by identifying regions with a large number of contiguous city blocks consisting primarily of “highly vegetative” green space (Fig. 4). Our analysis using landscape metrics revealed that only 53 percent of “highly vegetative” green space in Pocatello (UZ+SZ) was classified as core area, while 65 percent of

Table 1. Reclassification of NDVI Values for Green Space Analysis

Classification	NDVI Value	Example
Non-Vegetative	-1.0 – 0.0	Parking Lots, Light Industry
Moderately Vegetative	0.01 – 0.29	Sagebrush, Fallow Agricultural Fields
Highly Vegetative	0.3 – 1.0	Forested Areas, City Parks

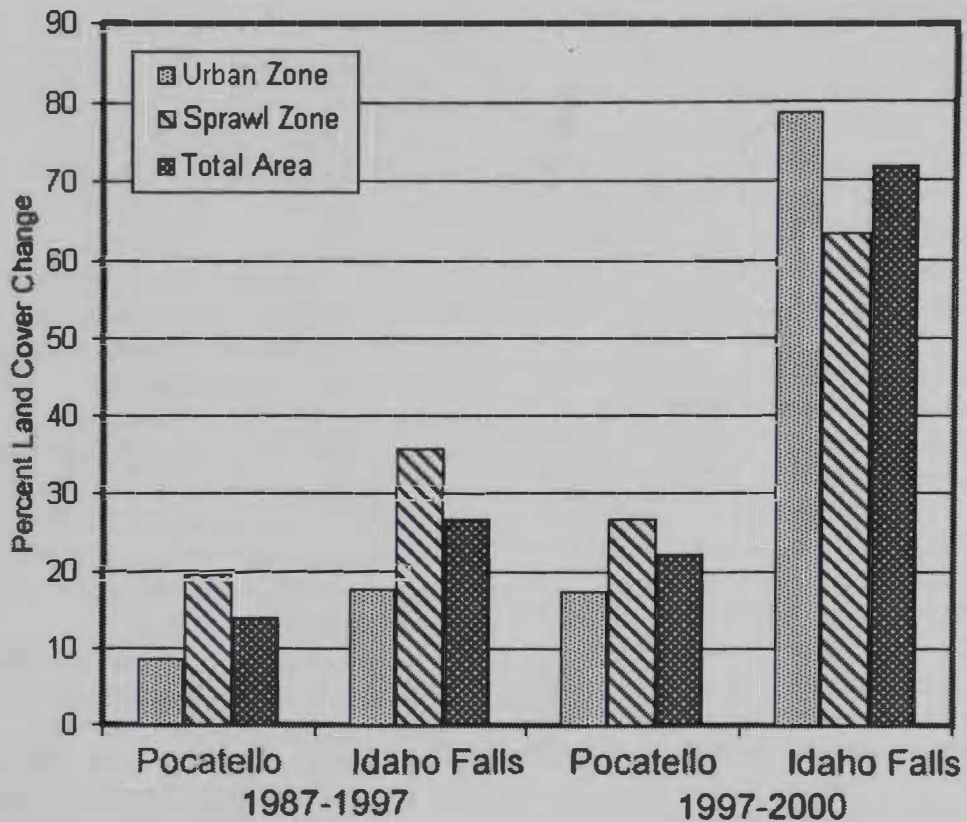


Figure 2. Land Cover Change (1987-1997 and 1997-2000) for Pocatello and Idaho Falls, Idaho.

“highly vegetative” green space in Idaho Falls was classified as core area. Additionally, for both cities and for each year of the analysis more core green space areas were present in the SZ when compared to the UZ (Figs. 3a, 3b).

DISCUSSION

Monitoring patterns of urban growth and green space change is an important part of holistic land use management. Common economic, ecological, and social consequences of urban sprawl and green space loss include: 1) increased cost of providing infrastructure and services, e.g., schools, roads, emergency services, and other utilities, to a sprawling population, 2) increases in traffic congestion, noise pollution, and air pollution as distances driven by daily commuters and general automobile dependence increases, 3) failing public transportation systems as it becomes economically infeasible for cities to provide adequate services for commuters, 4)

conversion of green space and arable agricultural land to urban and residential developments, and 5) degradation and fragmentation of existing urban green space areas. The methods described in this paper provide a means to quantify urban changes and their effects on the aforementioned issues.

Our results also provide useful information describing the location and direction of growth, including an assessment of some of the factors that influence growth and development. The rugged topography surrounding Pocatello, much of which is publicly owned, provides limited opportunity for urban development. Conversely, much of the area surrounding Idaho Falls is private agricultural land that is more readily available for development. Geographic factors restricting growth of Pocatello have led to the rapid development observed north of Pocatello, whereas developments around Idaho Falls have occurred more radially from city center.

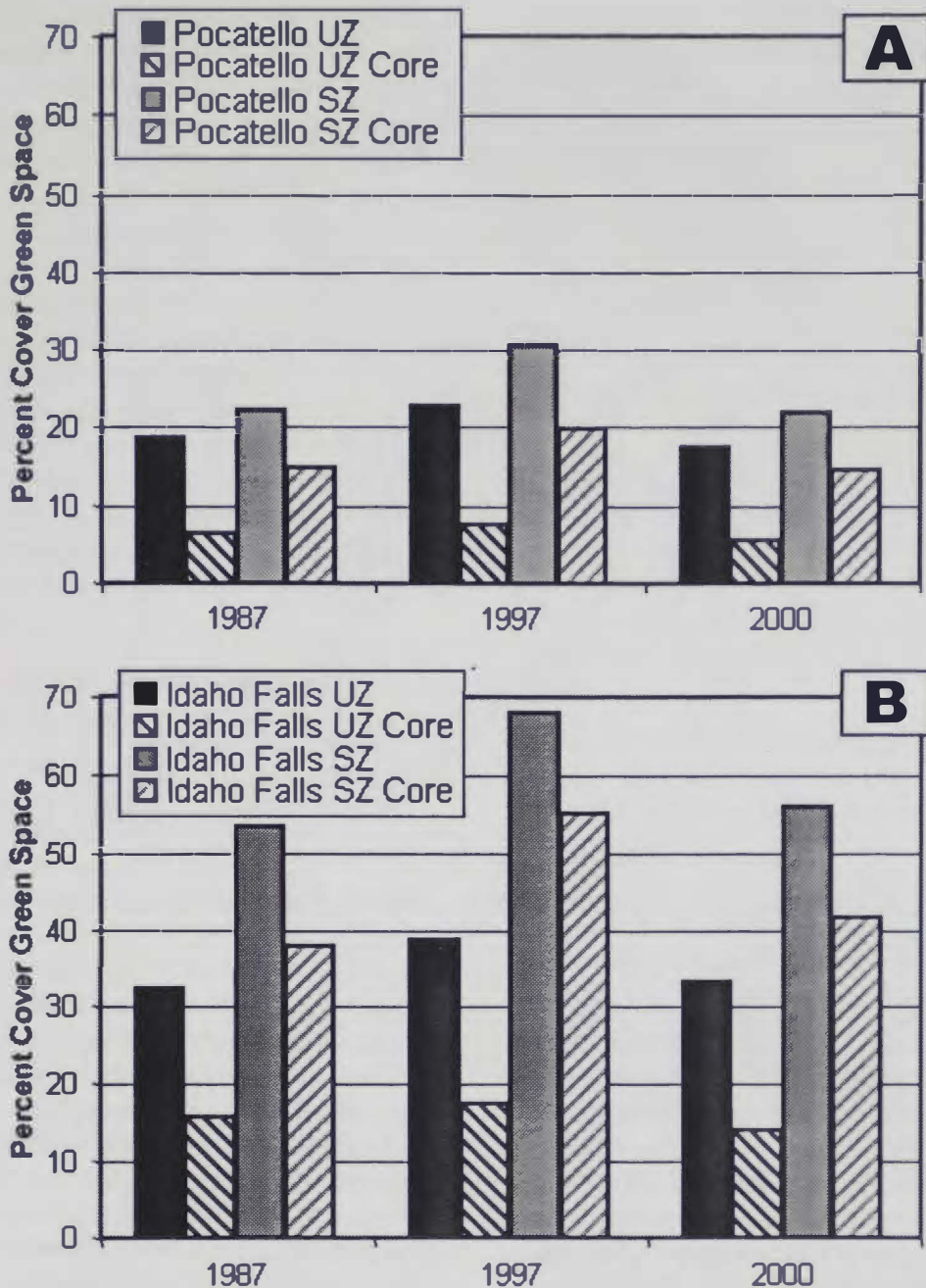


Figure 3. Percent cover of total green space vs. core green space categorized by zone type for Pocatello (A) and Idaho Falls (B).

Additionally, much of the growth in both cities occurred in the SZ, which illustrates a common trend of sprawling developments taking precedence over renewal within existing urban areas. These are important factors to consider in developing a growth management plan that is suitable for a region, especially the roles that physical and political geographies of the region may have in shaping growth patterns.

The NDVI green space analysis focused on the amount of “highly vegetative” green space present in each city for the three years of our analysis. The total amount of “highly vegetative” green space remained relatively constant for both cities, whereas distribution of green space varied as influenced by active/fallow agricultural fields in the SZ of both cities. We attributed some of this variability to precipitation



Figure 4. A 200 x 200m grid was used to better examine the distribution and concentration of green space areas.

differences, the effect of crop rotation, and irrigation practices. Results within the UZ were less affected by these factors and may more accurately describe the distribution of green space within the city. The ability to quantify the location and concentration of green space areas is important, especially loss of green space over time. This would allow urban planners to identify existing green space areas to protect from urban development, or to target certain areas for conversion into new green space areas, e.g., vacant lots into city parks, or unused rail lines into greenways, etc.

The standardized city block analysis addressed some of the shortcomings of the general NDVI green space analysis, and provided insight into the concentration and fragmentation of quality green space within the UZ and SZ. Much of the "highly vegetative" green space in the two cities is fragmented, especially within the urban zones. Such fragmentation decreased the

amount of usable green space and degraded the natural landscape.

Landscape metrics analysis provided even more specific information concerning the degree of green space fragmentation in Pocatello and Idaho Falls. Similar agricultural biases existed as mentioned above, whereas agricultural regions representing large areas of "highly vegetative" green space did not represent usable, quality green space. Therefore, calculation of fragmentation within the UZ was the most useful data that we generated in this analysis. Despite the relatively constant amount of high-quality green space within the UZ, the percent of "highly vegetative" green space that was core area (contiguous) decreased for both cities over the three years of analysis. This trend of green space fragmentation will have a greater impact on the overall landscape than simple loss of green space. This emphasized the importance of analyzing

contiguity of green space in addition to the total amount of green space in an urban area.

Utilization of remotely-sensed imagery for monitoring urban sprawl and changes in the distribution and fragmentation of green space can aid in development of growth plans for communities. Remotely-sensed data, used in conjunction with other tools currently available to land-use planners, will permit a more comprehensive approach to managing urban growth and green space. These data also may serve to identify areas of intrinsic value to be reserved from development and establish management regimes such as development boundaries that limit the extent of urban sprawl and subsequent loss and fragmentation of green space.

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EVALUATION OF PROTECTIVE CLOTHING FOR HANDLING SMALL MAMMALS POTENTIALLY INFECTED WITH AEROSOL-BORNE ZOOONOTIC AGENTS

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ABSTRACT

The purpose of this study was to describe and compare the protection provided by surgical gowns and coveralls against aerosol contamination. We also sought to quantify the aerosol exposure in terms of particles depositing on the clothing of workers involved in the Montana Longitudinal Hantavirus Study. Prior to sampling, florescent dust was inserted into live rodent traps. Sampling strategies involved two individuals mimicking established rodent handling procedures while wearing protective clothing in the form of tyvek coveralls and/or surgical gowns. A protocol was designed to quantify exposures by counting the number of squares on a pre-drawn grid which were contaminated with florescent particles. This grid covered the front of the tyvek suits worn by the workers, excluding the face, hands and feet, and extended around the cuff of both sleeves. Tyvek coveralls were found to provide a significant degree of protection against aerosolized dust originating from small rodent live traps relative to wearing no form of protective clothing. Surgical gowns provided a significantly greater degree of protection against aerosolized dust than tyvek coveralls. The individual handling the mice (biologist) consistently had greater mean exposure values than the data recorder (technician).

Key Words: aerosol, coveralls, exposure, Hantavirus, *Peromyscus*, surgical gowns

INTRODUCTION

Hantavirus pulmonary syndrome (HPS) was first described in 1993 as an acute disease induced by a diverse group of related viral strains in the genus Hantavirus (Nichol et al. 1993, Hjelle et al. 1994). The deer mouse (*Peromyscus maniculatus*) has been found to be the principal reservoir (Childs 1994) and a single virus isolated from mice in New Mexico has been associated with the majority of documented cases (Childs et al. 1995). A variety of rodent species have been shown to possess antibody, and other species of *Peromyscus* may act as competent hosts (Childs 1994). Virus may be shed in feces, urine, and saliva for several weeks, but the exact

duration of shedding and period of greatest infectivity are unknown (LeDuc 1987).

Possible routes of exposure include direct contact with lacerated skin or mucous membranes and rodent bites; however, the primary route of infection to humans is believed to be inhalation of aerosolized virus particles (Mills et al. 1995). HPS is characterized by a febrile prodrome, followed by rapid onset of noncardiogenic pulmonary edema and hypotension, or shock. Approximately 45 percent of identified patients have died. Infection of humans by rodent-borne hantavirus in the United States stimulated a series of longitudinal studies of rodent populations

(primarily *Peromyscus* spp.) in both the southwestern States (Abbott et al. 1999, Calisher et al. 1999, Kuenzi et al. 1999, Mills et al. 1999) and Montana (Douglass 1996 et al.).

Special precautions should be observed to minimize risk of infection because of the high morbidity and mortality associated with onset of HPS, and the possibility of aerosol transmission of viral particles. The United States Centers for Disease Control and Prevention (CDC) published recommendations to assist residents of endemic areas, as well as mammalogists working with potentially infected rodents (CDC 1993, Douglass et al. 1996). These recommendations emphasize the importance of respiratory protection, protective clothing, choice and use of disinfectants, decontamination of instruments and traps, proper disposal of infectious wastes, and preservation and shipment of samples intended for hantavirus testing. Although these guidelines were generated in response to the 1993 HPS outbreak, they are applicable to any study of small mammals potentially infected with a zoonotic agent transmissible by aerosol (Mills et al. 1995).

Mills et al. (1995) advises individuals handling live rodents to wear protective clothing, including a surgeon's gown or coveralls (preferably disposable). The primary function of this precaution is to minimize the probability of worker contact with rodent body fluids, i.e., blood and urine. A secondary purpose is to minimize the amount of aerosolized viral particles anchoring to the workers clothing. Despite the severity of symptoms associated with HPS, no published studies have described or compared the effectiveness of surgical gowns and/or coveralls in protecting against aerosol contamination.

The purpose of our study was to describe and compare the protection provided by tyvek coveralls and surgical gowns against aerosol contamination. We also sought to quantify and compare aerosol exposure in terms of particles landing on clothing of workers involved in the Montana Longitudinal Hantavirus Study.

Six large-scale hantavirus studies are currently in progress within the United States. Each study has developed a unique set of procedures for collecting required ecological and serological data, while observing the safety guidelines established by Mills et al. (1995). Differences between the various studies include, but are not limited to the following: the number of field workers involved, whether or not mice are anesthetized, the specific types of personal protective equipment used, and the work station configuration. Our sampling procedures followed the work practices of the Montana Longitudinal Hantavirus Study (Douglass et al. 1996).

The Montana study involved six study sites. The six sites were trapped individually three nights/month from May through October. Each site was composed of three grids, each containing one hundred live rodent traps. Each morning grids were checked and occupied traps were placed in clear plastic bread bags. The bagged traps were then transported back to the truck. Mice were processed on site, using the tailgate of the truck as the processing station. Two large plastic tubs were placed on the tailgate to elevate the working platforms of both biologist and technician. During mice processing, the technician and biologist wear tyvek coveralls, latex gloves, and half-mask negative pressure respirators.

The biologist stands on the left while the technician stands on the right. The technician was responsible for picking up the bagged traps, opening the trap door, and dropping the mouse into the bag. At this time the bedding material, bait, and accumulated dust also drop into the bread bag. The bagged mouse and debris would then be handed to the biologist. The technician recorded the various ecological data as the biologist dictated. The technician would then wash his / her hands with a disinfectant and prepare the next mouse. The biologist, once handed the bagged mouse, would maneuver the mouse out of the bag and secure it by the skin of the neck. The biologist would then inspect the mouse and dictate data on body mass,

sex, sexual status, scars, and ear tag number, if a recapture, to the technician. Newly captured mice were ear tagged. The biologist would then collect a blood sample using the retro-orbital sinus technique. This procedure involves inserting a heparinized capillary tube into the back corner of the right eye and allowing several drops of blood to collect into a plastic cryovial. The mouse would then be released and the blood sample stored on dry ice. The biologist then washed his / her hands, utensils, and the working platform with a disinfectant.

All bedding material, paper towels, used bags, torn gloves, and other trash were deposited into a trash bag under the tailgate in front of the biologist. This cycle would continue until all mice were processed (≥ 70 mice at times). At this point the biologist would close the trash bag. This involved compressing the bag, to conserve space in the truck bed, and sealing it. Both the biologist and the technician would then remove all personal protective equipment and disinfect their hands. The protocol for this study was approved by the University of Montana Institutional Animal Care and Use Committee (AICUC).

METHODS

Two sampling series were conducted from March through December 2000. The two series varied only by the type of protective clothing worn and sample size. Series one consisted of thirty runs, while series two consisted of twenty-five runs. Each run involved the processing of fifteen mice at one minute/mouse. Mouse-handling procedures mimicked those of the Montana Longitudinal Hantavirus Study with five exceptions: white lab mice were used instead of wild mice, collection of blood samples was only simulated, plastic tubs were placed on a desk instead of the tailgate a truck, mice were not released but placed in a holding container, and the experiment was conducted indoors to minimize the influence of air movements on aerosolized particles. Mice were cared for and treated in accordance with established

guidelines (University of Montana Institutional Animal Care and Use Committee 1998).

Prior to each sampling run mice were placed in fully-baited Sherman traps with an ample amount of bedding material. Bait included peanut butter smeared on the back door of the trap and a tablespoon of oats. Bedding material was composed of a handful of synthetic cotton.

Each trap received 1/16 tsp. of dry florescent paint pigment (Palmer Paint Products, Inc., Fluorescent Dry Temp 354017) and was placed in a clear bread bag. The volume of florescent dust placed in the traps was determined during preliminary sampling, and reflected a balance between estimated true values and the amount required to provide observable breakthrough. The fifteen traps were then carried to the sampling room and placed next to the workstation.

Protective clothing worn by the biologist and technician, during series one consisted of an inner and outer Kappler tyvek/pros 3 coverall. A grid was drawn on each set of coveralls consisting of 128 10-cm X 10-cm squares. This grid covered the front of the workers bodies, excluding the face, hands and feet, and extended around the cuff of both sleeves (Fig. 1).

The outer coveralls represented the exposure that may be observed without protective clothing, while the inner set represented the protection provided by wearing coveralls. After the mice were processed, both workers carefully removed their coveralls and placed them in an isolated area. The coveralls were then placed in a dark room and examined under a hand held short-wave ultraviolet light source (Ultra-Violet Prod., Inc. Mineralight Lamp Model H4-S). Each square containing florescent dust, as determined without the aid of magnification, was considered contaminated and recorded accordingly. We also recorded the time required to examine each set of coveralls.

Protective clothing worn by the biologist and technician during series two included an inner pair of coveralls and an

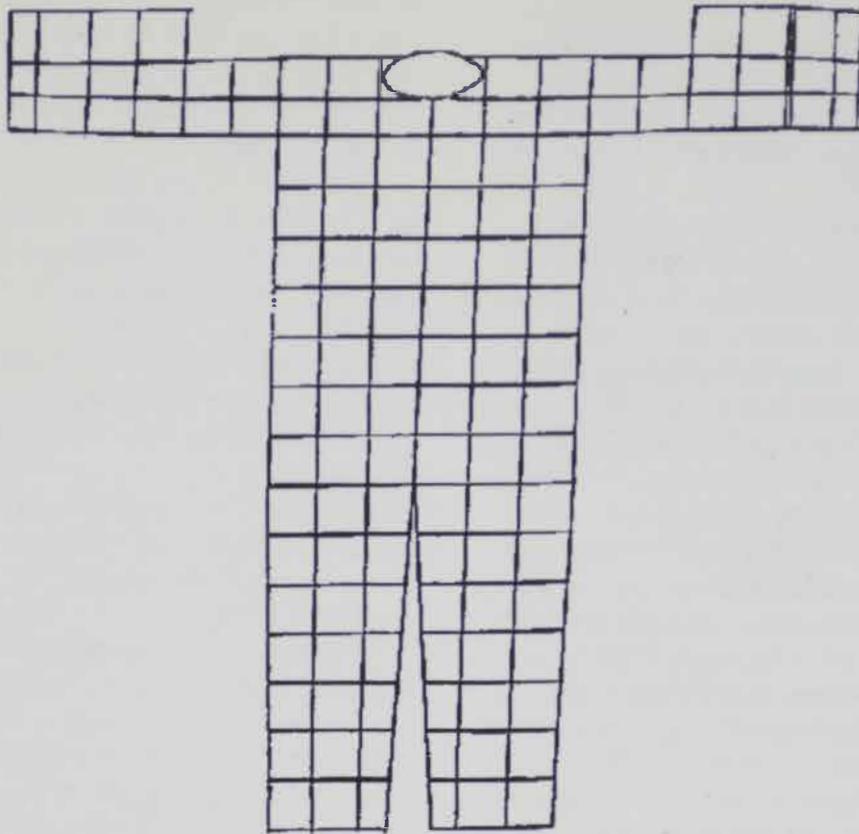


Figure 1. Graphical representation of the grid drawn on each pair of coveralls.

outer Kimberly-Clark ULTRA Surgical Gown. The coveralls were prepared as in series one and represented the protection that may be attained by wearing a surgical gown. The gown and coveralls were carefully removed and the coveralls were processed as in series one.

Quality control measures were introduced at several phases of the experiment. Prior to sampling, traps were thoroughly washed to insure that all florescent dust, peanut butter, and miscellaneous debris from previous sampling was discharged. The coveralls were examined under a short wave UV light after the grid was drawn and then placed in Ziploc plastic bags, where they remained until just before sampling. Ten pairs of coveralls from each series were randomly chosen to be re-examined just prior to sampling. We regressed the number of contaminated squares (c.s.)/pair of coveralls for each exposure group against the order in which samples were collected to determine

if a significant amount of florescent dust accumulated on the mice, workstation, or any unidentified mediums.

Mean exposure values reflected the average number of contaminated squares/128 squares. We used ANOVA to compare mean time required to inspect coveralls (TRI) and mean exposure values between various groups including: inner biologist vs. inner technician, inner biologist vs. outer biologist, inner biologist vs. biologist with gown, outer biologist vs. outer technician, inner technician vs. outer technician, inner technician vs. technician with gown, and biologist with gown vs. technician with gown. Mean exposure values were regressed against TRI to determine if TRI was an adequate indication of exposure magnitude. We set α at 0.05 for all statistical comparisons.

RESULTS AND DISCUSSION

A significant negative regression between mean exposure values and TRI was

found ($P = 0.005$, $r^2 = 88.2$; Fig. 2). If a negative relationship exists, then TRI may be an adequate indication of exposure magnitude. Further analysis assumes that TRI and exposure magnitude are inversely correlated.

Mean exposure values ranged from 35.6 to 124.9 c.s./ pair of coveralls (Table 1). Significant differences between mean exposures were found in the following comparisons: inner biologist vs. inner technician ($P = 0.018$), inner biologist vs. biologist with gown ($P = 0.006$), inner technician vs. outer technician ($P < 0.001$), and inner technician vs. technician with gown ($P = 0.029$). No significant differences between mean exposures were found in the following comparisons: inner biologist vs. outer biologist ($P = 0.111$), outer biologist vs. outer biologist ($P = 0.353$), and biologist with gown vs. technician with gown ($P = 0.905$).

The mean inner exposure values, for both biologist and technician, were lower than mean outer values, but significant differences were restricted to the technician. Mean gowned exposure values were

significantly lower, for both biologist and technician, than those observed while wearing coveralls. Biologist mean inner exposure values were significantly greater than the technician's.

Mean TRI ranged from 51.53 to 373.0 sec (see Table 2). Significant differences between mean TRI were found in the following comparisons: inner biologist vs. inner technician ($P < 0.001$), inner biologist vs. outer biologist ($P = 0.003$), outer biologist vs. outer technician ($P < 0.001$), inner technician vs. outer technician ($P < 0.001$), inner technician vs. technician with gown ($P = 0.029$), inner biologist vs. biologist with gown ($P = 0.003$), and biologist with gown vs. technician with gown ($P < 0.001$).

The biologist and technician TRI were significantly greater for the inner coveralls, which indicates a differences in exposure magnitude, i.e., inner coveralls required more time to inspect therefore the exposure was not as pronounced. Biologist and technician mean gowned TRI were significantly greater than those observed while wearing coveralls. Technician inner,

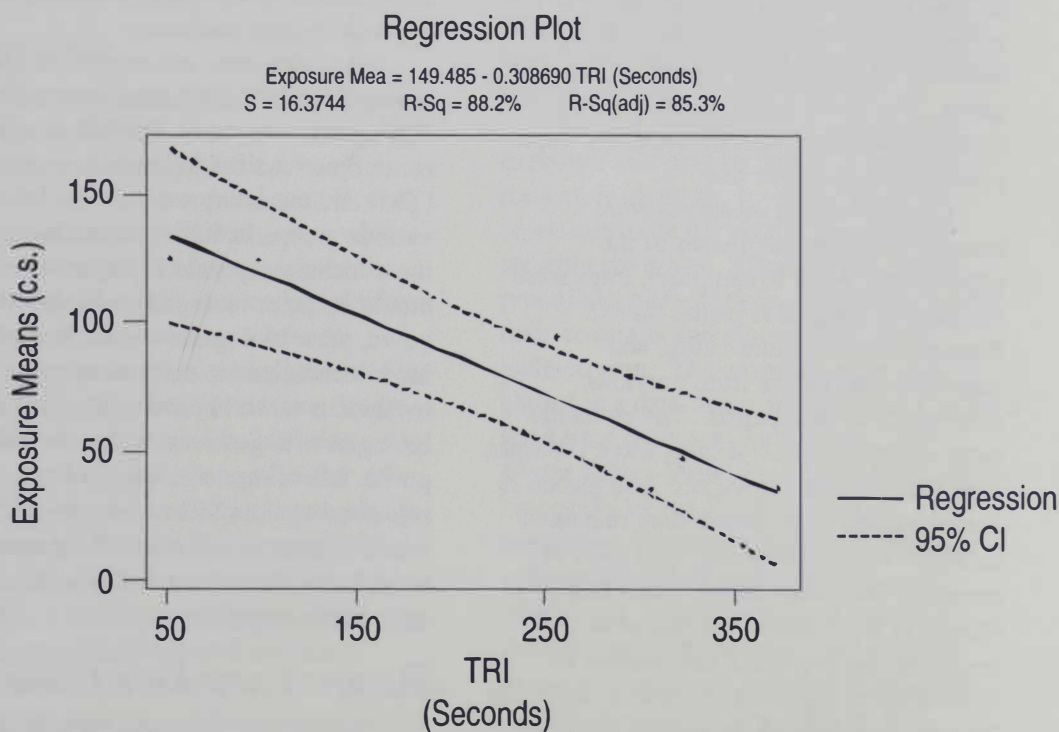


Figure 2. Mean exposure vs. Times required to inspect (TRI) regressional analysis.

Table 1. Summary of mean numbers of contaminated squares (c.s.) per pair of coveralls.

	Variable	N	Mean (c.s.)	St. Dev.
Series I	Inner Biologist	30	94.4	103.1
	Outer Biologist	30	124.9	2.51
	Inner Technician	30	47.3	23.59
	Outer Technician	30	124.3	2.45
Series II	Biologist With Gown	25	35.6	11.1
	Technician With Gown	25	35.96	10.0

outer and gowned TRI were found to be significantly greater than the biologist's values.

No significant regressions between any of the six exposure groups and time were found ($P = 0.401-0.919$, $r^2 = 0.0-2.5$). The lack of a relationship between these parameters is an indication that fluorescent dust was not accumulating in significant amounts.

CONCLUSIONS

We found that coveralls provide a significant degree of protection against aerosolized dust originating from small live rodent live traps, relative to wearing no form of protective clothing. Our data strongly suggested that surgical gowns provide significantly greater protection than coveralls against aerosolized dust originating from traps. In our opinion established guidelines should be amended to remove coveralls from the personal protective equipment options. Further investigations should examine the protection provided by coveralls that have been sealed with tape.

We conclude that the biologist was exposed to a greater amount of aerosolized

dust originating from traps, corroborating air samples from a previous study (Young 2001). If our experimental process adequately approximated true field exposures, then information of this nature may be applied to the design of future engineering and administrative controls.

It is important to note that applications of our conclusions are limited to unmodified surgical gowns and coveralls of a specific design. Further limitations inherent to this experiment include how accurately: fluorescent dust approximated the aerodynamic properties of actual trap dust; the amount of fluorescent dust applied to each trap approximated the quantity of dust that occurs in actual traps; and the semi-controlled experimental environment approximated actual field conditions.

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Table 2. Summary of mean times required to inspect coveralls (TRI).

	Variable	N	Mean (c.s.)	St. Dev.
Series I	Inner Biologist TRI	30	256.3	56.4
	Outer Biologist TRI	30	51.5	12.3
	Inner Technician TRI	30	322.3	101.0
	Outer Technician TRI	30	98.6	38.8
Series II	Biologist With Gown TRI	25	305.6	57.1
	Technician With Gown TRI	25	373.0	55.0

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