Assessment of habitat fragmentation, roads and weather on elk harvest vulnerability in the upper Bitterroot Valley, Montana
by Clifton Conrad Youmans

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Biological Sciences
Montana State University

Abstract:
Vulnerability of elk (Cervus elaphus) to hunters is widely accepted as the consequence of many variables: habitat fragmentation, road density, number of hunters, season length, elk behavior, hunter behavior, and weather. The importance of each of these variables to elk vulnerability is not well understood. Long-term data from hunter check stations offer a continuous historical record of harvest information and are potentially a valuable source of information on elk vulnerability. This study evaluates long-term check station data from Darby, Montana, with respect to its utility to provide insight into elk vulnerability questions.

Thirty-seven years of elk harvest data obtained at the Darby hunter check station were compiled and analyzed for two hunting districts (HD 250 and HD 270) in the upper Bitterroot Valley. Concurrent information on annual changes in road density, percent of area logged, season length, and number of hunters was also compiled and analyzed. An index of winter severity (IWS) was computed for 15-day intervals across all years based on snow depth and used to examine the influence of weather on elk vulnerability. Several indices were found useful to measure changes in elk vulnerability: hunter success, distribution of the harvest, percent of total harvest occurring opening day, mean and variance of the rate of harvest (number killed/ day). Statistical analysis of variables was severely constrained by problems of autocorrelation (due to time trend) and multicollinearity. Principle components analysis (PCA) of variables was conducted to create independent synthetic variables. Results of graphical and statistical analysis of data from two hunting districts revealed large increases in vulnerability occurred in the mid-sixties concurrent with periods of peak road construction and logging, but resolution of the data was insufficient to detect incremental increases in vulnerability during the most recent decade. The influence of weather on elk vulnerability differed between the two hunting districts. In HD 270, where elk migrate from large tracts of secure habitat to concentrate on highly fragmented, accessible areas, weather accounts for up to 50% of the variation in the harvest. In HD 250, where elk migration is less pronounced and elk are uniformly more accessible, numbers of hunters and road density were more important in determining vulnerability.

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Clifton Conrad Youmans

A thesis submitted in partial fulfillment
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APPROVAL

of a thesis submitted by

Clifton Conrad Youmans

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Vulnerability of elk *(Cervus elaphus)* to hunters is widely accepted as the consequence of many variables: habitat fragmentation, road density, number of hunters, season length, elk behavior, hunter behavior, and weather. The importance of each of these variables to elk vulnerability is not well understood. Long-term data from hunter check stations offer a continuous historical record of harvest information and are potentially a valuable source of information on elk vulnerability. This study evaluates long-term check station data from Darby, Montana, with respect to its utility to provide insight into elk vulnerability questions.

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INTRODUCTION

The term "elk vulnerability" is a fairly new term used in wildlife management to describe the susceptibility of elk *(Cervus elaphus)* to being killed during the hunting season (Lyon and Christensen 1990). It is the antonym of security during the hunting season (Lyon and Christensen 1990). Increased elk vulnerability is the consequence of many factors that cumulatively lower the probability that an elk will survive the hunting season. These factors include (but are not limited to) number of hunters, road density, vegetation, weather, topography, hunter behavior, and elk behavior. Despite a recent shift in emphasis in elk management toward elk vulnerability questions, the factors which increase elk vulnerability are not well understood and remain largely hypothetical (Lyon and Christensen 1990, Christensen et al., 1991). Most elk vulnerability studies have been extremely limited in scope and characterized by small sample size and lack of replication (Thomas 1991). A clear pattern of results does emerge from the current research on elk vulnerability, but none of the studies to date is definitive (Thomas 1991). The current budget status of state and federal wildlife agencies provides little optimism that funding will become available for intensive new field studies on elk vulnerability - at least of scope sufficient to address fairly the research needs enumerated by Thomas (1991). It is unlikely that this situation will change in the near future (Don Childress, Administrator, Wildlife Division, Montana Department of Fish, Wildlife and Parks, pers. comm.).

Lack of data has not deterred development and use of models to address elk vulnerability. Models developed to evaluate elk habitat selection and use (Lyon 1983, Lyon et al. 1984, Wisdom et al. 1986) have been erroneously applied to assess elk vulnerability (Lyon and Christensen 1990). Other models have been developed based on limited research results and questionable assumptions (Youmans and Brussard, 1986). Hillis et al. (1991) developed a model intended to maintain elk security by providing for fewer open roads and larger and more continuous stands of timber. The Hillis model has been incorporated into the management of at least one National Forest to reduce elk vulnerability, but it has not been empirically validated. While the performance of the model may be measured over time, there is a critical need for long-term, site-specific information on the factors that determine elk vulnerability.

The absence of funds to initiate field studies leaves managers dependent upon existing sources of information. Long-term check station data offer a continuous record of harvest information and thus are a potentially valuable source of information on elk vulnerability. Montana Department of Fish, Wildlife and Parks (FWP) check station results and statewide harvest survey data are the primary sources of information on elk harvest trends in Montana. Figure 1 is a flow chart outlining the parameters that might be used in managing elk populations and identifying elk vulnerability trends (Terry Lonner, FWP Research Bureau, pers. comm.). This flow diagram validates FWP's continuing commitment to check station data as a primary source of information for wildlife managers. Most wildlife managers rely heavily on check station data and harvest survey information to make management decisions. Radio telemetry information sometimes augments this data base,

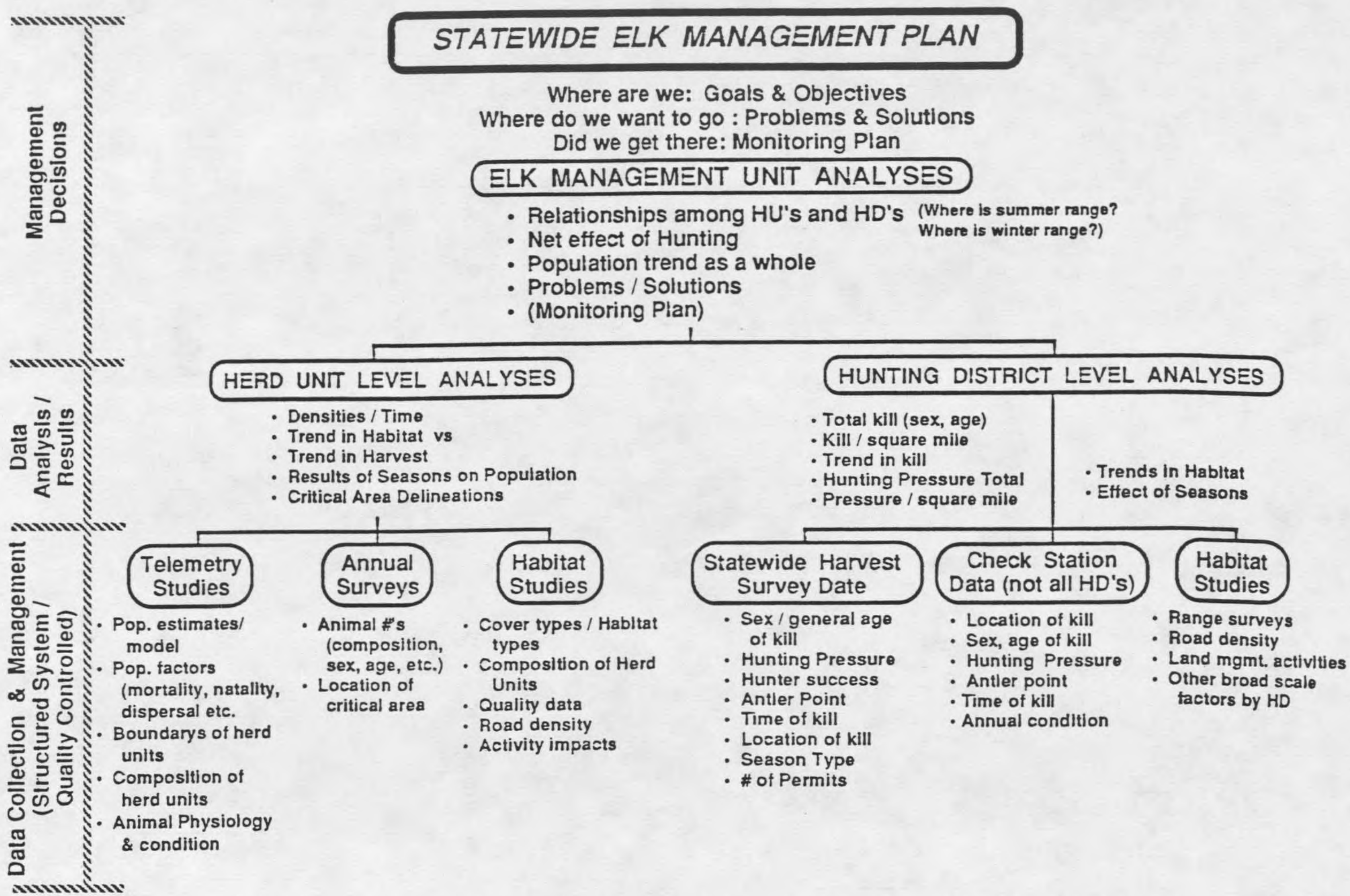

Figure 1. Schematic of proposed data management levels for managing elk populations. Note the role of check station data in hunting district line analysis (Courtesy of Research Technical Service Bureau, Montana Department of Fish, Wildlife and Parks [Unpublished memo by T.W. Lonner]).

but telemetry studies are generally too limited in scope to provide much insight into long-term trends in vulnerability. The primary drawback of habitat studies to address questions of elk vulnerability is that historical information on road construction and timber harvest is typically lacking. Findings obtained from long-term elk ecology research studies provide a more in depth understanding of population processes, but only for a few study areas in the state.

Given the need for information on elk vulnerability and the absence of funds and personnel to initiate new studies, a critical evaluation of long-term check station data is warranted. The data set from the Darby hunter check station spans four decades (1953-1989) and represents a considerable investment in data collection by FWP. The focus of this study was to gain insight into trends in elk vulnerability in the upper Bitterroot through compilation, analysis, and evaluation of Darby check station records coupled with synthesis and analysis of weather, logging and road construction records for the study area.

Objectives

The objective of this study is to address the following basic questions: 1) Can long-term check station data provide insight into trends in elk vulnerability? 2) What kinds of check station data are most useful in assessing trends in elk vulnerability? 3) Which variables related to access, habitat, number of hunters and weather have had the greatest impacts on elk vulnerability? 4) What are the management implications of the study findings?

DESCRIPTION OF STUDY AREA

Study Area

The Bitterroot National Forest comprises about 647,520 ha (1,600,000 ac) and encompasses two mountain ranges which form the east and west sides of the Bitterroot Valley (USDA Forest Service 1987). The Bitterroot Valley floor is about 97 km (60 mi) long and varies in width from 6.4 to 16 km (3-4 mi). Bordering the valley on the west is the Bitterroot Range, which rises about 1524 m (5000 ft) in 3 to 6 km (3-4 mi) from the valley floor. Deep, rocky, glaciated canyons break this front at 2-5 km (1-3 mi) intervals (USDA Forest Service 1987). The Sapphire Mountains lie to the east of the Valley where vertical relief is more gentle, rising about 914 m (3000 ft) from the valley floor in 6-8 km (4-5 mi).

The Bitterroot Valley increases in elevation from north to south and abuts against the Continental Divide at its southern boundary. The portion of the Valley situated south of the town of Darby is typically referred to as the upper Bitterroot. Two hunting districts: (HD 250 and HD 270) encompass the area known as the upper Bitterroot (Fig. 2). HD 270 encompasses approximately 128,694 ha (318,000 ac) of National Forest, and private and state forest lands and extends westward from the crest of the Sapphire Mountains to the East Fork of the Bitterroot River. It is bounded on the north by

Figure 2. Map of the upper Bitterroot Valley depicting boundaries of Hunting District 250 and Hunting District 270. Location of four elk management areas are also depicted within each respective hunting district. Ravalli Co., MT.

the Skalkaho Pass road and on the south by the Continental Divide. Hunting district 250 encompasses approximately 187,376 ha (463,000 ac) of National Forest lands bordered on the west and south by the Bitterroot Mountains and the Montana-Idaho border and extends eastward to abut against HD 270. To the North, HD 250 extends to Tin Cup Creek (directly west of Darby, Montana).

Description of Hunting Districts

HD 250

Hunting District 250 encompasses two management areas, the West Fork and the Triangle Area (Fig. 2). These two management areas were delineated in the 1950s based on topography and what was then known of elk herd movements. The boundary between the West Fork and the Triangle Area is the West Fork of the Bitterroot River. West Fork elevations range from approximately 1490-3048 m (4900-10,000 ft). The terrain is mountainous with 50% of the land area in excess of 2133 m (7000 ft) elevation (USDA Forest Service 1987). Stream bottoms are typically narrow with side slopes rising steeply to narrow ridges. More than half the area's slopes are in excess of 60%, confining most trail and road access to stream bottoms or ridge tops (USDA Forest Service 1987). The area is forested except for a few large meadows in stream headwaters and dry, south-facing slopes. At higher elevations, rock rubble and grassbalds are common. Coniferous forests are dominated by Douglas fir (*Pseudotsuga menziesii*, [Mirbel] Franco.) and ponderosa pine (*Pinus ponderosa*, Dougl.) on the warmer, lower elevation sites and lodgepole pine (*Pinus contorta*, Dougl.) on cooler sites at midslope.

Whitebark pine (*Pinus albicaulis*, Engelm.) is a dominant species at higher elevations.

In the Triangle Area, elevations range from about 1400-2700 m (4800-8831 ft) at Piquett Mountain. Approximately 60% of the area is above 2100 m (7000 ft). Topography is steep and rocky with shallow, sandy-loam soils (USDA Forest Service 1987). Drainage bottoms are narrow with steepened slopes rising to narrow ridges. The area is mostly forested except for peaks in the Piquett Mountain area and ridges in the upper Warm Springs drainage. Lodgepole pine, subalpine fir (*Abies lasiocarpa*, [Hook.] Nutt.) and whitebark pine dominate above 2100 m (7000 ft). At lower elevations, Douglas fir, ponderosa pine , lodgepole pine and Engelmann spruce (*Pinus engelmannii*, Parry) are the major species (USDA Forest Service 1987).

<u>HD 270</u>

Hunting district 270 encompasses two management areas, the East Fork Area and Rye Creek Area (Fig. 2). These two management areas were established at the same time as the West Fork and Triangle Areas, based on geography and elk herd movements. The East Fork and Rye Creek Areas are separated by the Rye Creek-East Fork divide. The dominant landscape feature, the Sapphire Range, forms the eastern boundary of both management areas. Steep, rocky cirque basins and trough walls lie along the crest of this Range. Exposed bedrock and rubble predominate along the Sapphire crest, Whetstone Ridge, and the southern portion bordering the Anaconda-Pintler Wilderness (USDA Forest Service 1987). Slopes are moderately steep with flat or rolling lands comprising a small part of the total land area (Rognrud 1955). Elevations range from 1219 m to 2743 m (4,000-9,000 ft) at Kent Peak. The forested landscape is interspersed with stream-side meadows at lower elevations. Vegetative cover on lower and warmer exposures consists of bunch grasses and bitterbrush (*Purshia tridentata*, Pursh.) association and mountain mahogany (*Cercocarpus ledifolius*, Nutt.) (Rognrud 1955). As elevation increases, Ponderosa pine replaces browse plants. At about 1828 m (6000 ft), Douglas fir replaces Ponderosa pine on southerly exposures. Lodgepole pine replaces Douglas fir on moist sites and above 2133 m (7000 ft). Whitebark pine and subalpine larch (*Larix lyallii*, Parl.) exist above 2438 m (8000 ft).

Human Population Trends

Between 1870 and 1910, the population of the Bitterroot Valley increased from 314 to 11,666 (Montana Historical County Census Data 1910-1970) and then remained relatively stable through 1960 (12,341 in 1960). From 1960 to 1970 the population increased 16% to 14,409. Rapid growth began in the 1970s, with the population increasing 56% to 22,493 in 1980 (U.S. Bureau of the Census 1981). Population growth then slowed, reaching 25,010 by 1990 (11% increase) (U.S. Bureau of the Census 1991). Much of the rapid growth in Ravalli County was due to an influx of people seeking a rural lifestyle in a scenic environment (Sylvester 1981).

Roads

On the Bitterroot National Forest there are approximately 5,632 km (3,500 mi) of roads providing access to about 25% of the Forest (USDA Forest Service 1987). Excluding designated wilderness, eleven roadless areas comprising about 163,903 ha (405,000 ac) remain. (USDA Forest Service 1987). These remaining roadless areas (Fig. 3) are under consideration for future development (USDA Forest Service 1987). Road densities in HD 250 have increased 300% in the past 37 years, from 1.09 km/km^2 (0.68 mi/mi^2) in 1953 to 4.4 km/km^2 (2.74 mi/mi^2) in 1989 on the non-wilderness portion of the Forest. A period of extensive road building occurred from 1965 to 1970, when approximately 25% of existing roads in HD 250 were constructed (Fig. 4).

In HD 270, road densities have increased 350% since 1953 (1.2 -5.56 km/km^2 [0.77-3.52 mi/mi^2] on the non-wilderness portion). Two dramatic peaks in road construction occurred in HD 270: during the 11,700 ha (29,000 ac) Sleeping Child fire in 1961 and the following year when numerous salvage sales were active, and again in 1968-1969. Road construction during these four years accounts for approximately 35% of existing road miles in HD 270 (Fig. 5).

Timber Harvest/ Habitat Changes

Both wildfire and timber harvest have influenced the forest landscape in the upper Bitterroot. Approximately 238,368 ha (589,000 ac) in the Bitterroot Forest are designated as "tentatively suitable" for timber production (USDA Forest Service 1987). Tentatively suitable timber lands include areas

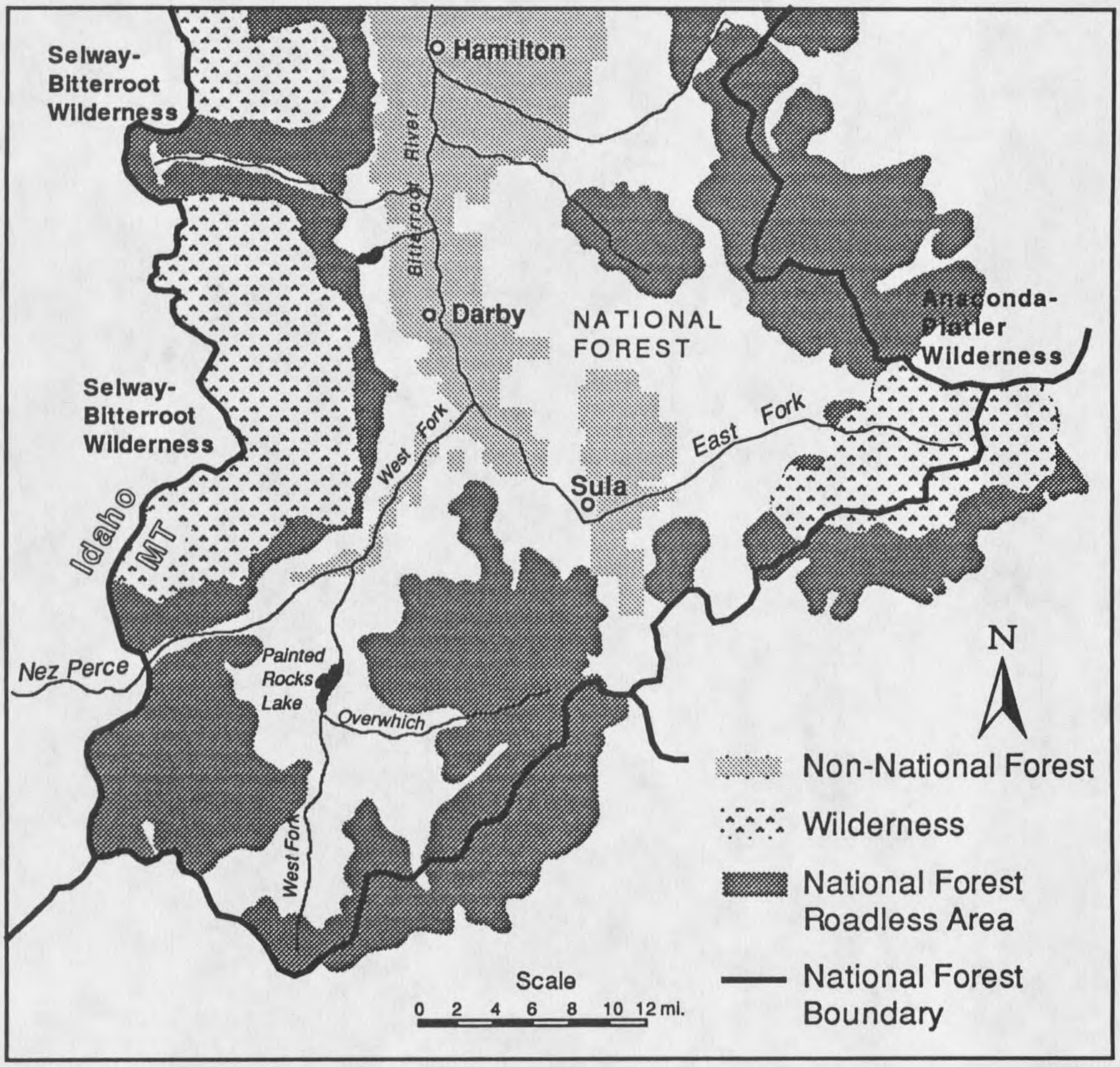

Figure 3. Map of roadless areas in the upper Bitterroot valley. Note the large tracts of roadless lands along the Sapphire Divide (HD 270). These roadless areas currently provide early season security for elk in HD 270.

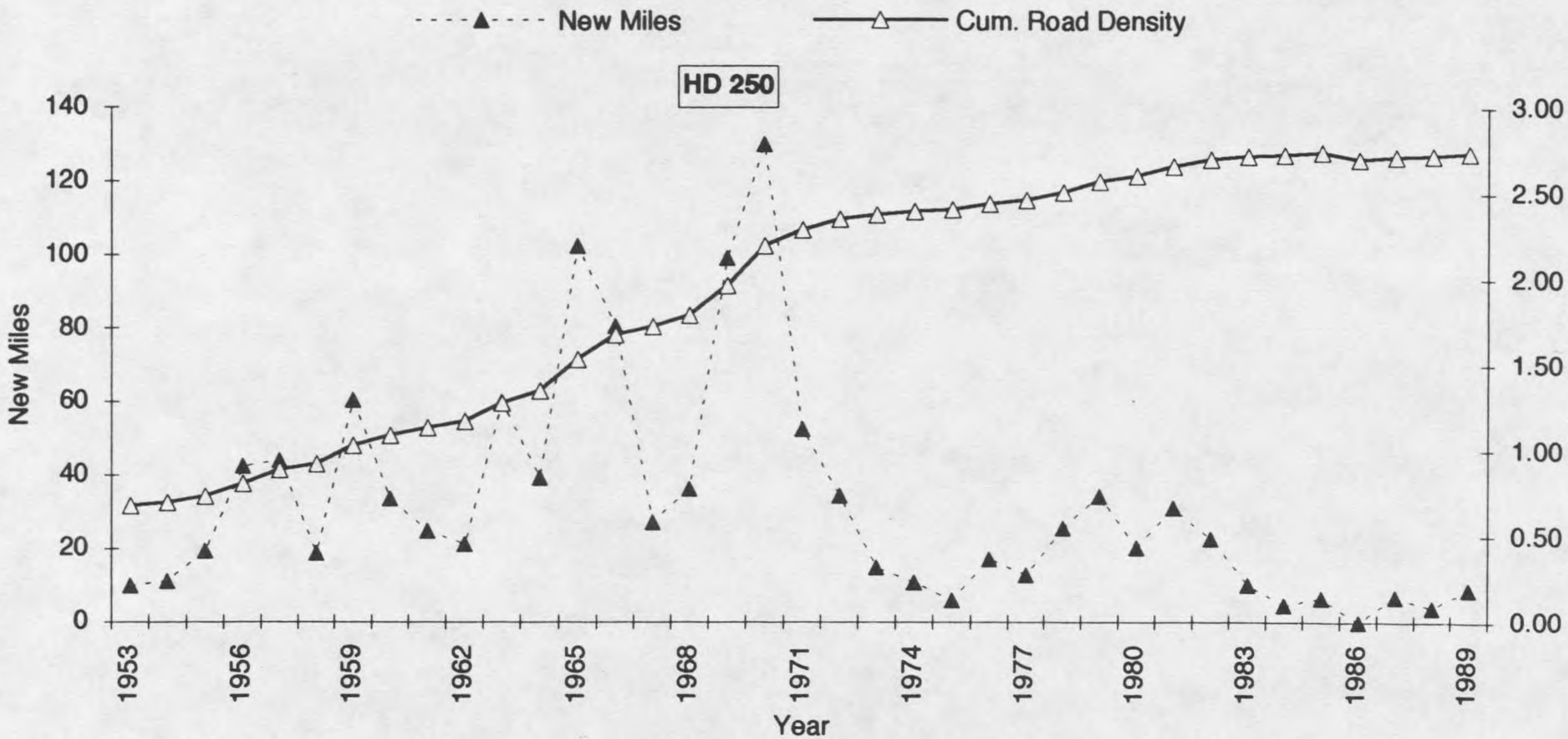

Figure 4. HD 250. Trend in road construction in HD 250, upper Bitterroot, Ravalli Co., MT.

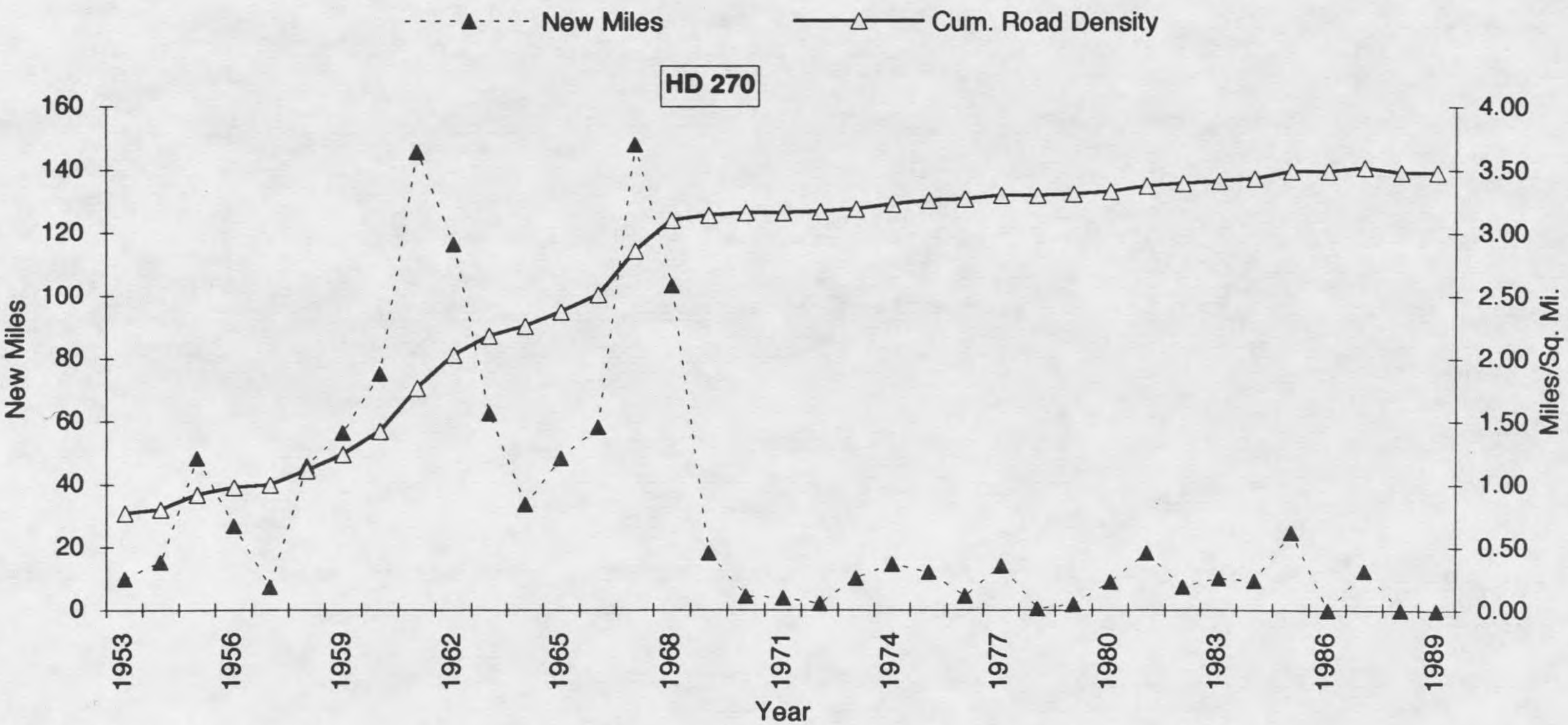

Figure 5. HD 270. Trend in road construction in HD 270, upper Bitterroot, Ravalli Co., MT.

which are currently roadless, but not designated as wilderness. An average of 30 million board feet of timber was sold annually by the Bitterroot Forest during the period from 1976 to 1985 (USDA Forest Service 1987). Acreage altered by logging and wildfire in HD 250 has increased from 357 ha (883 ac) in 1953 to 17,299 ha (42,746 ac) in 1989, affecting about 12% of the non-wilderness portion of the hunting district (Fig. 6). The number of acres logged in any one year in HD 250 has varied greatly, with the period of the late sixties being particularly notable with respect to acres logged (Fig. 6). However, when the cumulative percent of habitat impacted is plotted, annual variation in logging activity is less apparent (Fig. 6). Note that the slope of the line plotting the cumulative percent of habitat impacted is steepest in the 1960s and, in contrast to plots of cumulative road density (Fig. 4), the rate of change appears much more constant over the 37-year time span.

In HD 270, fire has played a dominant role in shaping habitat conditions. The Sleeping Child fire burned approximately 11,700 ha (29,000 ac) in 1961. Hectares of habitat altered by logging and wildfire have increased from 803 in 1953 to 27,773 in 1989, affecting about 25% of the total non-wilderness acreage (1,984 and 68,519 ac, respectively). A dramatic peak in habitat impacted occurred in 1961 as a result of the Sleeping Child fire (Fig. 7). Since 1953, approximately 27,520 ha (68,000 ac) have been affected from logging or wildfire in HD 270. The Sleeping Child fire and associated salvage sales comprised approximately 45% of this total (12,343 ha). Regeneration has occurred on much of the burn area, and hiding cover for elk exists on a large portion of the lower-elevations that were burned in 1961.

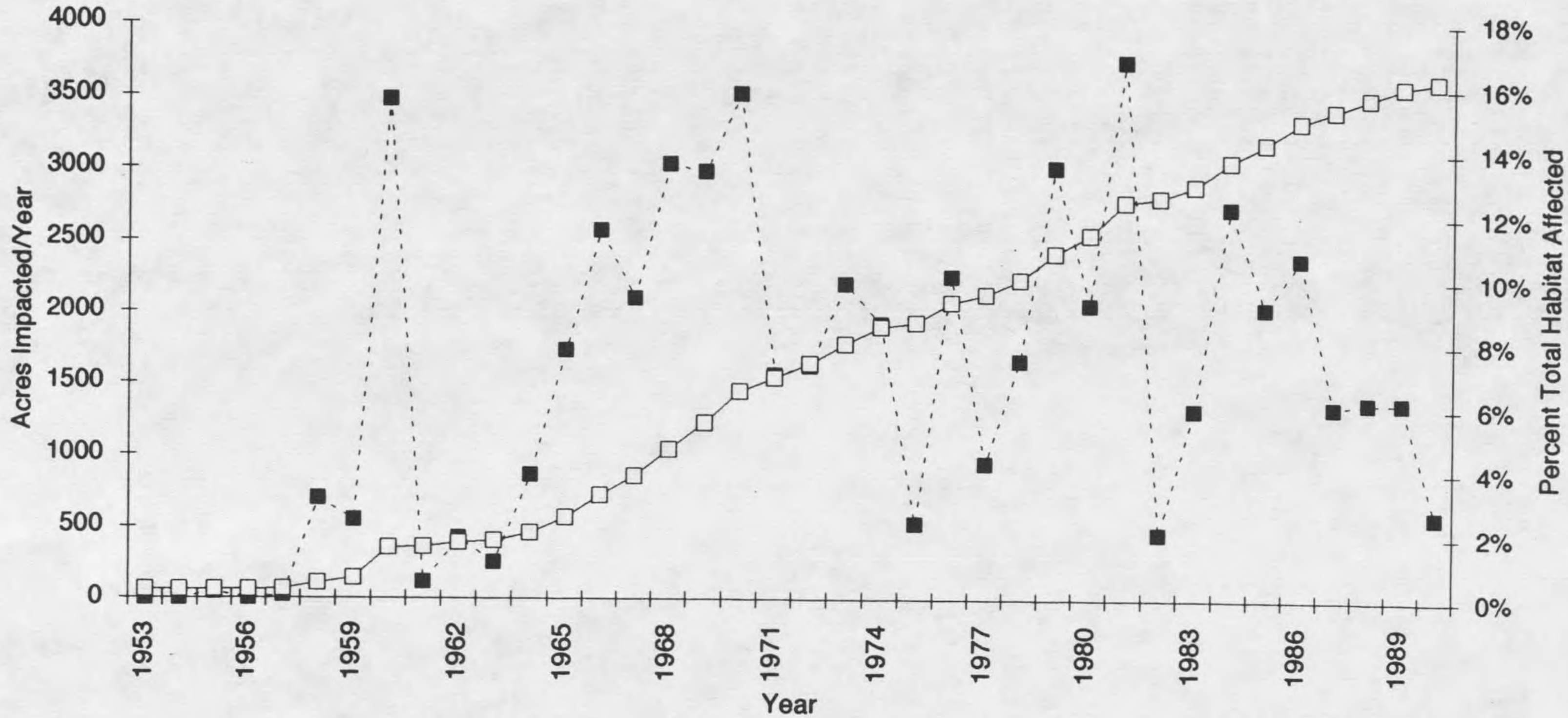

Figure 6. HD 250. Trend in change in habitat as a result of logging and wildfire. upper Bitterroot, Ravalli Co. MT.

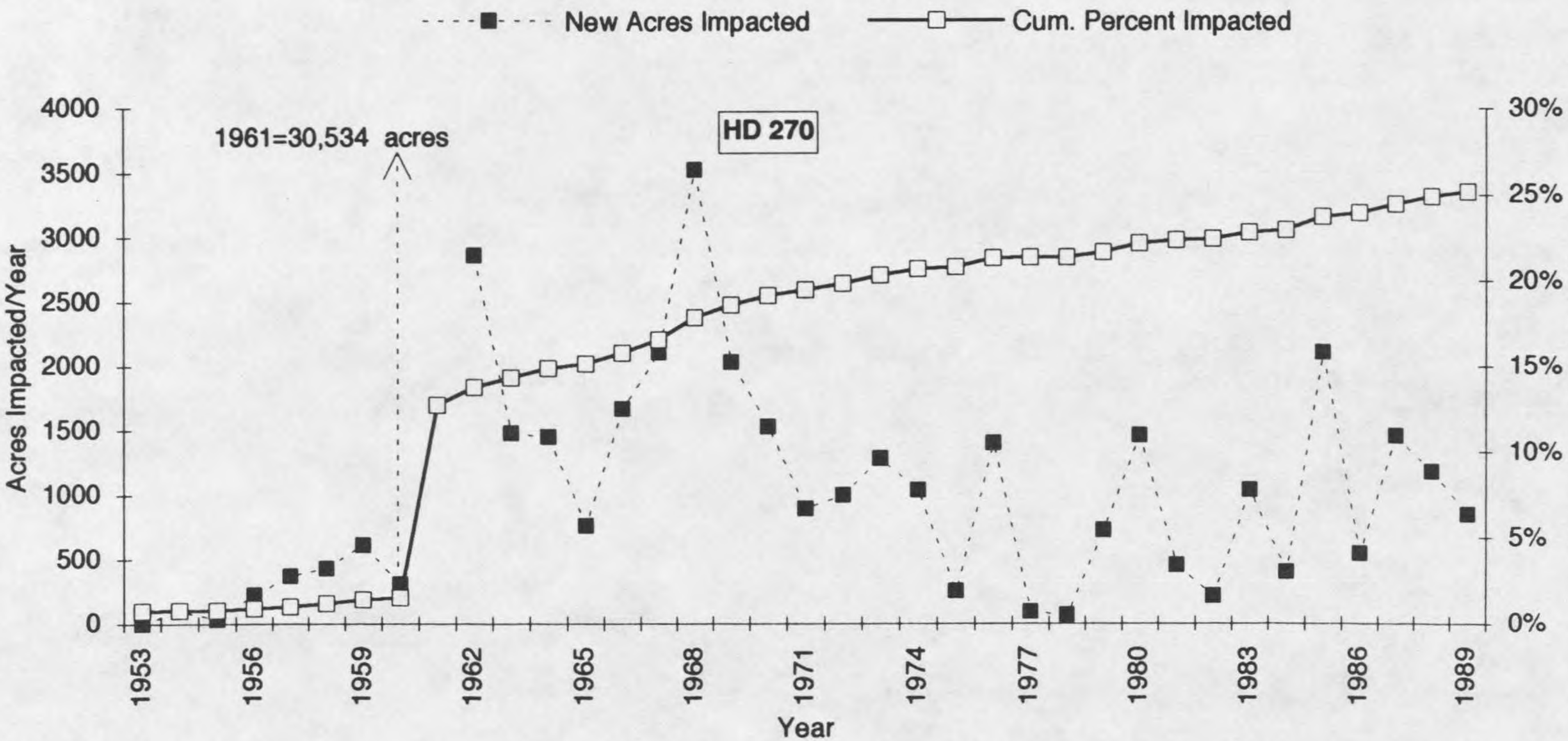

Figure 7. HD 270. Trend in change in habitat as a result of logging and wildfire. upper Bitterroot, Ravalli Co. MT.

Precipitation/ Climate

Annual precipitation varies from less than 36 cm (14 in) in the Bitterroot Valley to > 254 cm (100 in) at higher elevations in the Bitterroot Range (USDA Forest Service 1987). Approximately 30% of the Bitterroot Forest receives 50-76 cm (20-30 in) of precipitation annually (USDA Forest Service 1987). Average annual precipitation exceeds 76 cm on 60% of the Forest, ranging from 127 cm on the Sapphire Divide to 254 cm in higher elevations of the Bitterroot Range (USDA Forest Service 1987). Winters are mild for northern Rocky Mountain latitudes, and summers are cool. From 1957 to 1990, January daily maximum and minimum temperatures at Sula were 32.7 and 8.6 F, respectively. Average daily temperature during January was 20.6 F. Maximum and minimum average daily temperatures during July were 82.9 and 39.4 F, respectively, with an average daily temperature of 61.1 degrees F (USDA Soil Conservation Service Snow Survey Office, Bozeman, MT, pers. comm.).

Overview of History of the Elk Population

The first homesteader in the Sula vicinity was of the opinion that approximately the same number of elk - but fewer mule deer - existed in 1955 as when he arrived in 1885 (Rognrud 1955). He also recalled that most of the elk were killed during the influx of homesteaders, prior to 1905 (Rognrud 1955). Than Wilkerson, the first Forest Ranger in the upper Bitterroot, estimated that there were only seven elk in the East Fork Area in 1902 (Hollibaugh 1942). Elk from Yellowstone Park were released in the East Fork in 1911. Cross (1965) estimated that the release involved "somewhat less [*sic*] than 40 animals." Elk numbers increased slowly and hunting regulations remained conservative through the 1920s (Cross 1965). Rognrud (1955) notes there were very few elk in the upper Bitterroot until 1922-25. Aerial censuses in the East Fork were conducted during the winters of 1953, 1954 and 1955. Elk counted increased from 366 in 1953 to 677 in 1955. Rognrud (1955) suggests that apparent population increases were probably due in large part to better aircraft and more intensive survey efforts. Elk numbers in the East Fork were believed to have plateaued in about 1958 when 651 elk were counted (Cross 1965). Aerial censuses indicated that elk numbers in the East Fork remained stable through 1961.

Questions surrounding the harvest of elk and the vulnerability of elk are not new to the upper Bitterroot. In the early 1960s considerable public debate centered on concern that elk populations had declined and that long, either-sex seasons were responsible for the decline (Cross 1965). In the absence of aerial census results for the early sixties, it is unclear whether the elk population of the East Fork declined or mild weather conditions during the hunting season led to a perception of reduced numbers. Cross (1965) notes that aerial census results in 1965 were comparable with counts obtained in 1958.

Systematic aerial censuses of both HD 250 and HD 270 were initiated in 1965. Figure 8 illustrates trend in elk population numbers as determined by spring aerial trend census flights. Elk numbers remained relatively stable in both hunting districts until the decade of the eighties. The population in HD 250 has shown a steady increase during the 1980s. Survey data indicate a population increase of less magnitude in HD 270.

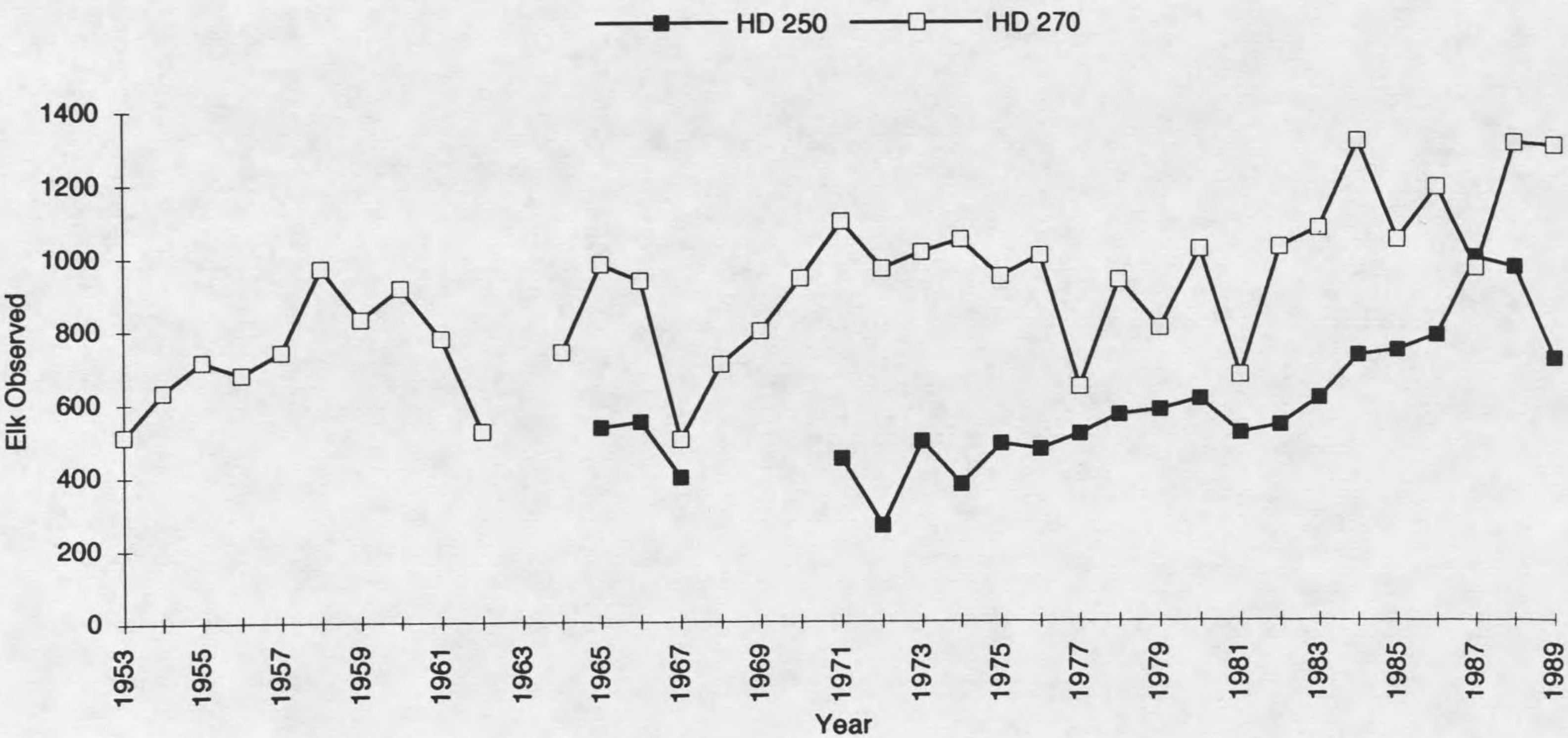

Figure 8. Trend in spring aerial elk census surveys for HD 250 and HD 270, upper Bitterroot, Ravalli Co., MT.

METHODS

Elk Harvest Information

Since 1953, daily elk harvest information has been collected during hunting season at the Darby check station. Data are recorded on kill summary sheets but prior to 1983 they were recorded on individual kill cards. Information collected included date killed, sex, age class (calf, spike, subadult, mature, old) and a descriptive location of the kill accurate to drainage. Measurement statistics, hunter residency, and effort level (days hunted) were recorded intermittently. Reliable information on the age of harvested elk does not exist prior to about 1970. All available harvest information recorded on kill cards and kill summary sheets was entered into a computer database to facilitate analysis. Approximately 16,000 individual records from 1953 to 1989 have been incorporated into the database.

Limitations of Check Station Data

Hunter check station data capture only a fraction of the animals harvested in the upper Bitterroot. Estimates of check station efficiency range from 50% to 60% (John Firebaugh, FWP, personal comm.). Check station data provide information only on harvested game animals. Because elk are differentially vulnerable to hunters as a result of such factors as weather, season length, roads, logging, and number of hunters, changes in the harvest from year to year do not necessarily represent corresponding changes in the population. Check station data alone are insufficient to assess the underlying demography of the elk population. Only if elk were equally vulnerable across years (i.e. the population was sampled with approximately equal precision each year) could check station data provide much insight into underlying population dynamics.

Information on Number of Hunters

Two sources for numbers of hunters exist for the study period, Darby check station data and hunter harvest survey data. Hunter harvest survey data were collected by FWP from mail-in or telephone questionnaires. At the Darby check station, unsuccessful hunters were asked which of four management areas (West Fork, Triangle, East Fork, Rye Creek) they hunted. The daily tally of unsuccessful hunters (by management area) was incorporated into the computer database for all years except 1960, 1961, 1962 and 1964. Data for these years were lost.

Beginning with 1959, information on number of hunters by each hunting district is available from the annual big game hunter survey questionnaire. I compared total unsuccessful hunter numbers tallied at Darby check station with results from hunter survey returns. For 1959 to 1973, the number of hunters was greater based on questionnaire returns than for check station data. After 1973, this reversed, and check station tallies of unsuccessful hunters were greater. In 1973 a new state law went into effect requiring all hunters (successful and unsuccessful) to stop at hunter check stations. Use of unsuccessful number of hunters as a sole indicator for number of hunters would have underestimated hunting pressure prior to 1973 because only a fraction of unsuccessful hunters stopped. Beginning in 1973, a sudden inflection in unsuccessful hunters occurred with the change in the law. This inflection in unsuccessful hunter numbers is an artifact of the change in the check station law - not an effect of hunting pressure. Attempts to apply a weighting coefficient to correct for differences between the two sources would have required additional assumptions. Therefore, I used the larger of the two estimates of total hunter pressure to describe the trend in hunting pressure. The larger of the two estimates represents the "worst case" level of hunting pressure. Figure 9 illustrates the trend in hunting pressure in both hunting districts for the period 1953 to 1989.

Analysis Units

To link the location of each elk kill to a discrete elk population unit, each hunting district was subdivided into analysis units corresponding to elk population units (Fig. 10). John Firebaugh, FWP Regional Wildlife Manager in Missoula, delineated these analysis units based on results of long-term studies of elk movements and migration patterns in the upper Bitterroot.

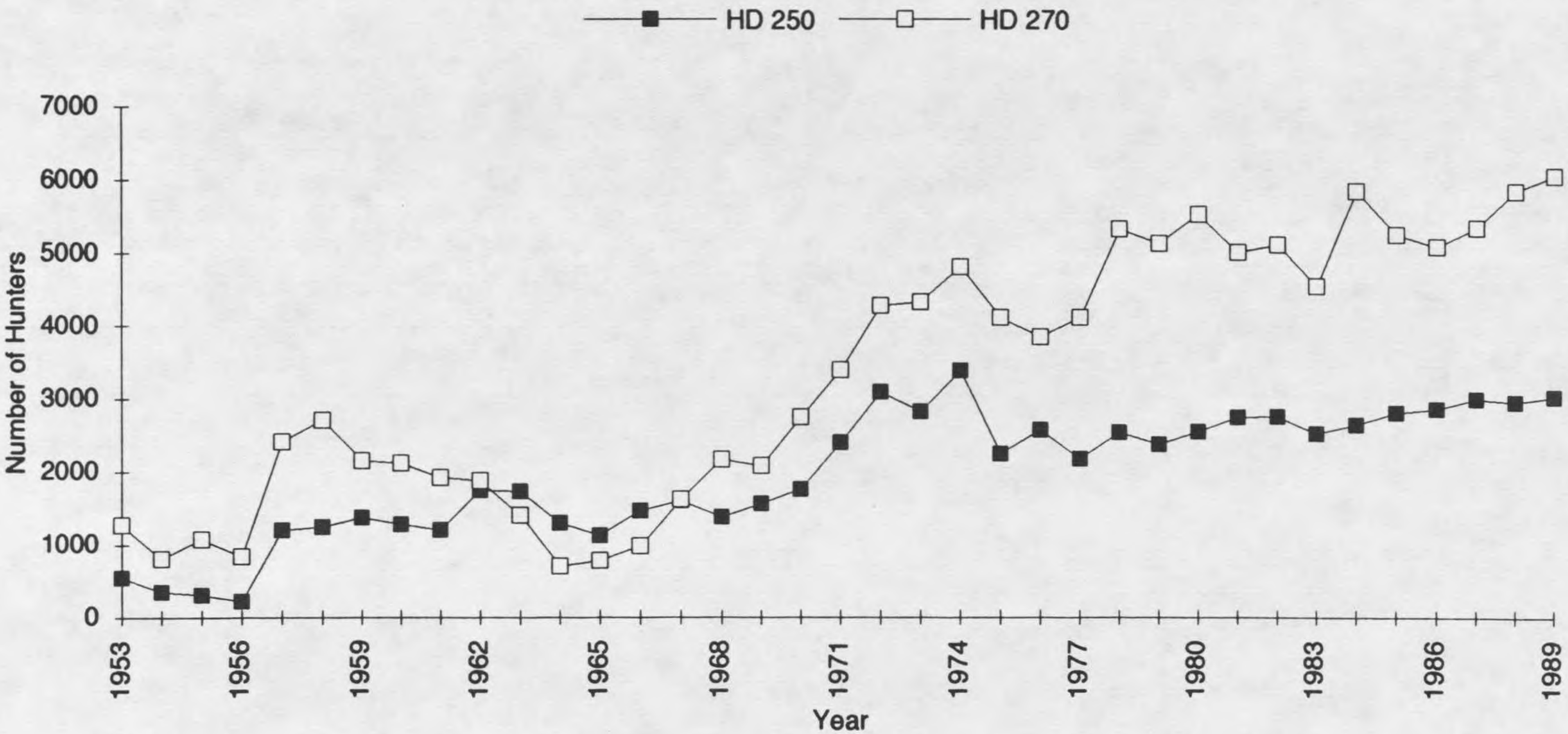

Figure 9. Trend in number of hunters in HD 250 and HD 270. Darby check station results and hunter survey data, upper Bitterroot, Ravalli Co., MT.

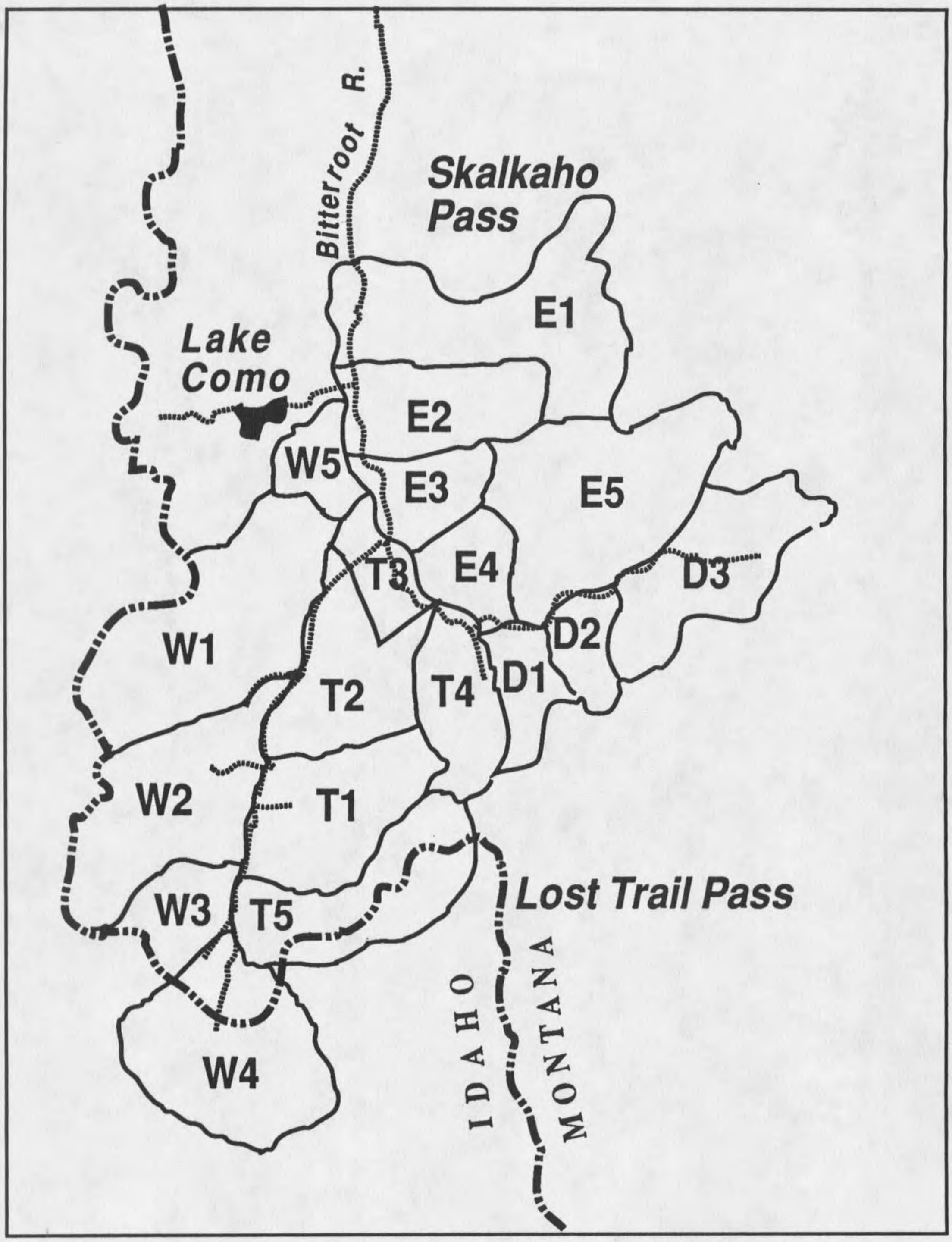

Figure 10. Elk herd analysis units in the Upper Bitterroot. Prefix W = West Fork analysis units, Prefix T = Triangle analysis units, Prefix E = East Fork analysis units, Prefix D = Divide analysis units. Analysis units delineated on the basis of elk herd annual home range movements.

Snow Pillow

After check station records were compiled in a computer database, information on weather, roads and timber harvest was sought. Daily snow pillow data for portions of the study area are available beginning in 1965. Daily snow pillow information has been recorded remotely at the Saddle Mountain SNOTEL site in the upper Bitterroot since 1968. SNOTEL sites are administered by the USDA SCS Snow Survey. Data collected at SNOTEL sites includes max-min ambient air temperature and snow weight recorded in snow water equivalents (SWE). The Saddle Mountain SNOTEL site (elev. 2420 m) was chosen for the initial analysis because it has been in full operation since 1968 and because it is representative of the overall snow pattern in the upper Bitterroot (Phil Farnes, SCS Snow Survey supervisor (retired), Bozeman, pers. comm.). Long-term daily precipitation records from Gibbons Pass (elev. 2164 m) in conjunction with annual Snow Course measurements on Gibbons Pass (recorded on 1 January) were utilized in construction of a model of daily snow pillow chronology for 1953 to 1967. The model was constructed by Phil Farnes, hydrologist and SCS Snow Survey supervisor (retired). Snow pillow data were converted to approximate depth of snow on the ground (1 inch of water =10 inches of new snow).

Index of Winter Severity

A method for scaling weather severity based on analysis of the frequency distribution of weather variables across years is described by Farnes (1991). A frequency distribution of snow water equivalent measurements was constructed for 15-day intervals between 1 October and 1 January for each year. Normal probability analysis was used to calculate a probability of non-exceedence (PN) for each period. A normal probability analysis results in an arithmetic average = 50% probability. The following formula was then applied to the PN to arrive at each index of winter severity (IWS).

$$IWS = PN-50/12.25$$

Scaling by 12.25 compresses the range of 1% to 99% PN to a range of -4 to 4, with negative values being more severe and positive values less severe than average. All values of winter severity used in this study were calculated by Phil Farnes.

Severity index values for each 15-day IWS were tabularized and matched against hunting season dates for each year. Season dates varied from year to year, dependent on hunting season format (antlered bull, either-sex, etc.) For each year an average IWS for both hunting districts was then computed (Table 1.).

Daily IWS values were computed in an attempt to estimate the influence of daily winter severity. Unlike IWS values computed for 15-day periods, daily IWS values are not independent. Computation of independent IWS values for each day of the season across 37 years was not feasible. However, daily IWS values could be estimated from 15-day period IWS values. Daily IWS values were computed by interpolating between adjacent 15-day periods.

Table 1. Index of winter severity (IWS) values for 15-day intervals from 1953-1989. Most severe (-4) to least severe (+4) (Farnes 1991). Saddle Mountain SCS Snow Survey SNOTEL data, upper Bitterroot, Ravalli County, Montana.

Year	≤1 Oct	≤ 15 Oct	≤1 Nov	≤ 15 Nov	≤1 Dec	≤15 Dec	≤1 Jan
1953	4	-0.5	0.4	2	-2	-2.7	-1.6
1954	4	4	4	3.8	3.8	3.8	3.4
1955	-4	-4	-4	-4	-3.9	-3.8	-4
1956	4	0.9	-3.6	-1.1	-0.4	-3.7	-1.7
1957	4	-3.9	-3.1	-1.6	-0.2	0.6	-1.6
1958	4	1.7	2.4	-3.8	-3.7	-3	-0.3
1959	-3.2	-2.8	-0.3	0.6	-0.3	1.8	2.7
1960	4	-1.6	-1.7	-3.8	-3.7	-1.7	0
1961	-4	-1.6	-3.3	-2.3	-1.5	-0.5	-1.6
1962	4	-3.8	1.8	2.2	-1.6	-0.5	1.1
1963	4	4	1.6	-1.6	-0.3	1	0.7
1964	4	0.5	1.8	2	0.5	0.3	-3.9
1965	-3.7	4	4	2.7	2.7	3.3	3.4
1966	4	4	1.4	1.8	2	0.9	1.8
1967	4	0.9	-3.7	-2.4	-1.9	-0.8	-2.3
1968	4	-3.8	-1.6	-2.7	-1.1	-0.9	-2
1969	0.1	-2.8	0	1.2	2.7	2.8	2.5
1970	4	0	-2	0	-3.3	-3.2	-3.1
1971	-3.9	0.9	-1.5	0.6	1.1	-1.5	-1.3
1972	4	4	1.8	2.5	3.2	2	0.6
1973	4	4	-0.8	-2	-2.8	-2.5	-2.7
1974	4	4	4	2.2	2.7	2.9	1.6
1975	4	4	-3.8	-2.9	-3.8	-3.7	-3.2
1976	4	4	4	3.4	3.8	3.8	3.8
1977	4	4	2.5	2.4	-2	-4	-3.8
1978	4	4	4	2.1	2.4	1.1	0.8
1979	4	4	0	2.2	3.2	2.7	2.9
1980	4	0.5	-1.1	0.4	2.4	2.5	0.2
1981	4	-2.4	-0.3	1.8	0.2	-1.2	-1.4
1982	-3.9	-2.8	2	2.7	3.2	2.1	0.1
1983	4	0.5	4	2.4	1.4	1	1.6
1984	4	0.5	-1.5	-2.4	-2.3	-1	-1.5
1985	-2.4	-2.4	-1.6	-2.4	-1.1	1	2.5
1986	4	1.3	2.5	1.2	0.4	2.2	3
1987	4	4	4	3.4	3.8	2.8	2.9
1988	4	4	4	0	-2.2	-0.2	0.7
1989	4	4	2	-1.1	0.9	2.2	1.9

Road Construction

Detailed, long-term chronological information on road construction exists for the Bitterroot Forest. Ms. Lee Andrews, an engineering technician in the Bitterroot Supervisor's Office is responsible for compiling and preserving this exceptional historical record. This record facilitated compilation of a chronology of road status and miles of road constructed each year for each of the 17 analysis units. This road chronology includes all Forest Service roads, almost every county road, and many private roads in each analysis unit. Information on road closures was lost or incomplete prior to 1983. Therefore, analysis of the influence of road closures on elk vulnerability had to be abandoned.

Timber Harvest/Wildfire

Long term chronological information on timber harvest in the upper Bitterroot was obtained from records (timber stand history master lists) provided by each of the three Ranger Districts within the study area. Detailed records exist at three scales: timber compartment, subcompartment and stand. The management action taken (clear-cut, selection cut, pre-commercial thinning, etc.) and the total acres affected by the action were recorded for each stand. Stand information was compiled for each analysis unit. Percent of habitat affected was then calculated for each analysis unit and compiled for each hunting district. The percent of habitat affected is the total number of acres receiving a management action (type of logging) divided by the total acres in the analysis unit and then multiplied by 100 to produce a percent .

Two models were constructed to plot the percent habitat affected, one incorporating and one not incorporating a regeneration formula. The model with regeneration assumed hiding cover was regained 20-25 years after timber harvest. Since most timber harvests did not occur on a substantial scale prior to the mid-sixties, there was little difference between the results (percent habitat affected) generated by the two models. The structural component of certain types of hiding cover, such as canopy cover, tree height, and downfall cannot be regained in 20 years. Nor could the suitability of "regenerated stands" be validated empirically. Therefore, I will present results only from the linear "no-regeneration" model.

Statistical Methods

In a study with such a voluminous amount of data and many candidate variables, the opportunity to employ a wide array of statistical methods exists. However, I chose to concentrate on an examination of the pattern of the data as revealed through graphical presentation and where possible, to limit statistical analysis to simple descriptive statistics. Results from simple linear regression (using least squares regression) are presented throughout the text as a means to quantify the relationship between two variables. The percent of the variance explained (r^2) in several test results is quite low. I report these low r^2 results because I am interested in establishing: 1) the existence of a trend between two variables and 2) establish a basis to measure any variation in trends that occurred over time. A more detailed description of the statistical problems associated with the variables ultimately selected for principal components analysis (PCA) is presented immediately prior to a discussion on PCA. Statistical problems associated with the specific variables selected are discussed in the Results and Discussion section following the search and selection for dependent variables. PCA was conducted because the data incorporate an obvious time series trend and variables are not independent. All statistical analysis were conducted using Statview II™ (Abacus Concepts, Inc. 1990) .

RESULTS AND DISCUSSION

Number of Hunters and Success

Hunter success is a principal variable monitored at hunter check stations and is an obvious place to begin a broad examination of elk vulnerability. Figure 11 depicts the trend in hunter success in the upper Bitterroot since 1953. This trend is typical of the trend in elk hunting and hunter success in the northern Rocky Mountain region (Carpenter 1991, Leckenby et al. 1991, Leptich and Zager 1991). As number of hunters increases, hunter success declines. Changes in hunter success over time should be interpreted with caution with respect to elk vulnerability because hunter success (hunters/harvested elk) appears to capture most directly variance in number of hunters rather than changes in elk vulnerability. However, if the number of hunters is held constant, changes in the relationship between number of hunters and harvest success should relate to efficiency with which hunters kill elk. Number of hunters remained relatively comparable from 1953 to 1970. Following a period of substantial increase in number of hunters in the early 1970s, number of hunters plateaued in the 1980s (Fig. 9). Inflections in number of hunters in HD 270 in 1988 and 1989 are due to a change in the distribution of antlerless permits and do not relate to increased hunting pressure on bulls (John Firebaugh, FWP pers. comm.).

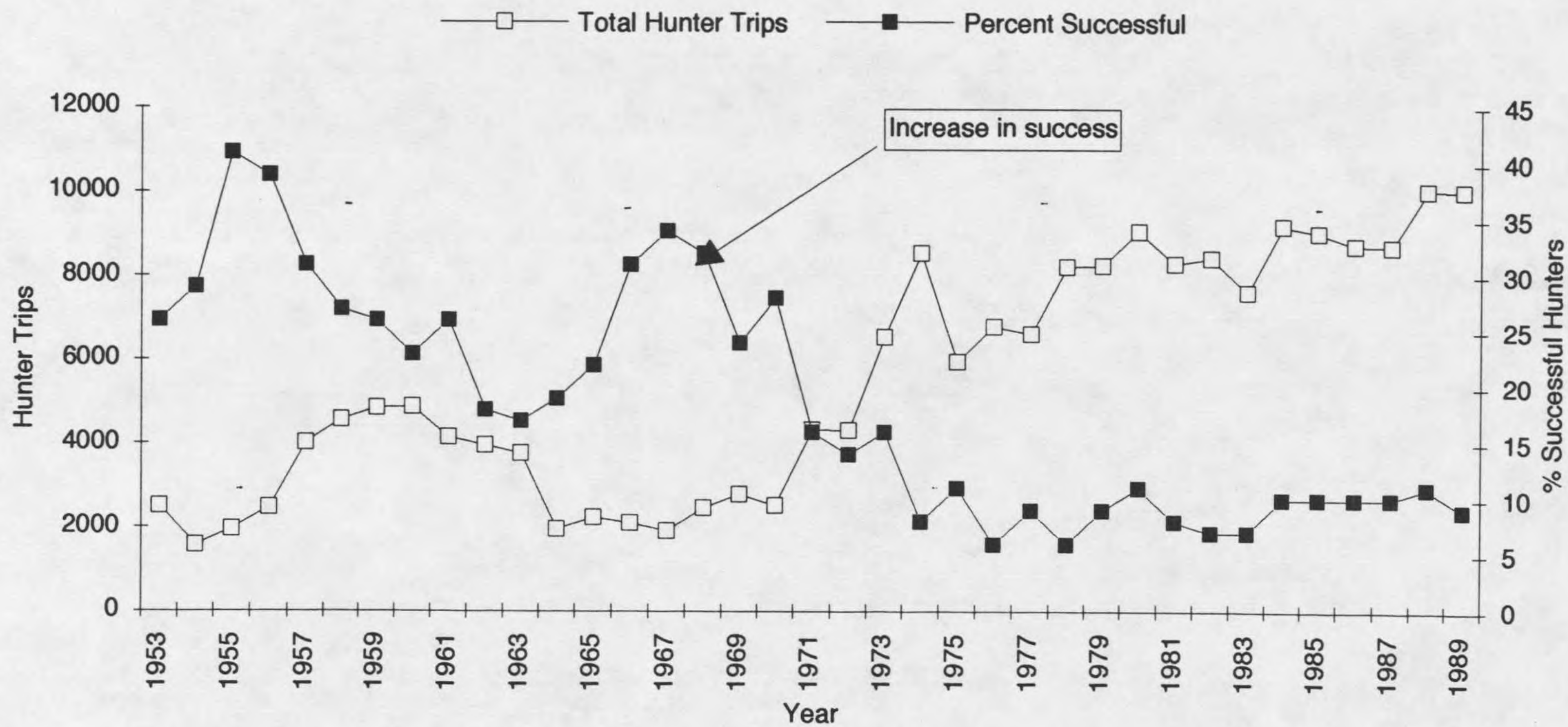

Figure 11. Trend in total hunter trips against percent successful hunters. Note increase in hunter success from 1966-1970. Darby check station results, upper Bitterroot, Ravalli Co., MT.

Insight into changes in hunter efficiency is directly related to elk vulnerability. Note that between 1964 and 1971 hunter success increased sharply, then declined during a period that number of hunters remained relatively constant (Fig. 11)

The pattern of hunter success is not particularly informative with respect to understanding changes in elk vulnerability because many underlying variables have influenced the shape and contour of this figure. Season length in the upper Bitterroot has been variable; bull seasons varied from 32 days to 108 days prior to 1981. Since 1981 antlered bull seasons have been 36 days long. The weather in the upper Bitterroot strongly influences the harvest in HD 270 where the elk population has a strong migratory component. (FWP Annual Pittman-Robertson Job Progress and Job Completion Reports, 1955-1989). Weather also influences elk harvest in HD 250, but to a lesser extent.

During the period 1978-89, number of hunters was largely stable; the elk population was either stable or increasing, but the average age of bulls checked at the Darby check station declined (Table 2). From 1982 to 1991 the average age of branch-antlered bulls checked from HD 250 declined from 4.0 to 3.5 years. During the same period, the average age of branch-antlered bulls from HD 270 declined from 3.9 to 3.3 years (Table 3). The number of yearling and sub-adult bulls in the harvest increased during this decade, reflecting increased recruitment (Fig. 8). However, survivorship to older age classes has obviously declined as indicated by the disappearance of older-aged bulls from the harvest and the absence of an upward trend in harvest of mature bulls despite a substantial increase in the population (Fig. 8).

Table 2. HD 250. Numbers of branch-antlered bull elk, by age, checked at Darby from 1982 to 1991. Upper Bitterroot Ravalli, Co., MT.

Age / Year	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Mean Age
1982	13	6	5	3	2	2	1	0	**4.03**
1983	12	6	1	4	1	2	0	0	**3.81**
1984	15	8	7	6	0	1	1	0	**3.84**
1985	14	7	5	2	4	1	0	1	**4.00**
1986	13	8	7	2	4	0	0	1	**3.96**
1987	13	6	6	3	1	0	0	0	**3.57**
1988	35	10	4	5	0	0	0	1	**3.23**
1989	22	16	5	1	2	1	0	0	**3.39**
1990	26	15	6	3	2	1	0	0	**3.42**
1991	33	15	13	5	2	0	1	0	**3.51**

Table 3. HD 270. Numbers of branch-antlered bull elk, by age, checked at Darby from 1982 to 1991. Upper Bitterroot Ravalli, Co., MT.

Age / Year	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Mean Age
1982	24	10	2	5	6	1	0	2	**3.94**
1983	22	8	9	4	2	1	0	0	**3.61**
1984	29	14	10	11	3	1	0	0	**3.74**
1985	22	6	9	2	2	1	0	0	**3.52**
1986	42	18	8	2	2	2	0	0	**3.28**
1987	20	8	4	2	3	0	0	1	**3.58**
1988	43	31	14	8	0	1	1	1	**3.52**
1989	36	9	6	2	1	0	2	1	**3.38**
1990	56	18	16	2	2	0	1	0	**3.24**
1991	57	17	14	7	0	1	0	1	**3.30**

Trend in First Week Hunter Success

Figures 12 and 13 depict the trend in hunter success during the first seven days of the general elk season in HD 250 and HD 270. This ratio is derived from total numbers of antlered bulls checked during the first seven days of the season against total unsuccessful hunters censused through the Darby check station. As discussed previously, success declines as the number hunters increase, provided that number of elk available remain relatively constant. If the elk numbers were to increase by the same proportion as hunters, then success would remain unchanged. A precipitous decline in first-week success occurs in both hunting districts in the late sixties and early seventies. Because the number of unsuccessful hunters tallied at Darby increased in 1973 as a result of a law change, the data set must be split in two at 1973. When data prior to 1973 are compared for both hunting districts and data after 1973 are compared for both hunting districts, the number of unsuccessful hunters is comparable.

The decline in success in HD 250 occurs prior to corresponding increases in number of hunters in 1973 (Fig. 12). Following the sharp decline in success, hunter success in HD 250 remained relatively uniform around 3.5% (SD = .71). The relationship between number of hunters and the antlered bull harvest in the first week is not significant for the period 1953-1972, but is significant for the period 1973-1989 (r^2 =.26, n=33, P=.033, linear regression). Prior to 1973, adding more hunters in the first week of the season did not increase the harvest in HD 250. After 1973, the number of elk harvested in the first week was significantly correlated with number of hunters.

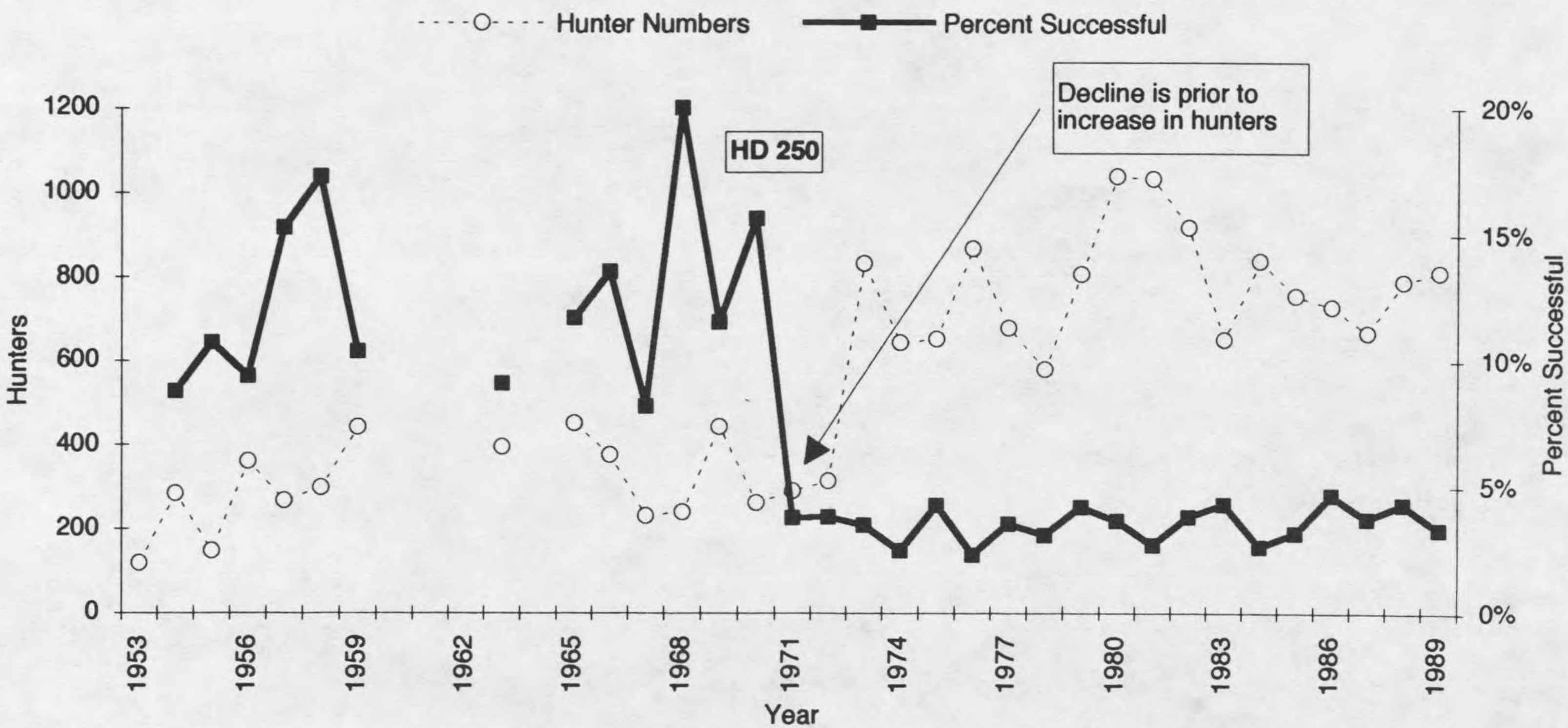

Figure 12. HD 250. Trend in success of elk hunters versus trend in number of hunters during the first seven days of the the general season, 1953-1989. Darby check station results, upper Bitterroot, Ravalli Co., MT.

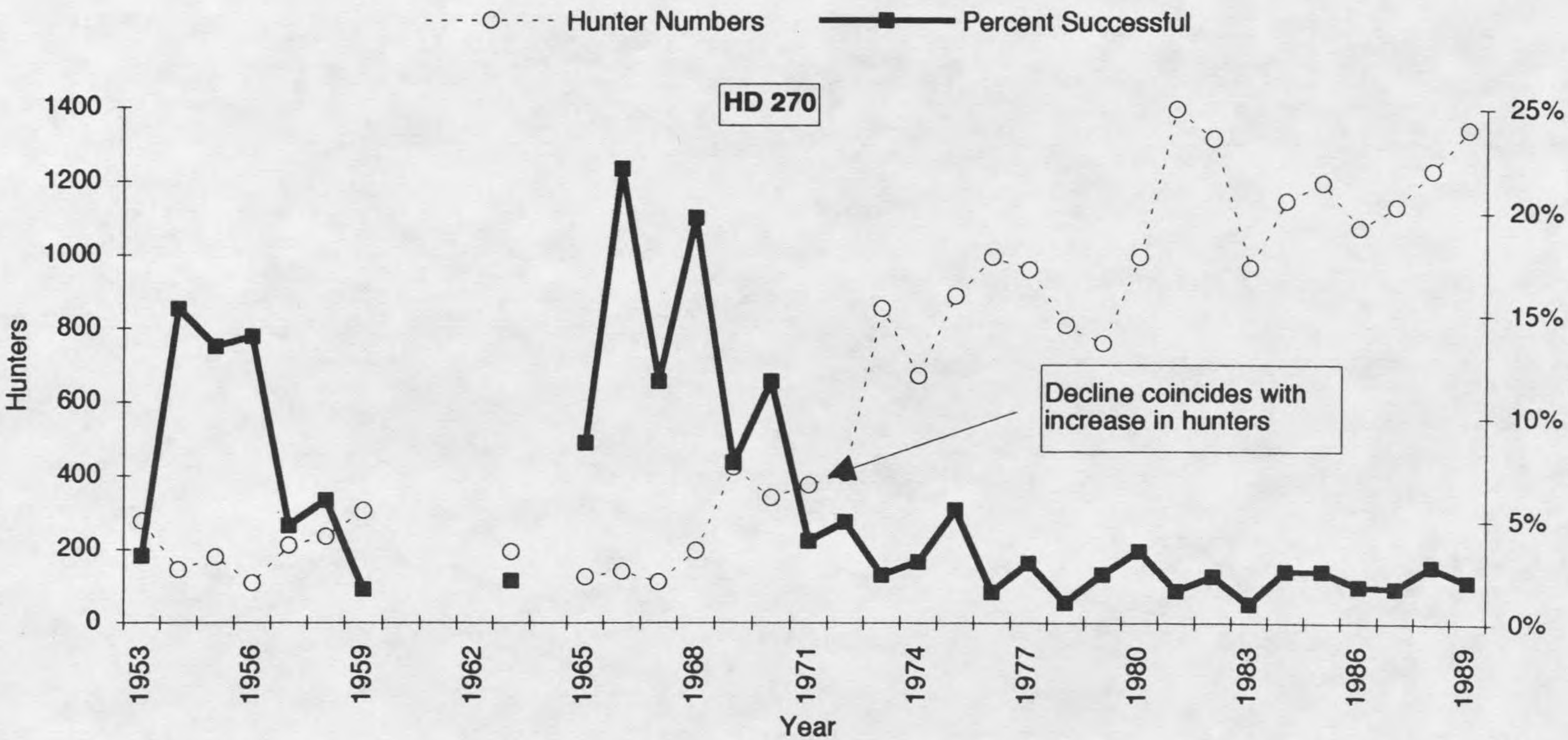

Figure 13. HD 270. Trend in success of elk hunters versus trend in number of hunters during the first seven days of the the general season, 1953-1989. Darby check station results, upper Bitterroot, Ravalli Co., MT.

In HD 250, weather does not appear to have been a factor in the low 1971 success rate. Opening day weather in 1971 was average with respect to the winter severity (IWS = .62); however, weather factors (IWS = 3.09) may have contributed to poor opening week success in 1972 (FWP Job Progress Report, 1973). As weather is less important in HD 250 than in HD 270, it remains unclear why hunter success fell so dramatically in 1971 following high success in the previous five years. One plausible explanation is that antlered bulls were less available as a result of substantial harvests during the previous five years.

During the period 1953-72 in HD 270, declines in hunter success correspond with increases in number of hunters (Fig 13). The relationship between number of hunters and antlered bull harvest during the first week is not significant for either period. Hunter success exhibits greater variability in HD 270 than observed in HD 250 (mean = 2.3%, SD 1.07). The greater variance in hunter success is likely due to the greater influence of weather in HD 270. Adding more hunters opening week did not influence the kill. Weather appears to be more important than number of hunters in determining elk vulnerability in HD 270. A detailed discussion of the influence of weather in HD 270 is discussed later (see Discussion on Weather and Elk Vulnerability).

Trend in Distribution of the Harvest

As long as the number of available elk is not drastically exceeded by number of hunters, a strong, functional relationship between number of hunters and elk harvest is clearly indicative of high elk vulnerability. In such circumstances wildlife managers have historically addressed vulnerability by instituting closely regulated hunts designed to restrict severely the number of hunters. However, there may be circumstances where the total harvest is largely independent of number of hunters. In such cases, other variables such as season length, weather, changes in habitat, access, trajectory of the elk population, and hunter behavior would be expected to influence elk vulnerability. Identification of the most critical variable(s) is contingent on the presence and recognition of a pattern in the distribution of harvest.

Mohler and Toweill (1982) provide examples of distribution of the percentage and composition of elk harvest by week of season for management areas with different levels of access. Harvest distribution is shown to be a function of season length and hunter access. In areas with high levels of access and short seasons, the distribution of the harvest is heavily skewed toward the first few days of the season and exhibits a pattern of exponential decay. Conversely, in areas where access is low and season length is long, more uniform distribution of the harvest over time is evident.

HD 250 Harvest Distribution

Season length appears to influence the shape of the frequency histogram for the harvest in both hunting districts. The very longest either-sex seasons (85 to 101 days) exhibited a more uniform distribution "kill" , as exhibited in 1959 (Fig. 14). However, for seasons as long as 58 days, the harvest pattern can change notably. For example, the pattern of the harvest in

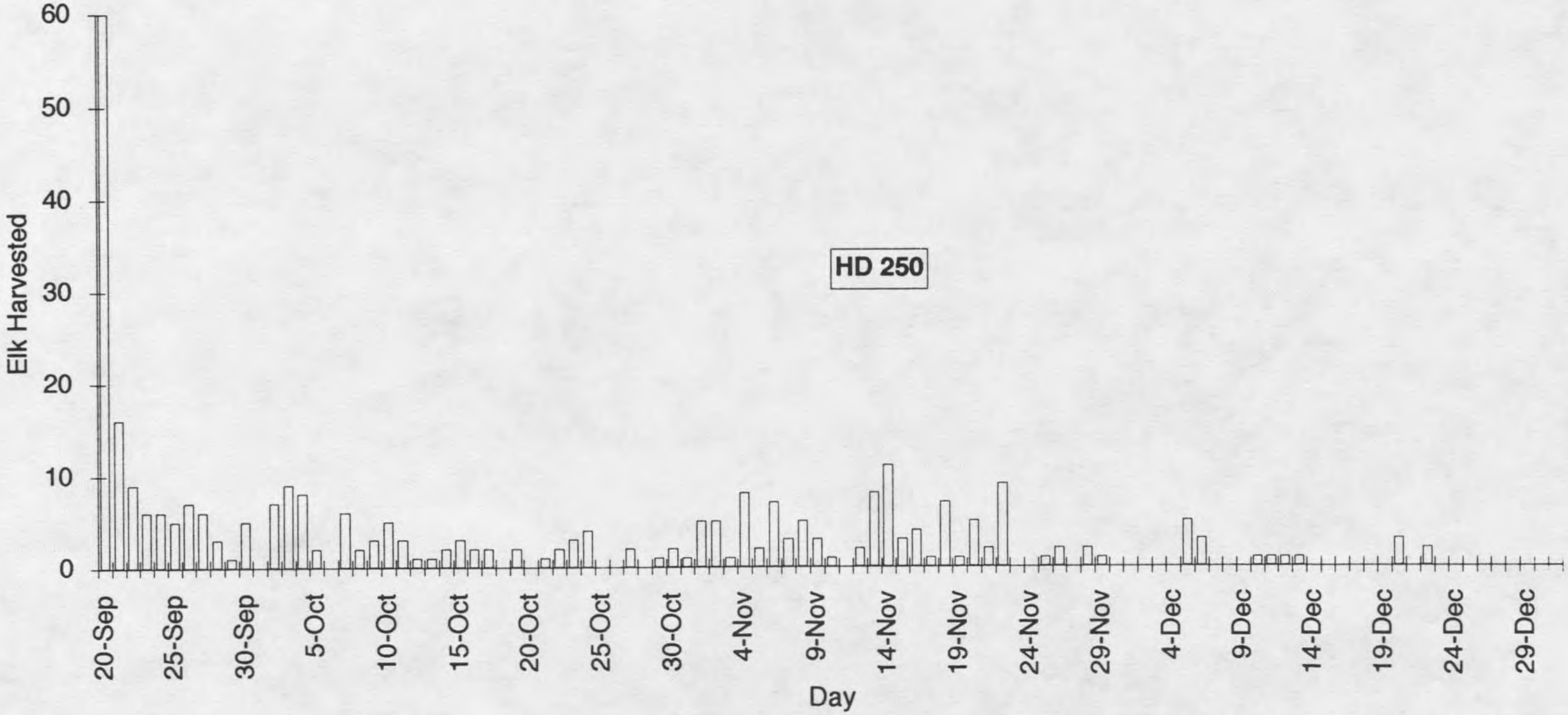

Figure 14. Frequency histogram of elk harvest in HD 250 in 1959. Darby check station results. Upper Bitterroot, Ravalli Co., MT.

1966 (Fig. 15) was an exponential decay skewed toward the opening week. The following year, 1967, the harvest remained relatively uniform throughout the season (Fig. 15). Both 1966 and 1967 had 58-day either-sex elk seasons. The difference in the distribution of the harvest may be attributed to different weather between 1966 and 1967. Weather conditions during the 1966 hunting season were mild while 1967 was more severe, perhaps resulting in a more uniform harvest that year. Despite increasing road densities, logging, and number of hunters, the pattern of elk harvest in HD 250 showed no clear trend over time.

HD 270 Harvest Distribution

In contrast to HD 250, hunting district 270 exhibited an inverse trend during the period of analysis. Figure 16 is a representative sample of the kind of harvest distributions observed among years in HD 270. Most years exhibit one of two shapes: uniform, or skewed toward the end of the season. The fact that the kill is heavily skewed to the latter part of the season in HD 270 indicates that elk became easier to kill later in the season. This observation is consistent with the hypothesis that weather (snow) may be an important variable in HD 270 in affecting vulnerability. If snow conditions forced elk from high elevation, secure habitats to more accessible, fragmented areas, then corresponding increases in the harvest would be expected. The pattern of the harvest suggests that elk remain relatively secure early in the season most years in HD 270. As is the case in HD 250, no clear trend in the distribution of the harvest occurred over time.

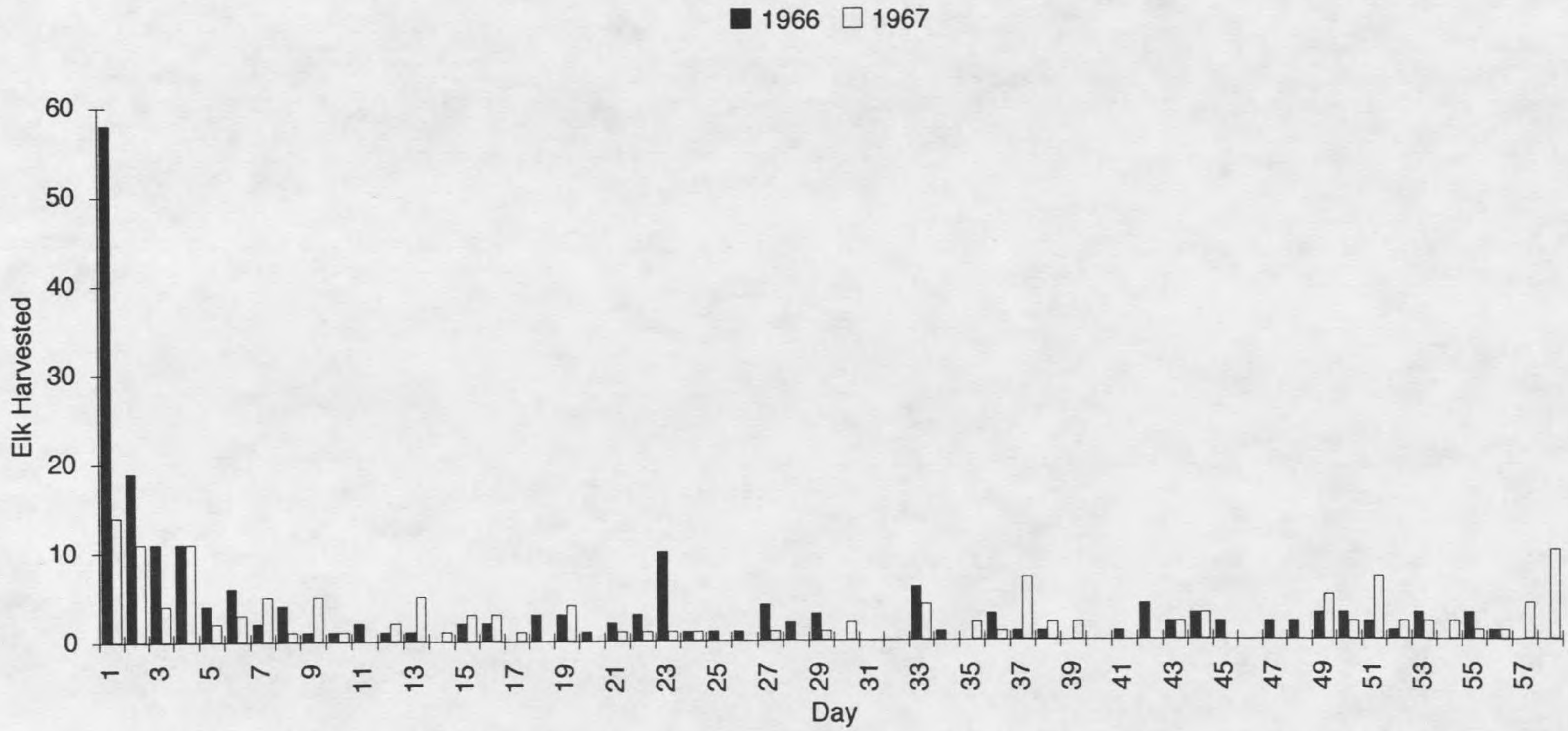

Figure 15. Comparison of distribution of elk harvest by day of season in HD 250 between years 1966 and 1967. Darby check station results, upper Bitterroot, Ravalli Co., MT.

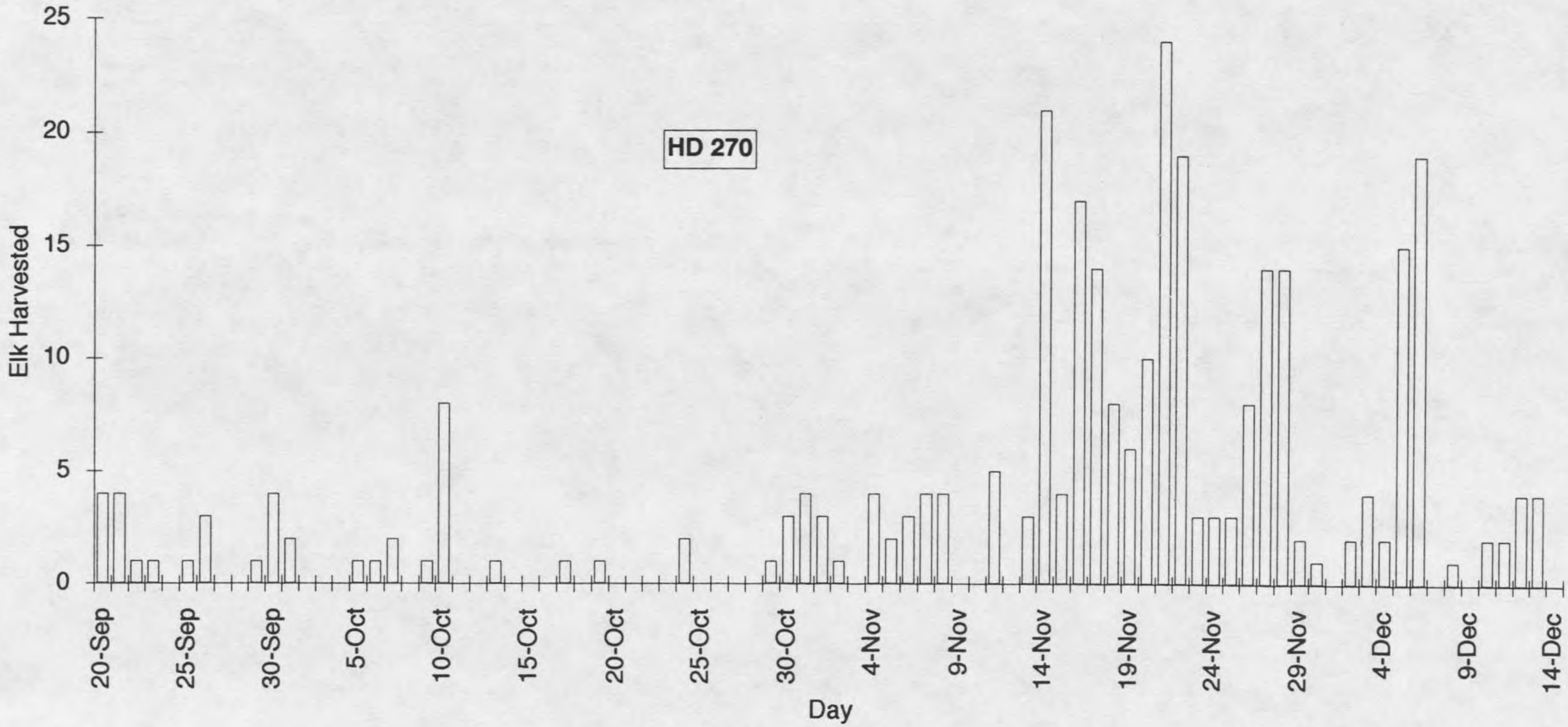

Figure 16. Frequency histogram of elk harvest in HD 270 in 1959. Darby check station results. Upper Bitterroot, Ravalli Co., MT.

Discussion of Opening Day Effect

Opening day of the hunting season is generally regarded as a period of high elk vulnerability, but little attention has been directed at determining the significance of changes in opening day harvest as an index to elk vulnerability. If the opening day harvest constitutes a substantial proportion of the total harvest, then one can assume the existence of an opening day effect. Opening day effect (large proportion of the harvest occurring opening day) is a phenomenon that managers have sought to reduce by adjusting season opening dates to limit hunter participation. Mohler and Toweill (1982) note that many states have experimented with changing opening day from a weekend to a weekday. They showed that in Idaho and Washington, weekday opening days reduced hunter participation by 20% and 30%, respectively. In the upper Bitterroot, weekend opening days predominate (33 of 37 years). General seasons opened on weekdays in 1953, 1954, 1956 and 1983.

While opening day effect is well-recognized with respect to its impact on the annual harvest, it is unclear how opening day harvest relates to vulnerability. In the upper Bitterroot, opening day effect is not a function of season length. When the percent of the total harvest occurring on opening day is regressed against season length, the percent of variance explained is low (HD 250: $r^2 = .03$, n=37, P= .27; HD 270 $r^2 = .05$, n=37, P =.12). However, there is a relationship between opening day effect and the percent of hunting pressure (total general season hunter trips) occurring on opening day (HD 250: $r^2 = 0.24$, n=33, P=0.003; HD 270: $r^2 = 0.41$, n=33 P= 0.0001). The regression in HD 270 is strongly influenced by three obvious outliers:1966, 1969, and 1970. These years are notable in that they coincide with the period of peak road construction. The weather severity indices for these years are average to mild, suggesting weather was not an important factor in the large opening day effects. If these years are excluded from the regression the result is not significant ($r^2 = .10$, n=30, P=.08). This result is consistent with previous findings suggesting that elk harvest in HD 270 tends to be independent of number of hunters early in the season because elk vulnerability is a function of weather conditions.

Picton (1991) suggests that elk are more vulnerable opening day because they have not acclimated to the increased disturbance. Coop (1973) found elk shift to dense stands of timber during the first two weeks of the hunting season. Irwin and Peek (1983) found elk selected dense, pole-sized timber stands and exhibited less variation in habitat use within home ranges during autumn. Lyon and Canfield (1991) found evidence for different behavioral strategies based on availability of adequate security. Average daily movement of about half the elk monitored by Lyon and Canfield (1991) increased when hunting season started while the remainder either maintained or dramatically constricted daily movement distance in response to hunting pressure. Increased movement by elk was interpreted as a consequence of lack of adequate security. In general, elk responded to hunters by moving to large, continuous forest communities (Lyon and Canfield 1991).

Based on the premise that elk are vulnerable on opening day because they have not adjusted to secure habitats or altered behavior to reduce encounters with hunters, it seems reasonable to argue that a substantial opening day effect must be related to habitat variables and number of hunters. This argument is supported by the frequency and magnitude of differences in opening day effect between HD 250 and HD 270. In an attempt to quantify opening day effect, I shall arbitrarily define opening day effect as being present if $\geq$ 10% the total general-season harvest (either-sex season from 1953-1980; antlered bull season from 1981-1989) occurs on the first day of the season. Opening effect will be defined as "large" if $\geq$ 25% of the harvest occurs on the first day of the season. In 35 of 37 years, opening day harvest in HD 250 comprised at least 10% of the general season harvest and in 8 of 37 years, opening day harvest exceeded 25% of the general season harvest. In HD 270 there have been fewer years with a detectable opening day effect (13 of 37 years opening day harvest $\geq$10% of the general season harvest). Opening day harvest in HD 270 comprised 25% of the general harvest in only one year (1969). Opening day effect in HD 270 was expressed only sporadically and was less related to hunting pressure than is the case in HD 250.

There are four years in which opening day in HD 270 was 14 to 30 days later than in HD 250 (1954, 1956, 1965,1966). I examined the possibility that staggered opening dates between the two hunting districts were responsible for suppression of opening day effect in HD 270. The season opened on a Friday in 1954 and a Monday in 1956, so it is difficult to separate the weekday influence from the delayed opening date. However, opening day for HD 270 occurred on a Sunday in 1965 and 1966 with 11% and 18.75% respectively of the total either-sex harvest occurring. These results are comparable with opening day effects from immediately preceding years, suggesting that staggered opening dates did not reduce opening day effect in HD 270. The absence of an opening day effect for most years suggests that elk in HD 270 generally experience a relatively high level of security in the early part of the season.

If a large opening day effect relates to elk vulnerability, then opening day effects should correlate with one or more of the variables known to increase elk vulnerability. Roads and logging have been shown to increase elk vulnerability (Christensen et al. 1991). In HD 250, four of the eight years with the largest opening day effects occurred in the mid-to-late 1960s. Weather conditions were not a factor during years in the late 1960s (opening day IWS values: 1966= + 4, 1967 = + 4, 1968 = + 4, 1969 = + 1.08). Weather was responsible for the opening day effect in 1955, with the most severe weather on record for opening day (IWS = - 4). Short general either-sex seasons (15 days) accounted for opening day effect in 1979 and 1980. The large opening day effect in 1982 may be partially due to weather (IWS = -.26 opening day), but is otherwise unexplained.

In HD 270, opening day harvest exceeded 15% of the total general season harvest in 4 of 37 years: 1964, 1966, 1969, 1970. Opening day weather (IWS = -.35) and short general season length (22 days) may account for the opening day effect in 1970. However, the three years in the 1960s had milder than normal opening day weather and season length was $\geq$ 36 days.

Section Summary

After consideration of the influence of weather and season length on opening day effect, the years with the greatest opening day effect fall into the interval of peak of road construction and logging in the upper Bitterroot, in both HD 250 and 270.

Opening Week Effect

Another way to present the distribution of the harvest is to plot the percentage of the total kill which occurs in the first week of the season (Fig. 17). Lonner and Cada (1982) found that a strong relationship exists between hiding cover, road densities, and the harvest rate during the first week of the general hunting season. Figure 17 is not particularly informative with respect to trend in vulnerability for either hunting district. However, note that both hunting districts demonstrate a similar pattern (Spearman Rank Correlation, $r_S = .557$, n=37, P=0.0008). The proportion of the bull harvest during the first week is consistently greater in HD 250 than in HD 270. Season lengths have varied greatly in both hunting districts, and Figures 18 and 19 illustrate the relationship between season length and the percent of harvest during the first week. Note that from 1956 to 1963 the percent of the harvest occurring in the first week is inversely related to season length in HD 270 (where weather factors are more important) but not in HD 250 (where weather is less important). The variance in the kill is much greater in HD 270. To compare variation between hunting districts, I chose to use the coefficient of variation (c.v.) which is computed as the ratio of the standard deviation to the mean multiplied by 100. This coefficient is independent of the unit of measurement. In HD 270, the coefficient of variation was = 46.8% while in HD 250, it was = 21.2%). Season length remained at 36 days after 1973 (except 1980, which was 43 days). During the period that season length is constant, neither hunting district exhibited a discernable trend in the proportion of bulls harvested in the first week.. Number of hunters remained relatively

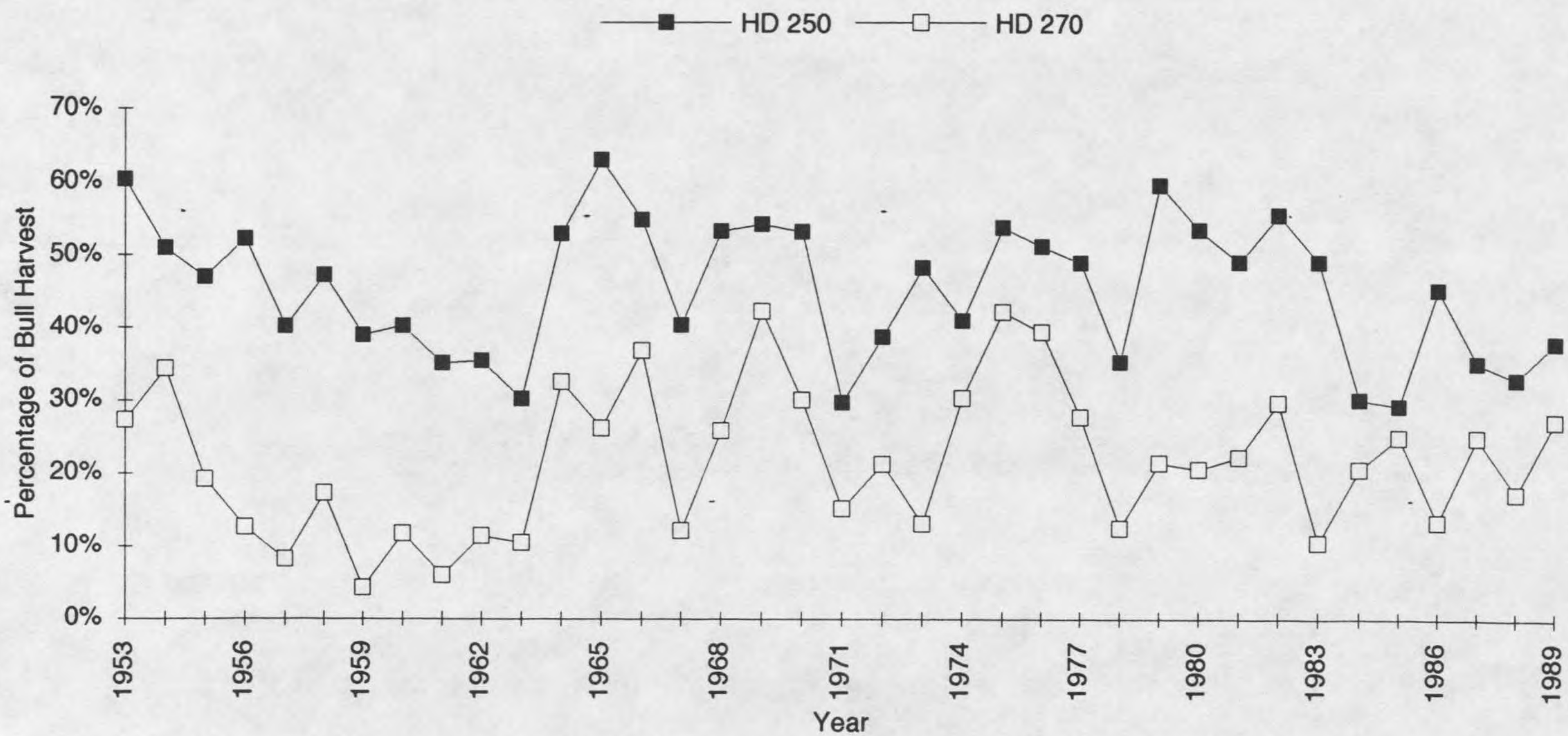

Figure 17. Comparison between HD 250 and HD 270 in percentage of antlered bull harvest (general season) occurring in first seven days of season. Darby check station results. Upper Bitterroot, Ravalli Co., MT.

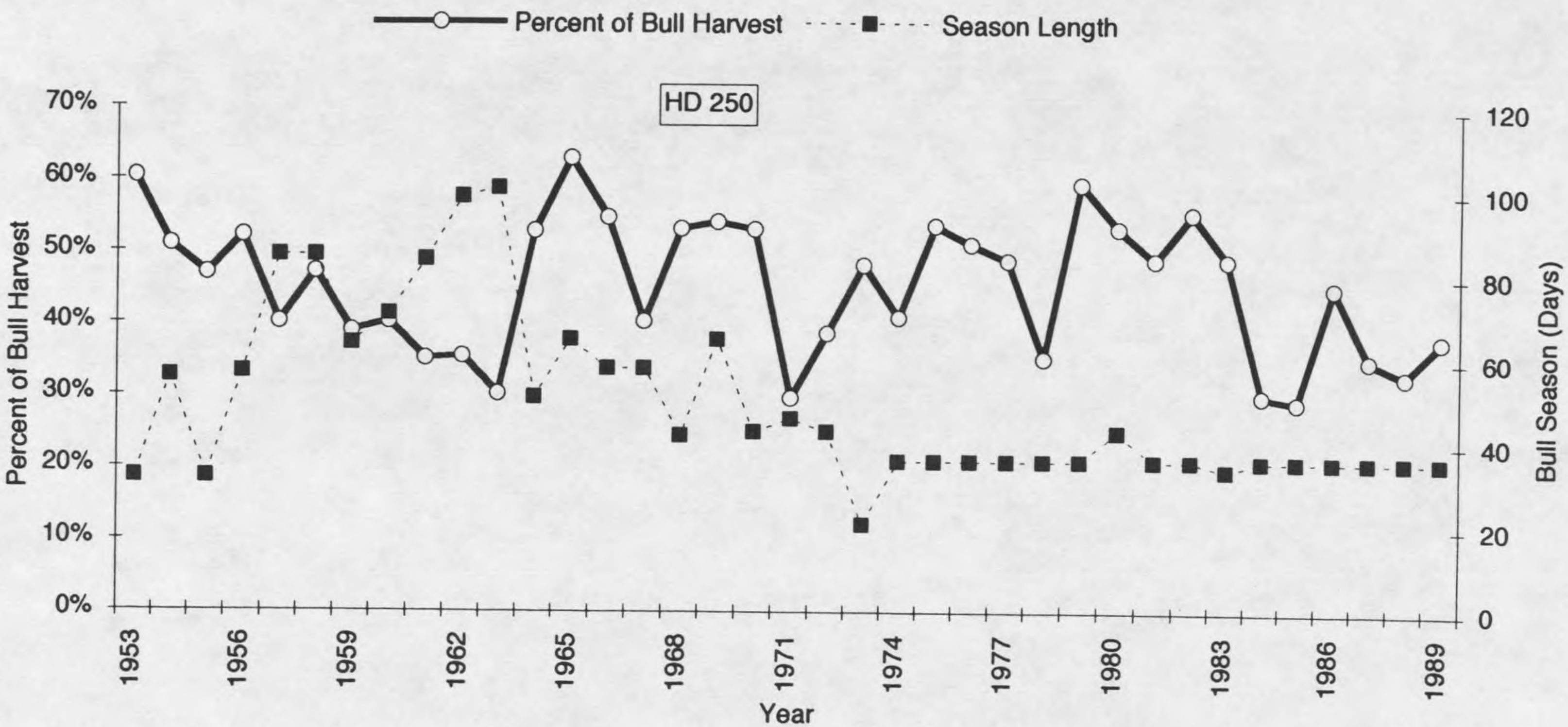

Figure 18. HD 250. Comparison between percent of total general season antlered bull harvest occurring in first seven days of season and length of general bull season. Darby check station results, upper Bitterroot, Ravalli Co., MT.

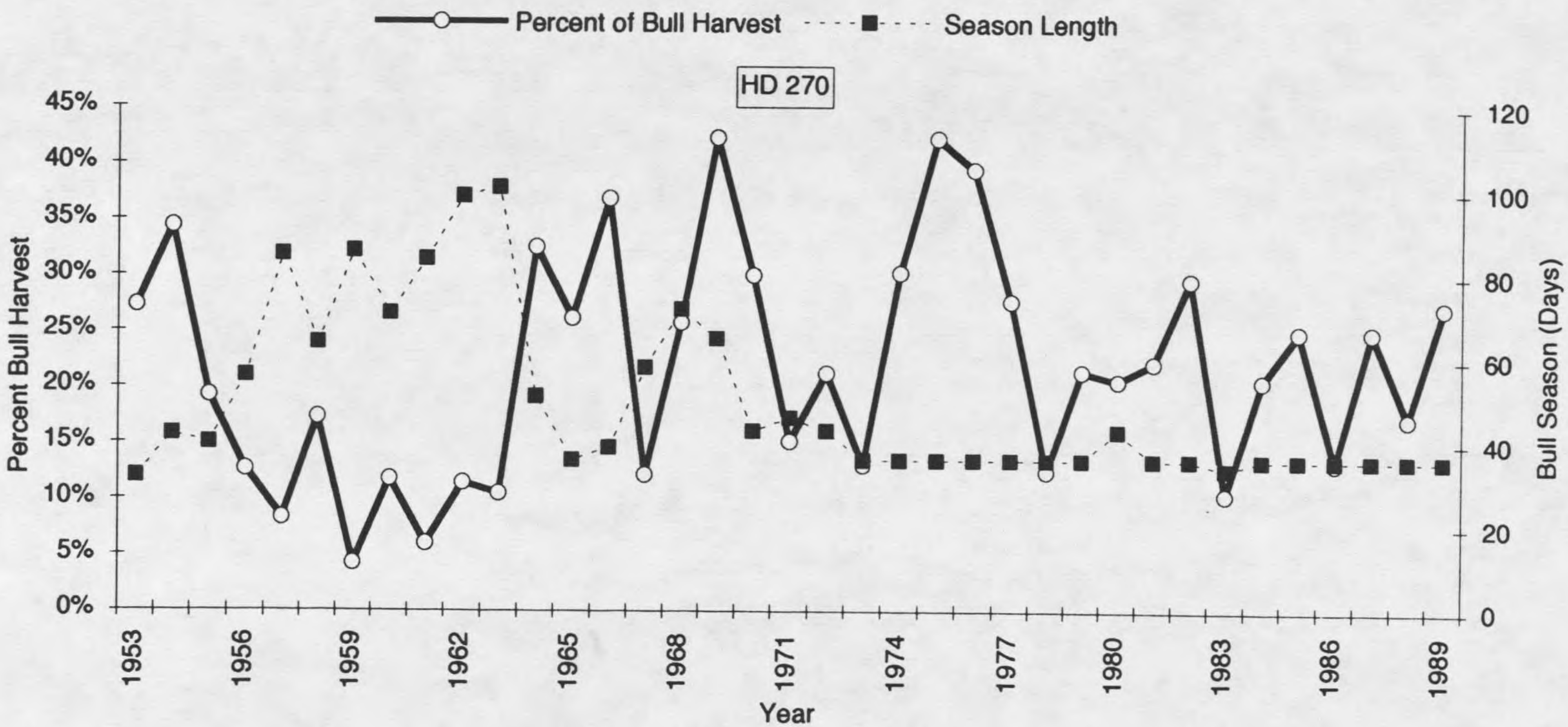

Figure 19. HD 270. Comparison between percent of total general season antlered bull harvest occurring in first seven days of season and length of the general bull season. Darby check station results, upper Bitterroot, Ravalli Co., MT.

comparable from 1953 to 1970 but increased sharply subsequent to 1970 in both hunting districts (Figs. 9 and 11). Note that during the period that season length was constant in HD 270 (1971-1989) the percentage of the kill occurring in the first week is quite variable and does not track trend in number of hunters (Figs. 11 and 19)

Interpretation of trends in harvest during the first week of the season is confounded by correlation with other variables, including season length, number of hunters and weather. A partial correlation matrix of selected variables for HD 250 and HD 270 allows insight into how these variables relate (Tables 4 and 5). In HD 270, season length has the highest partial correlation coefficient (-0.431) with percent of kill occurring in the first week. In HD 250, however, number of hunters correlates highest with kill (0.334). Weather is next in greatest partial correlation coefficient in HD 270 (0.360) but not in HD 250, where season length is next in greatest partial correlation coefficient (-0.120). The disparity between the two hunting districts in the importance of weather is also supported by the partial correlation coefficient between opening day weather severity and number of hunters during the first week (HD 270 = -0.410; HD 250 = -0.123) (Tables 4 and 5).

Table 4. HD 250. Table of partial correlation coefficients of selected harvest variables. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	Hunters in 7 days	Total kill	% kill in 7 days	Season Length	Winter Sev.
Year	0.7393					
Hunters in 7 days	0.6549	0.6439				
Total kill	0.2436	0.1029	0.5254			
% kill in 7 days	-0.5015	**0.3344**	0.0371	0.28		
Season Length	-0.4602	-0.0999	0.703	**-0.2107**	0.7222	
Winter Severity	0.2208	**-0.1232**	-0.1092	**-0.0072**	0.2914	0.1494

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 5. HD 270. Table of partial correlation coefficients of selected harvest variables. Darby check station results, upper Bitterroot, Ravalli County, MT

	Year	Hunters in 7 days	Total kill	% kill in 7 days	Season Length	Winter Sev.
Year	0.8422					
Hunters in 7 days	0.8452	0.8233				
Total kill	0.4562	-0.262	0.5938			
% kill in 7 days	-0.3644	**0.1806**	0.6884	0.5658		
Season Length	-0.2172	-0.1103	0.2147	**-0.431**	0.4812	
Winter Severity	0.5044	**-0.4104**	-0.4538	**0.3603**	0.2808	0.3588

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Section Summary

In HD 250, there is a lower coefficient of variation in the percentage of antlered bulls harvested in the first week than in HD 270. Number of hunters and season length yield the highest partial correlation coefficients with the proportion of antlered bulls harvested the first week. In HD 270, the coefficient of variation for the percentage of antlered bulls harvested in the first week is twice that of HD 250. Season length and weather yield the highest partial correlation coefficients with the proportion of antlered bulls harvested the first week. Season length is important because longer seasons allow weather factors to force elk to lower elevations. Variation in the harvest and reduced importance of number of hunters is consistent with previous indications of the low levels of elk vulnerability in HD 270, in the absence of weather influences.

Hunter Efficiency and Elk Vulnerability

A strong, functional relationship between number of hunters and hunter harvest is indicative of a high level of hunter efficiency and is arguably a measure of elk vulnerability. Vales et al. (1991) examined vulnerability for two heavily exploited elk populations in northeastern Oregon. Intensive timber management occurred in both management units, which are characterized by gentle topography and relatively open habitats throughout. Road density varies from 2.5 to 5.0 km/km^2 (4.02 mi/mi^2 and 8.0 mi/mi^2). The authors found that the hunter success rate (estimated harvest/ estimated number of hunters) in the combined units was related to the hunter/elk ratio in a negative exponential form (P<0.001, r^2=0.71). These results indicate that in open habitats where habitat security variables have been substantially compromised, elk vulnerability is solely a function of number of hunters and available elk.

In the case of the upper Bitterroot data, comparison of the relationship between number of hunters and the harvest among all four decades is confounded by increases in number of hunters during the 1970s. For the first two decades, however, the number of hunters was roughly constant, and data collection methods were comparable. If elk became more vulnerable to hunters in the sixties - the period of maximum roading and logging - then the relationship between number of hunters and the elk harvest should become stronger. Such a strong linear relationship begins to break down once the system becomes saturated with hunters. Saturation occurs when further increases in the number of hunters does not result in a corresponding increase in the elk harvest. Vales et al. (1991) found that in highly vulnerable populations the number of animals available pre-hunt is sometimes a better predictor of the harvest than number of hunters. They also found that reducing the number of hunters may simply increase hunter success rather than increase elk survivorship. As elk become easier to kill, hunter success will increase proportionally until a hunter saturation threshold is reached. The correlation begins to break down at the point when adding more hunters to the system no longer affects the total harvest. In addition to a stronger correlation between number of hunters and the harvest, we might expect the slope of the regression line between daily number of hunters and the harvest to increase as success increases.

There are several obvious limitations to using the trend in the correlation between number of hunters and the harvest to examine trend in elk vulnerability. Opening day effect is evident for both hunting districts, but is most pronounced in HD 250. The regression between number of hunters and the kill will typically be strongly influenced by an opening day effect. In HD 250, for example, the adjusted r^2 between daily harvest and number of hunters in September and October of 1958 reduces from $r^2 = 0.70$ to $r^2 = 0.007$ when the first two days of the hunting season are excluded from the regression (n= 41 and 39). The tendency for the opening two days to be outliers in the regression poses a dilemma. Is the exclusion of the first two days of the season likely to increase or to reduce the information contained in the regression?

Opening day effect in the Bitterroot coincides with one or more variables: 1) severe snow conditions 2) short general seasons and 3) peak roading and logging. This pattern of occurrence suggests that opening day effect is a measure of vulnerability. However, opening day effect may not relate to vulnerability two days later in the season - after elk have made the behavioral transition to hunters by moving to more secure habitats and reducing movements to reduce encounters with hunters. Thus, it seems that while the opening days are comparable from year to year, they should not be included in an analysis of the daily pattern of the harvest. Inclusion of opening day in analysis of the daily harvest rate confounds interpretation because of mixing two different behavioral strategies in one regression equation.

Weather conditions can increase or reduce elk vulnerability. Weather influence is observable in the pattern between hunters and the harvest. During the first decade, the relationship between the kill and number of hunters in both hunting districts tended to become linear when weather conditions became severe. Figure 20 illustrates how the pattern between the

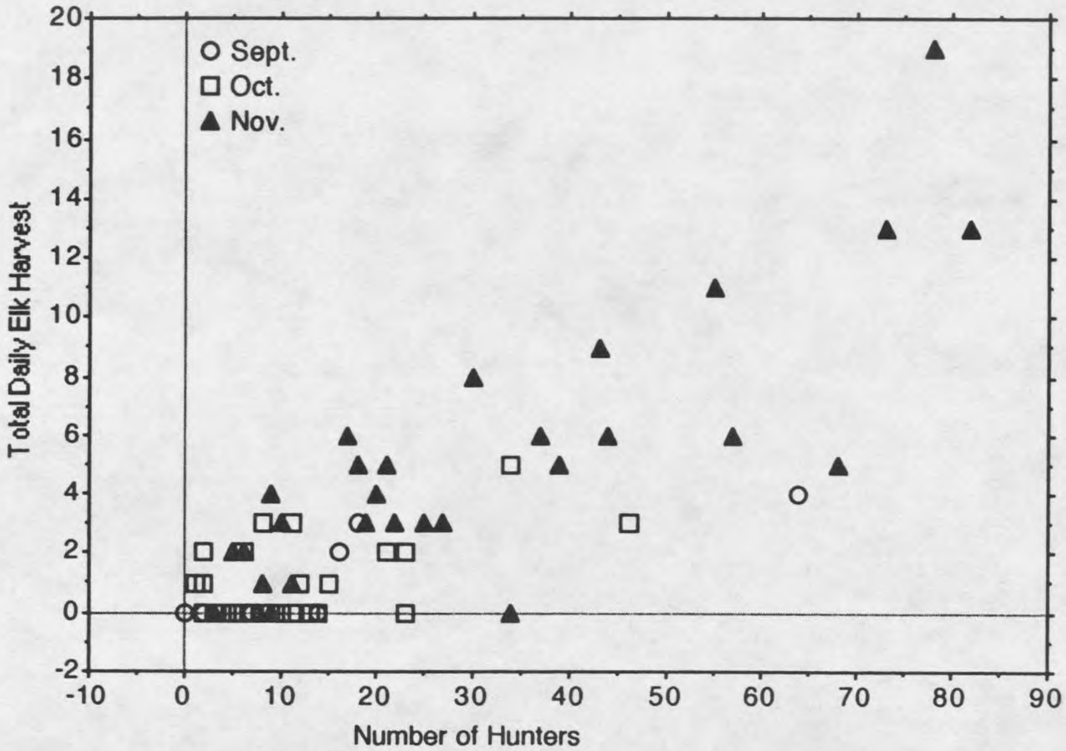

Figure 20. HD 270. Trend in the relationship between the daily elk harvest and daily unsuccessful hunter numbers by month for 1958 (opening 2 days of season excluded). Note increasingly linear relationship between daily number of hunters and daily elk harvest in latter portion (November) of hunting season. Darby check station results, upper Bitterroot, Ravalli Co., MT.

daily elk harvest and number of hunters becomes linear in the latter part of the season. Not all years demonstrate such a pattern, and weather severity indices do not completely explain the exceptions. The particularly strong relationship between number of hunters and daily kill observed in Figure 20 is likely the result of elk migration to lower elevations where vulnerability is increased. The winter severity index for November of 1958 was -3.8. Examination of pattern of accumulated snow depth versus accumulated kill for both hunting districts across all years, further illustrates the influence of snow on the harvest rate (Figs. 21-24).

The severest weather years in the first two decades occurred in 1955 and 1967. The correlation between daily number of hunters and harvest in HD 250 increased substantially in 1967 over that in 1955 (1955: $r^2 = 0.006$, n= 30, P=.68 ; 1967: $r^2 = 0.17$, n=60, P=.0006). The first two days of the season are excluded from the regression to exclude opening day effect. In HD 270, the correlation coefficient for 1967 was also higher than that in 1955 (1955: $r^2 = 0.220$, n=40, P=.002 ; 1967: $r^2 = 0.265$, n=54, P=.0001). This result is consistent with the hypothesis that hunters became more efficient in the latter part of the second decade, following peak roading and logging. However, more evidence is needed as comparison between two years hardly constitutes a trend.

Results of comparisons of the daily number of hunters and harvest rate for mild years during the first two decades are inconclusive. The years 1954, 1956, 1958, 1965, 1966, 1969 had comparably mild/average weather during October (Table 1). When daily number of hunters and harvest are pooled for the respective decades, and the opening two days of the season excluded, the regression coefficients for HD 250 are comparable between

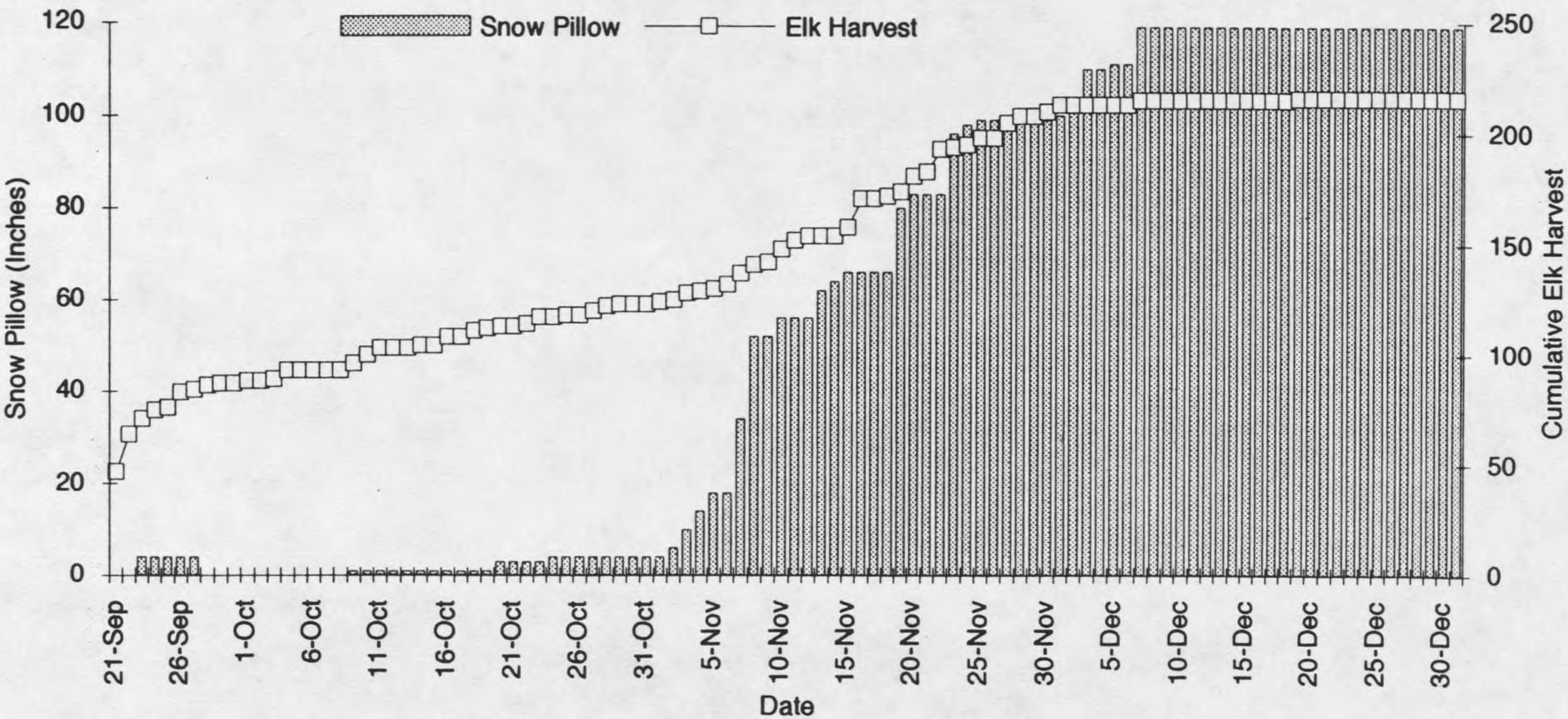

Figure 21. HD 250. Plot of the 1958 accumulated daily elk harvest against the accumulated Saddle Mountain snow pillow, upper Bitterroot, Ravalli Co., MT.

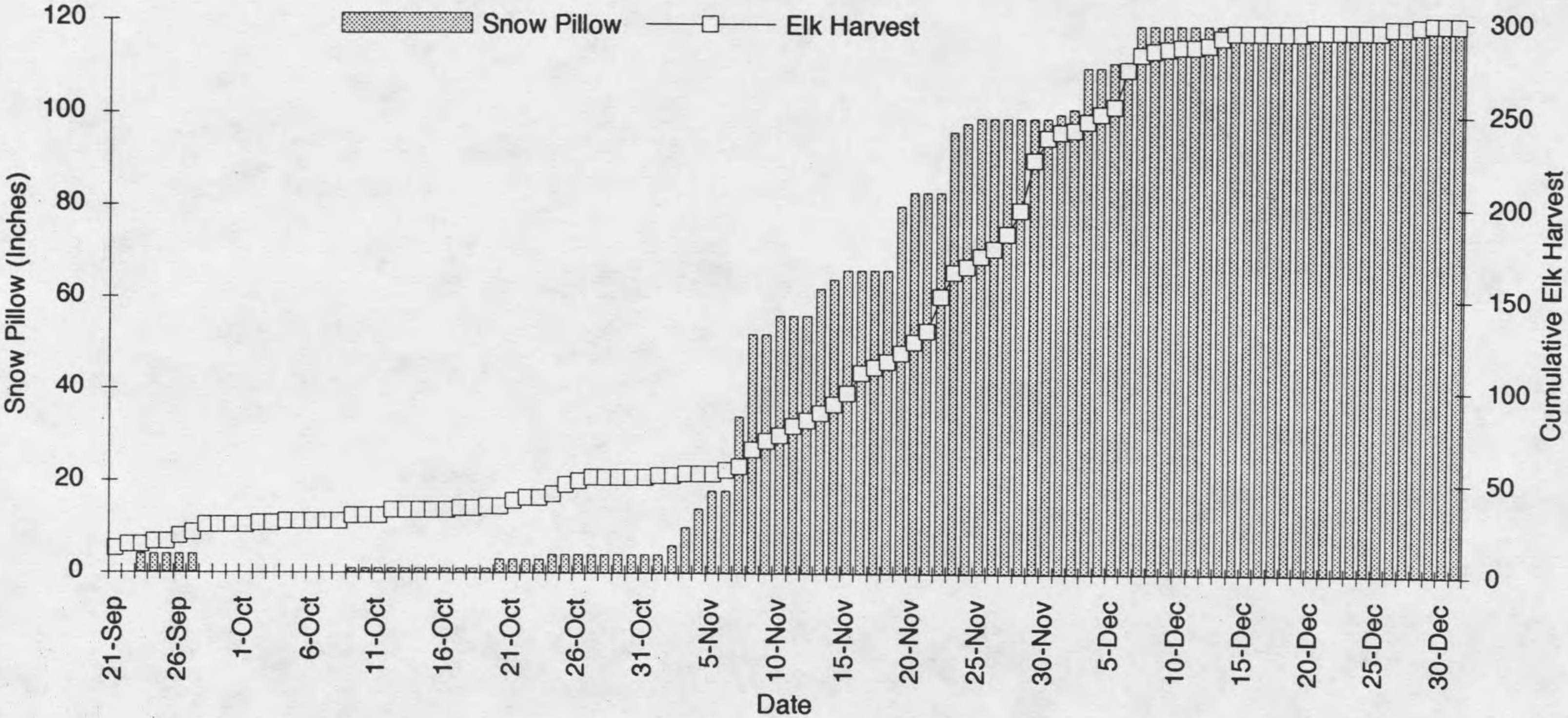

Figure 22. HD 270. Plot of the 1958 accumulated daily elk harvest against the accumulated Saddle Mountain snow pillow, upper Bitterroot, Ravalli Co., MT.

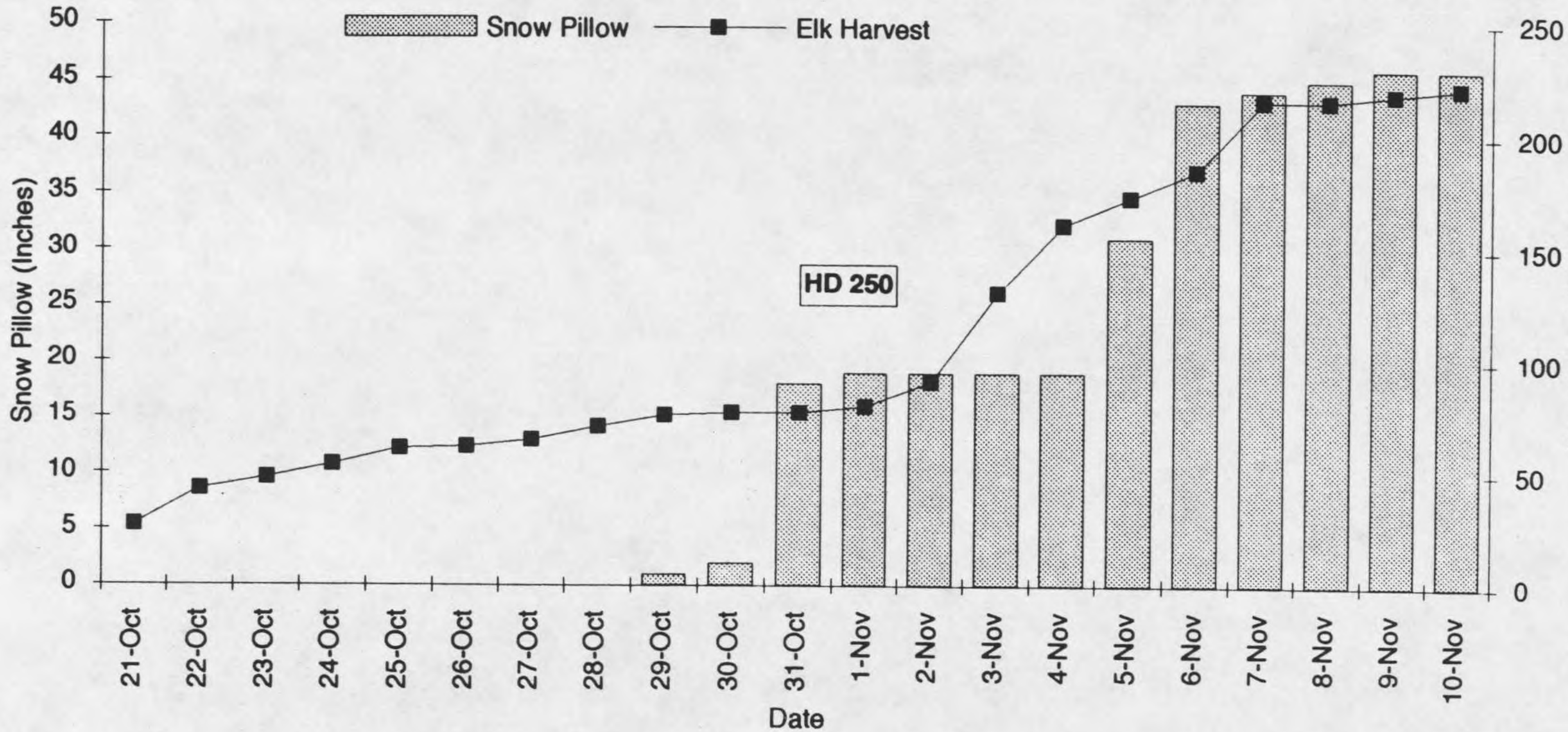

Figure 23. HD 250. Plot of the 1973 accumulated daily elk harvest against the accumulated daily snow pillow on Saddle Mountain, upper Bitterroot, Ravalli Co., MT.

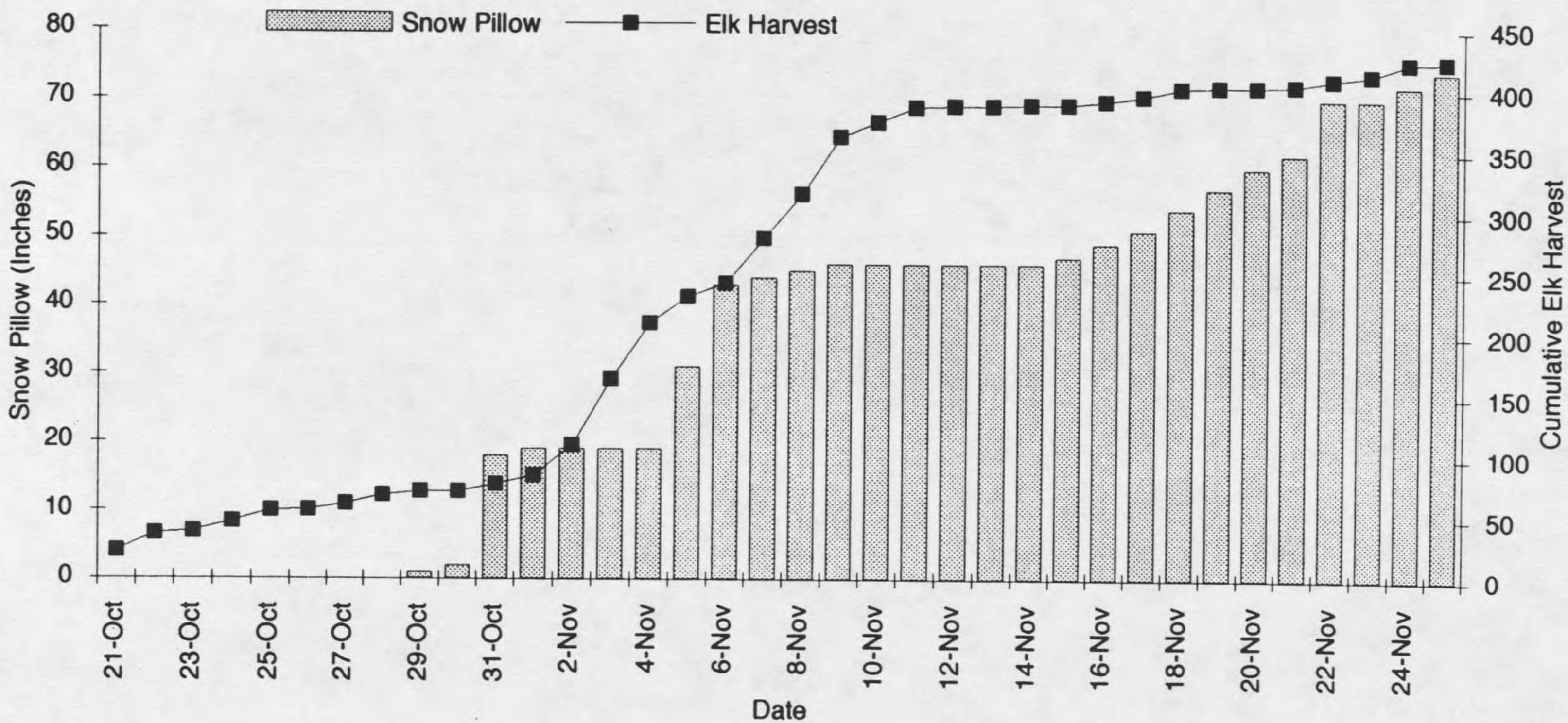

Figure 24. HD 270. Plot of the 1973 accumulated daily elk harvest against the accumulated daily snow pillow on Saddle Mountain, upper Bitterroot, Ravalli Co., MT.

decades (1950s: $r^2 = 0.121$, n=158, P = 0.0001; 1960s: $r^2 = 0.14$, n=143, P = 0.0001). In HD 270, the regression coefficients also remain comparable, however hunting seasons in HD 270 opened later than in HD 250, resulting in a smaller sample size (1950s: $r^2 = 0.18$, n= 69, P = 0.0001; 1960s: $r^2 = 0.16$, n=46, P = 0.0058).

Section Summary

Comparison of two years with comparably severe snow conditions (1955 and 1967) suggest that hunter efficiency increased in the second decade. This pattern is consistent with arguments that vulnerability increased as a result of increased road densities. For comparably mild weather years, no differences between decades were observed.

Total Kill in the First Week vs. Number of Hunters

Would a pattern emerge among decades if the relationship between numbers of hunters and the harvest were examined at a larger temporal scale? Figures 25 and 26 illustrate the relationship between numbers of hunters and total elk harvest in the first week of the season for HD 250 and HD 270. There are several notable differences in the pattern exhibited by each hunting district. First, note that in HD 250 there is an increasing linear relationship between number of hunters and harvest in the first three decades. In 1981, antlered bull general seasons were instituted, and the range in the harvest declined. Note the increase in the slope of the regression line

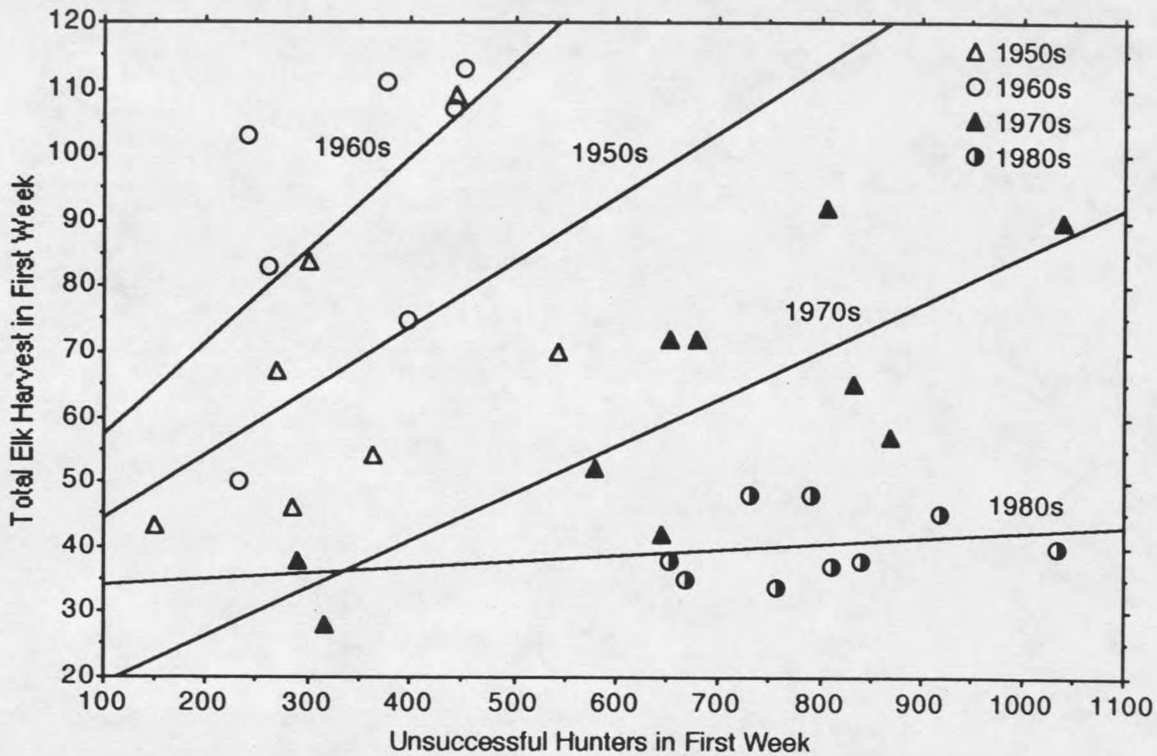

Figure 25 HD 250. Trend in relationship between unsuccessful hunter numbers in the first week and the total elk harvest in the first week. Darby check station results, upper Bitterroot.

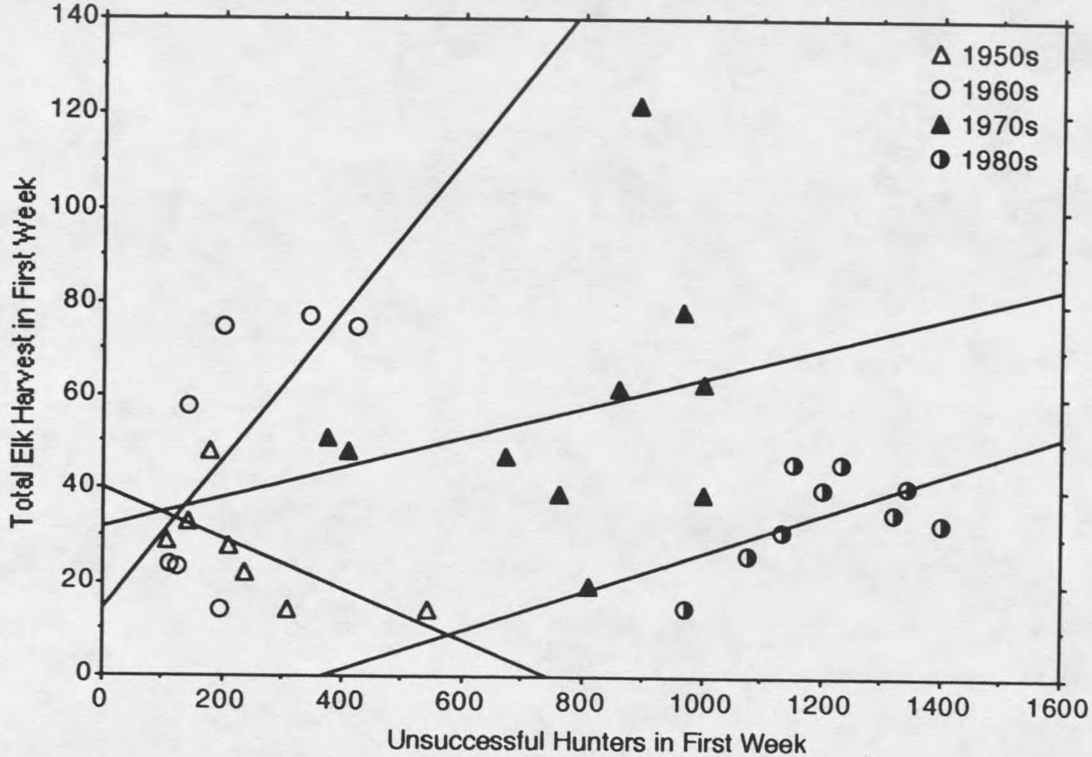

Figure 26. HD 270. Trend in relationship between unsuccessful hunter numbers in the first week and the total elk harvest in the first week. Darby check station results, upper Bitterroot.

between the fifties and sixties followed by successively shallower slopes in the seventies with corresponding decline in hunter success.

In HD 270, no pattern emerges with respect to trend in the correlation between number of hunters and elk harvest (Figure 26). Regression lines capture no pattern and outliers are more obvious, such as the extremely high kill in 1975 (IWS = -3.8). Within each decade, the variance in the harvest is clearly greater than observed in HD 250. In the fifties, a negative relationship exists between number of hunters and the harvest. Note that the lowest correlation of any decade occurs in the seventies when weather conditions varied greatly. This is in contrast to the pattern observed in HD 250 during the seventies, which exhibits a strongly linear relationship between number of hunters and the harvest. The lowest variance in the harvest occurred during the eighties. The one outlier in the eighties was 1983, with a Tuesday opener. Without 1983, the data cloud in the eighties is more tightly clustered with less variability in the harvest than other decades.

Antlered Bull Harvest in the First Week vs. Number of Hunters

If the plots for both hunting districts are limited to the antlered bull harvest only rather than total harvest, the general pattern remains the same. However more "noise" from a reduced sample size is present (Figs. 27 and 28). In HD 250, the number of antlered bulls harvested in the first week is greater in the decade of the sixties than in any other decade. In HD 270 the harvest is equally divided between high and low harvests in the decade of the sixties.

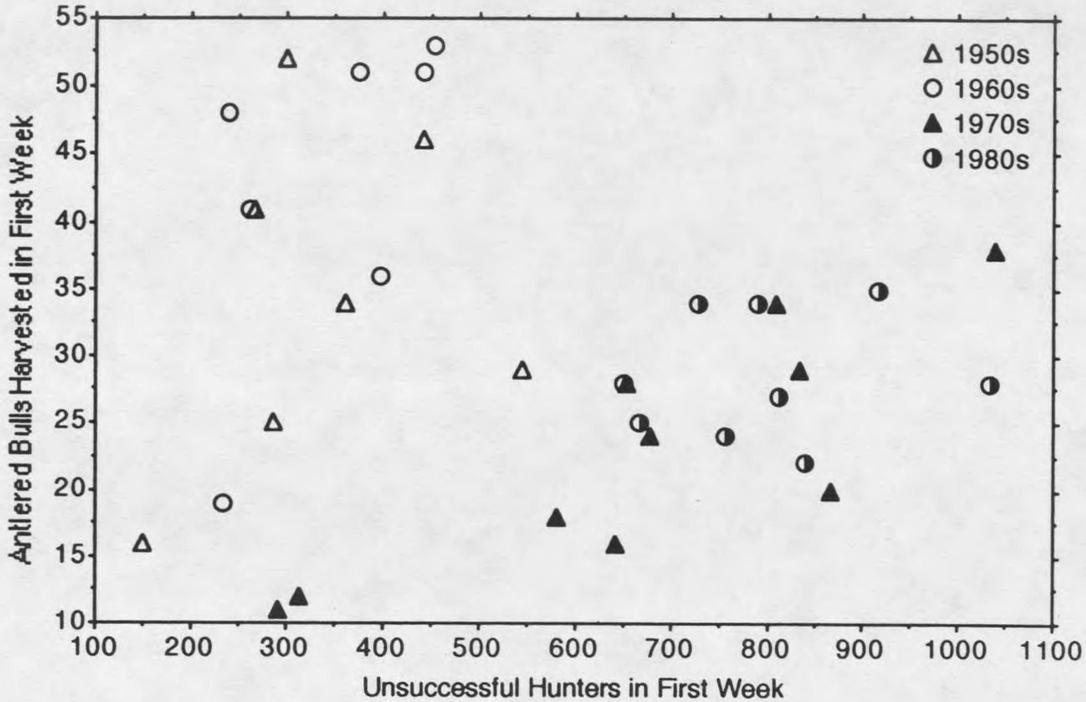

Figure 27. HD 250. Trend in relationship between unsuccessful hunter numbers in the first week and the antlered bull harvest in the first week. Darby check station results, upper Bitterroot.

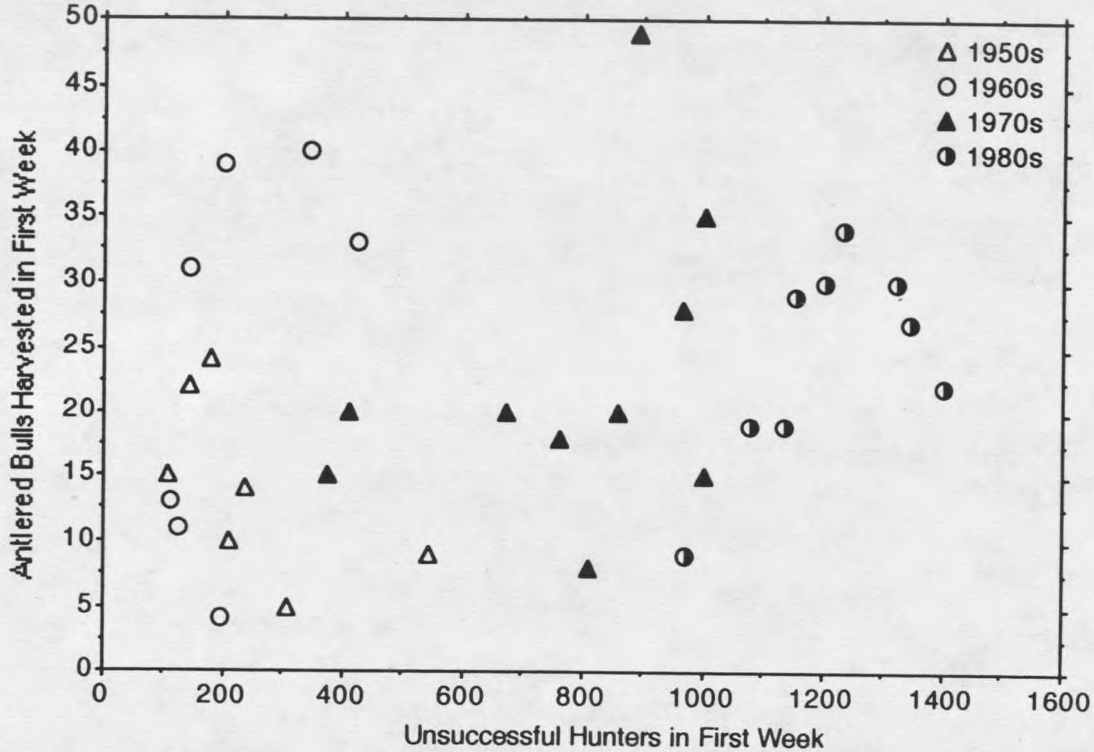

Figure 28. HD 270. Trend in relationship between unsuccessful hunter numbers in the first week and the antlered bull harvest in the first week. Darby check station results, upper Bitterroot.

During the late fifties and sixties in HD 250, comparatively few hunters harvested large numbers of antlered bulls during the first week of the season. Hunter success did not approach this 10-20% success rate during any other period (Fig. 27). During the years 1965 through 1969, 22% of the existing road miles in HD 250 were constructed (Table 18, Appendix A). The variability in harvest during the fifties is much greater than that which occurred in the sixties and may be partitioned into early fifties (when few miles of road were built) and late fifties (when up to 60 miles/year were built). These data indicate that the first week antlered bull harvest peaked in the sixties and then declined. The range of bull harvest the first week also declined in the latter two decades. Note that the linear pattern exhibited in the seventies is due in part to the range of number of hunters present the first week (375 - 998). As number of hunters increase, the harvest also increases, until a threshold is reached. This threshold is a function of the number of available elk. In the eighties, number of hunters varied less (969 - 1398) and the variability in the harvest is correspondingly less. The timing of the seasons may have also contributed substantially to the increased bull harvest in the sixties. During the sixties, most seasons opened in September, during the rut. The influence of the rut on vulnerability is discussed later (see September Seasons and the Rut).

During the sixties in HD 270, proportionately more antlered bulls were harvested in the first week by fewer hunters than at any other time. However, not all years in the sixties produced large first-week antlered bull harvests and, in contrast to HD 250, no year in the fifties had comparably large first-week bull harvests (Fig. 28). In HD 270 the three years which had low antlered bull harvests the first week were 1963, 1965 and 1967. These are the only years in the sixties that had mild weather during opening week (IWS =+4.0). Most years in the sixties had average weather opening week, and thus it is unclear if more severe weather conditions alone were responsible for the increased harvest or if increased road densities were a factor. This period coincided with peak road construction in HD 270: 25% of existing road miles were constructed between 1965 and 1969 (Table 19, Appendix A).

Comparison of IWS in the Last Two Decades

It might prove instructive to determine if the lower variance in the harvest during the eighties is attributable to more uniform weather than occurred during the decade of the seventies. I compared IWS values from the eighties with those observed in the seventies to determine if there were differences. The winter severity index correlates well with the harvest in HD 270, ($y = -30.9908x + 243.2962$, $r^2 = 0.4362$, $n = 37$, $P = 0.0001$) but may be insufficient to capture weather changes that trigger elk movement. When the winter severity index for both opening day and yearly plots of accumulated new snow versus the accumulated harvest are examined, the number of weather events which coincided with increased harvest rates may be tracked. From 1971 to 1980 there were three years in which the harvest rate increased coincident with snowfall the first week (1975, 1979, 1980). During the 1980s, there were four such years (1981, 1982, 1983 and 1984).

For both decades, the best index of snow conditions opening week is the IWS value for 1 November (the result of the previous 15 days accumulation). From 1971 through 1989, the first week of hunting season typically fell in the latter half of October. The mean IWS values for the two decades do not differ significantly (Mann-Whitney U, P=. 647). However the mean 1 November IWS for the seventies was lower (.91) than that for the eighties (1.7). The computed range of 1 November IWS values is greater in the seventies (range = 7.8) than the eighties (range = 5.6) as are the minimum/maximum IWS values in the seventies (-3.8 to 4) compared to the eighties (-1.6 to 4). The coefficient of variation for 1 November IWS values is also greater in the decade of the seventies (c.v. = 301.5%) than in the eighties (c.v. = 136.3%). Figures 29 and 30 illustrate the annual variation in the 1 November IWS for each decade. Note the IWS has successive sign changes in each of the first six years of the 1970s (Figure 29). Thus, opening week weather conditions were more severe in the seventies with respect to snow and exhibited a greater overall variance among years than observed in the eighties. This difference would explain the reduced variability in the opening week harvest apparent in HD 270 (Figs. 26 and 28).

Use of Age Information

Prior to about 1970, mandibular age estimates were recorded inconsistently and with varying degrees of reliability, depending on the experience of the observer. A more general age classification of elk - age class - may be reliably estimated on elk simply on the basis of antler size (males) and obvious mandibular characteristics (males and females). Unlike mandibular age information, age class information was consistently and reliably recorded over all years. Elk examined at check stations were

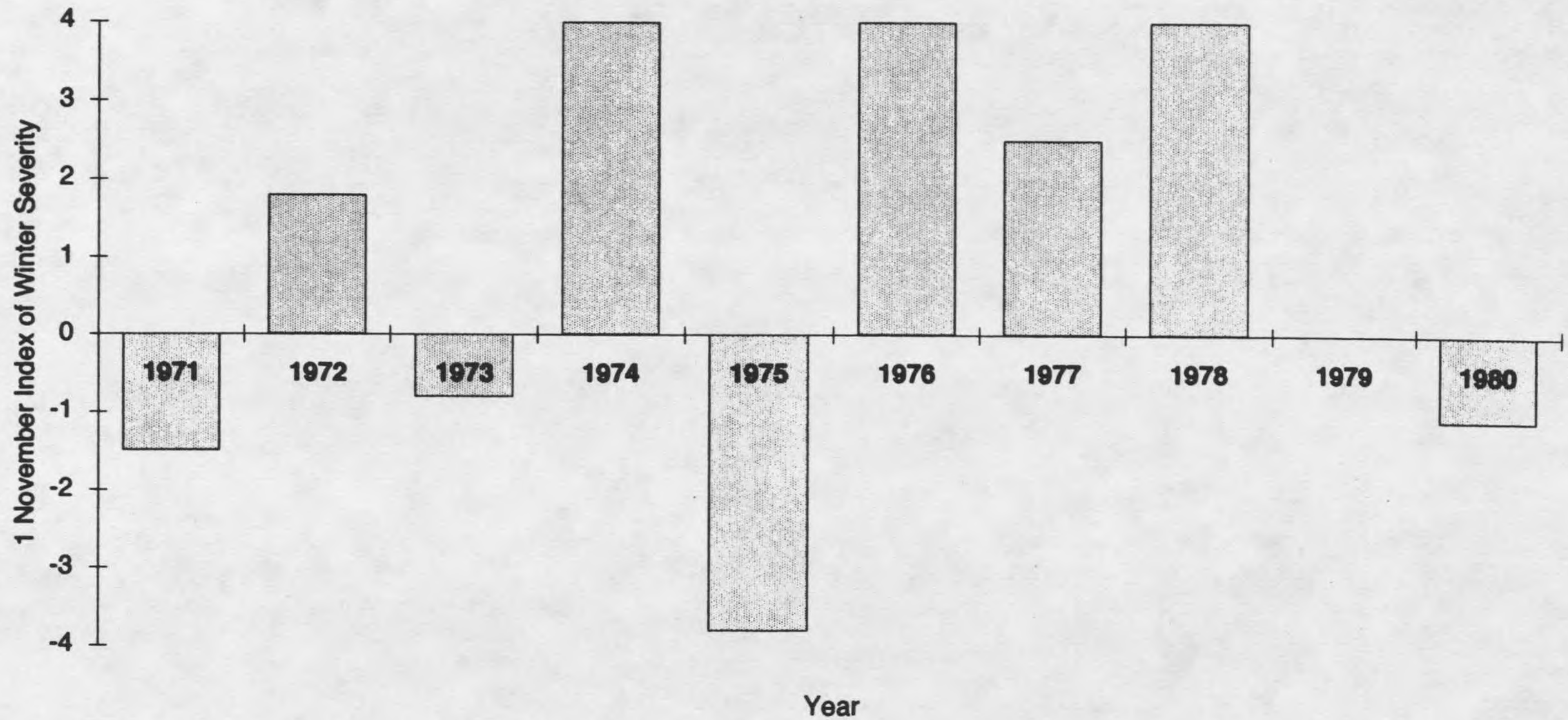

Figure 29. Trend in 1 November index of winter severity for the decade of the seventies. Saddle Mountain SNOTEL results, Ravalli Co., MT.

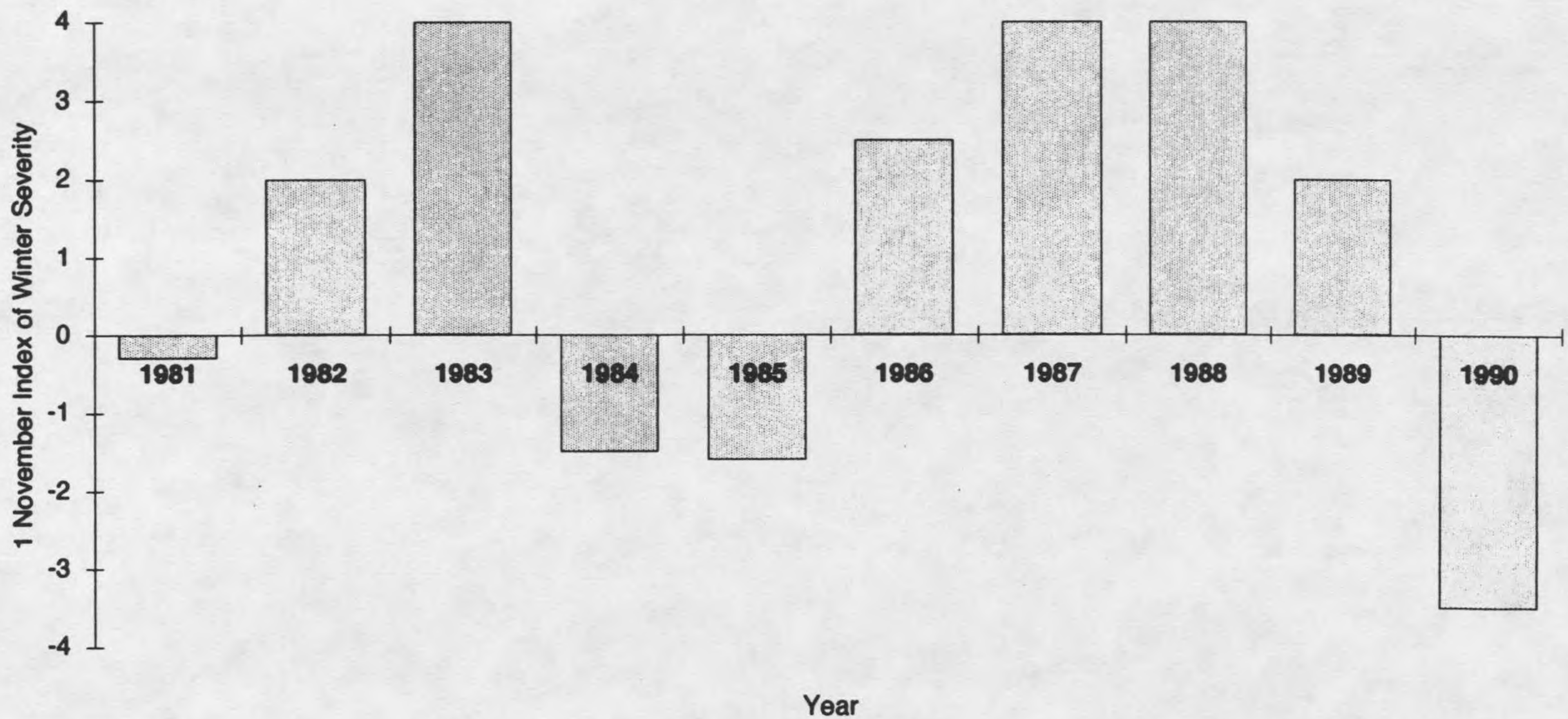

Figure 30. Trend in 1 November index of winter severity for the decade of the eighties. Saddle Mountain SNOTEL results, Ravalli Co., MT.

assigned to age class categories: spike (=1.5 years), subadult (=2.5 years), prime (=3.5, $\leq$ 7.5 years) or old ($\geq$7.5 years). Figures 31 and 32 illustrate the trend in the percentage of yearling males (spikes) in the total bull harvest. In both hunting districts and in most analysis units, a recent upsurge in the percentage of spikes in the harvest is apparent. Spring aerial census surveys indicate increases in the elk population during the 1980s (Fig. 8). Spring aerial trend counts in HD 270 have increased from 1016 elk in 1980 to 1297 in 1989 (28%). In HD 250, aerial trend counts increased from 606 in 1980 to 715 in 1989 (18%). It is unclear whether increases in the spike harvest are solely attributable to increased recruitment. In 1981 regulations changed from either-sex to bull-only. This change resulted in a subsequently higher harvest of spikes the following year because male calves survived in greater numbers in 1981 to be recruited as spikes in 1982 (John Firebaugh, FWP, pers. comm.). Increases in the proportion of spikes in the harvest during the 1980s are concomitant with a period of population expansion. It is possible that during the past decade, both reduced survival of older bulls as well as increased recruitment of spikes contributed to the increased proportion of spikes in the harvest.

Figures 33 and 34 illustrate the annual harvest of total bulls, mature bulls, and spikes in HD 250 and HD 270, respectively. In both hunting districts, the proportion of the total annual bull harvest comprised of spikes was comparable. There are several advantages of using both the total number of antlered bulls as well as the number of mature bulls in the harvest to track changes in vulnerability. Total antlered bulls have been accurately recorded at check stations over all 37 years and the sample size is large. The mature bull harvest clearly tracks the total bull harvest in HD 250; however,

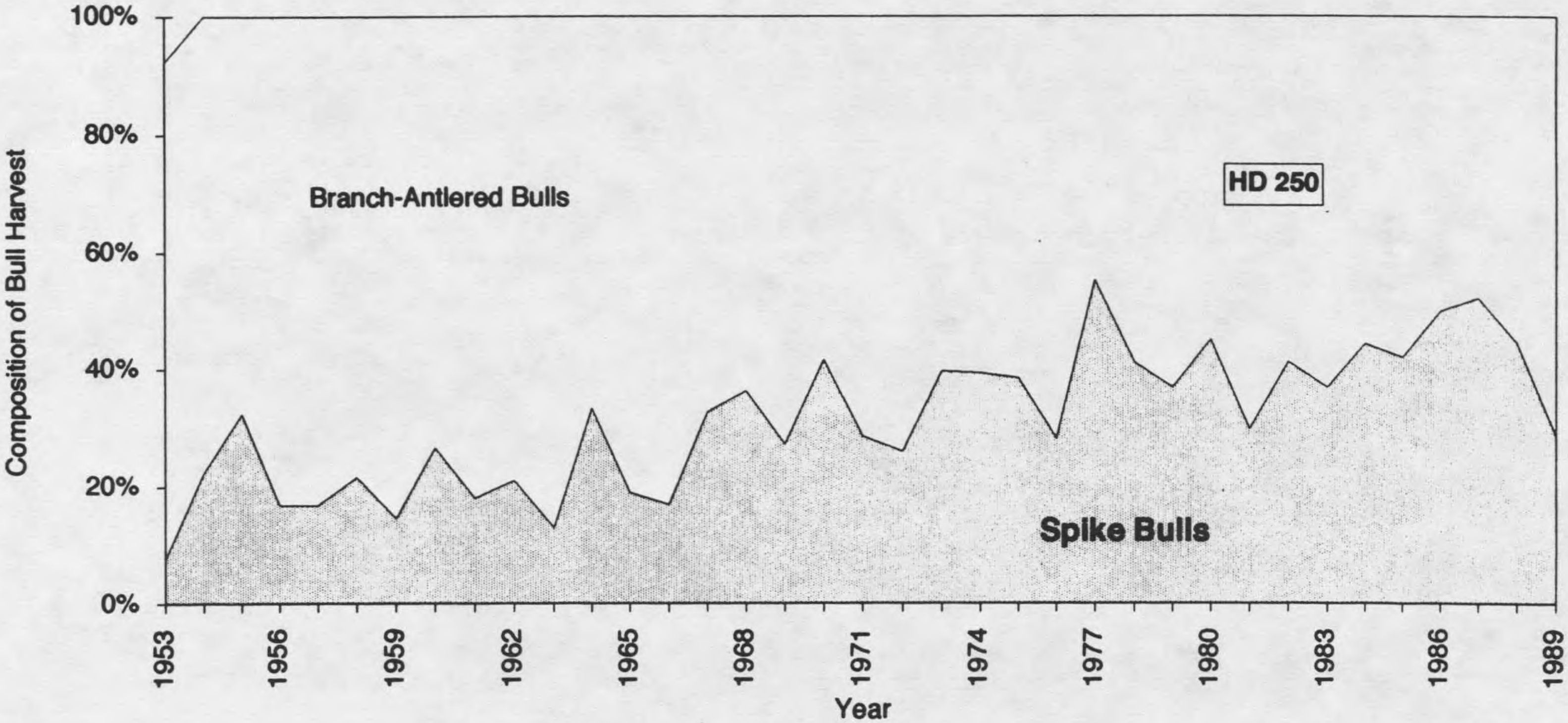

Figure 31. HD 250. Proportion of spike (yearling) bulls in total bull harvest. Darby check station results, upper Bitterroot, Ravalli Co., MT.

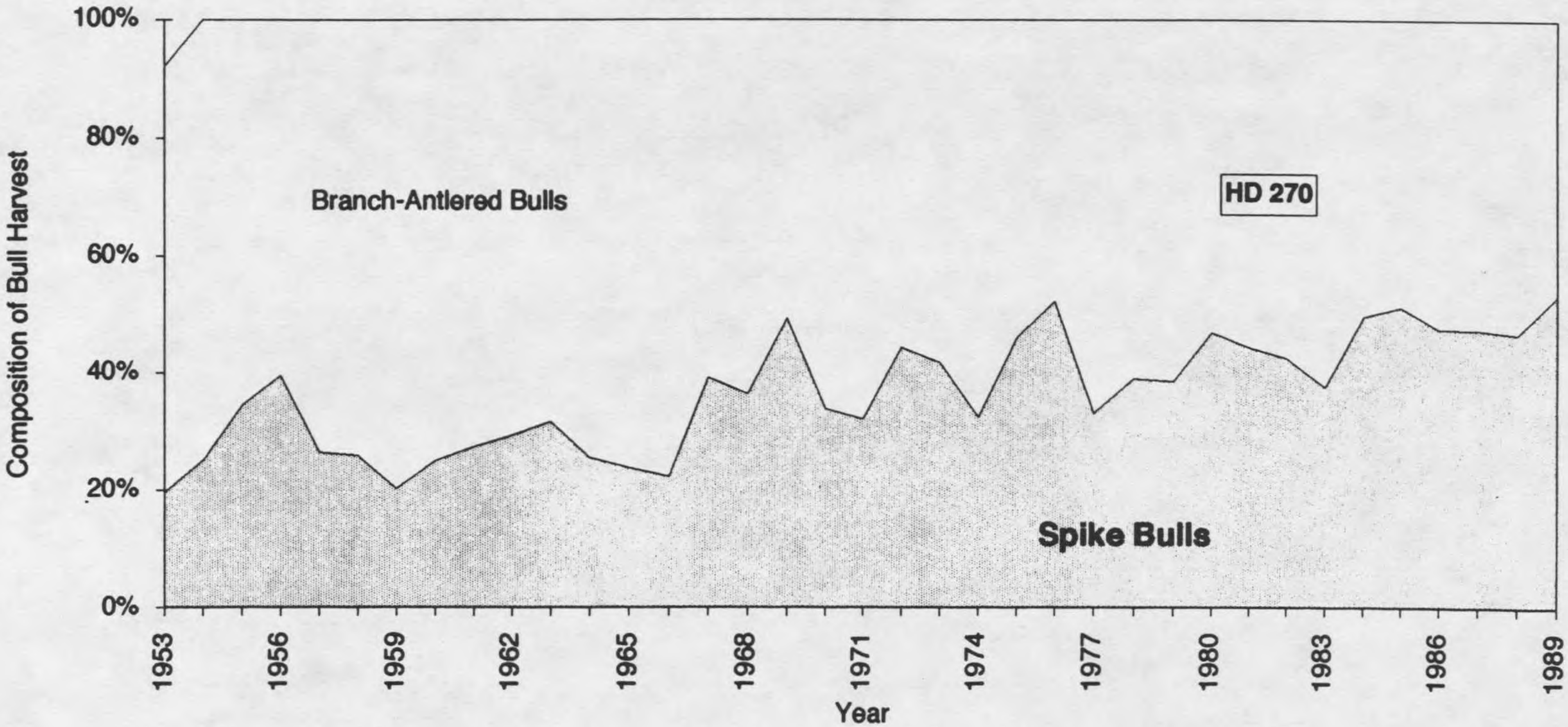

Figure 32. HD 270. Proportion of spike (yearling) bulls in total bull harvest. Darby check station data, upper Bitterroot, Ravalli Co., MT.

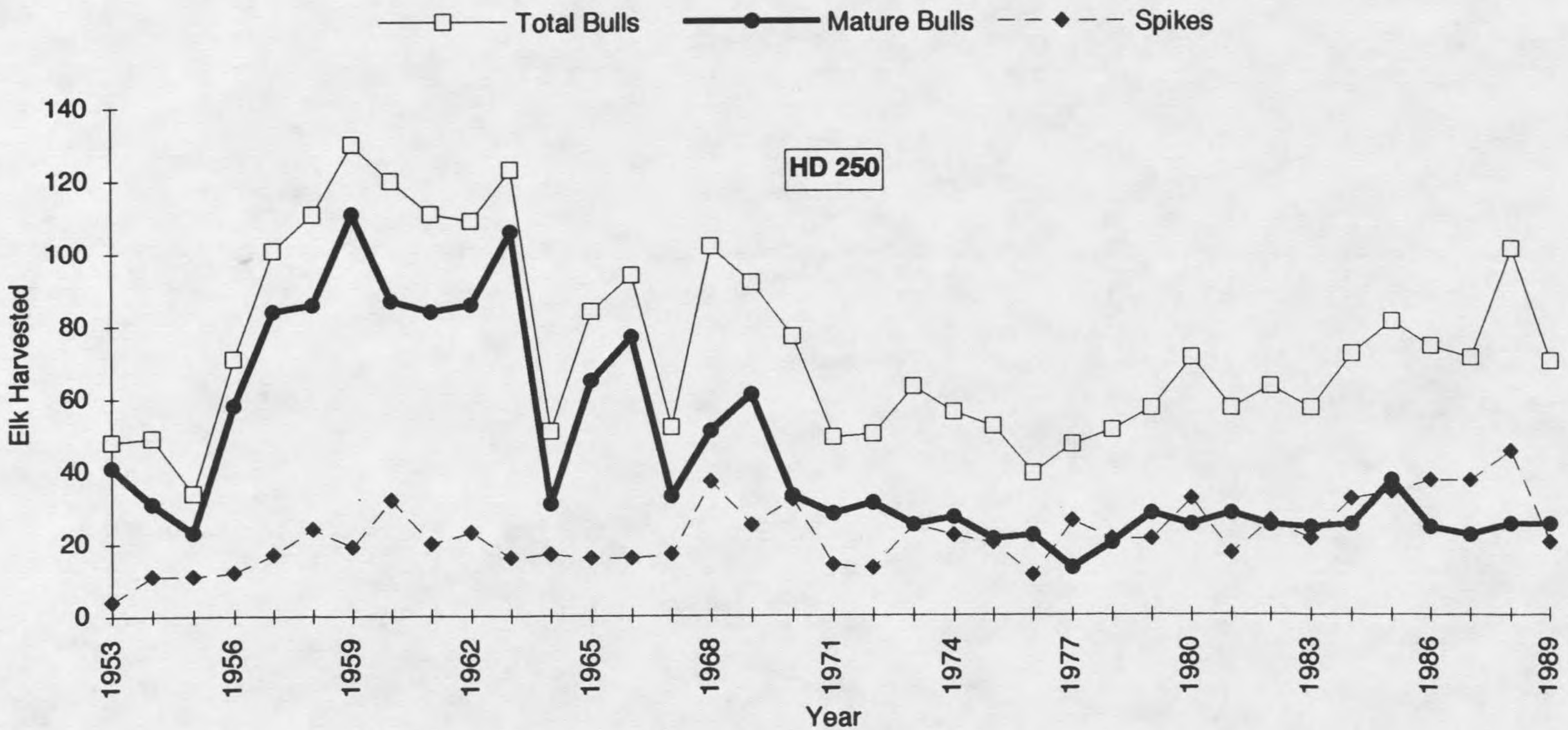

Figure 33. HD 250. Trend in annual harvest of antlered bull elk. Darby check station results, upper Bitterroot, Ravalli Co., MT.

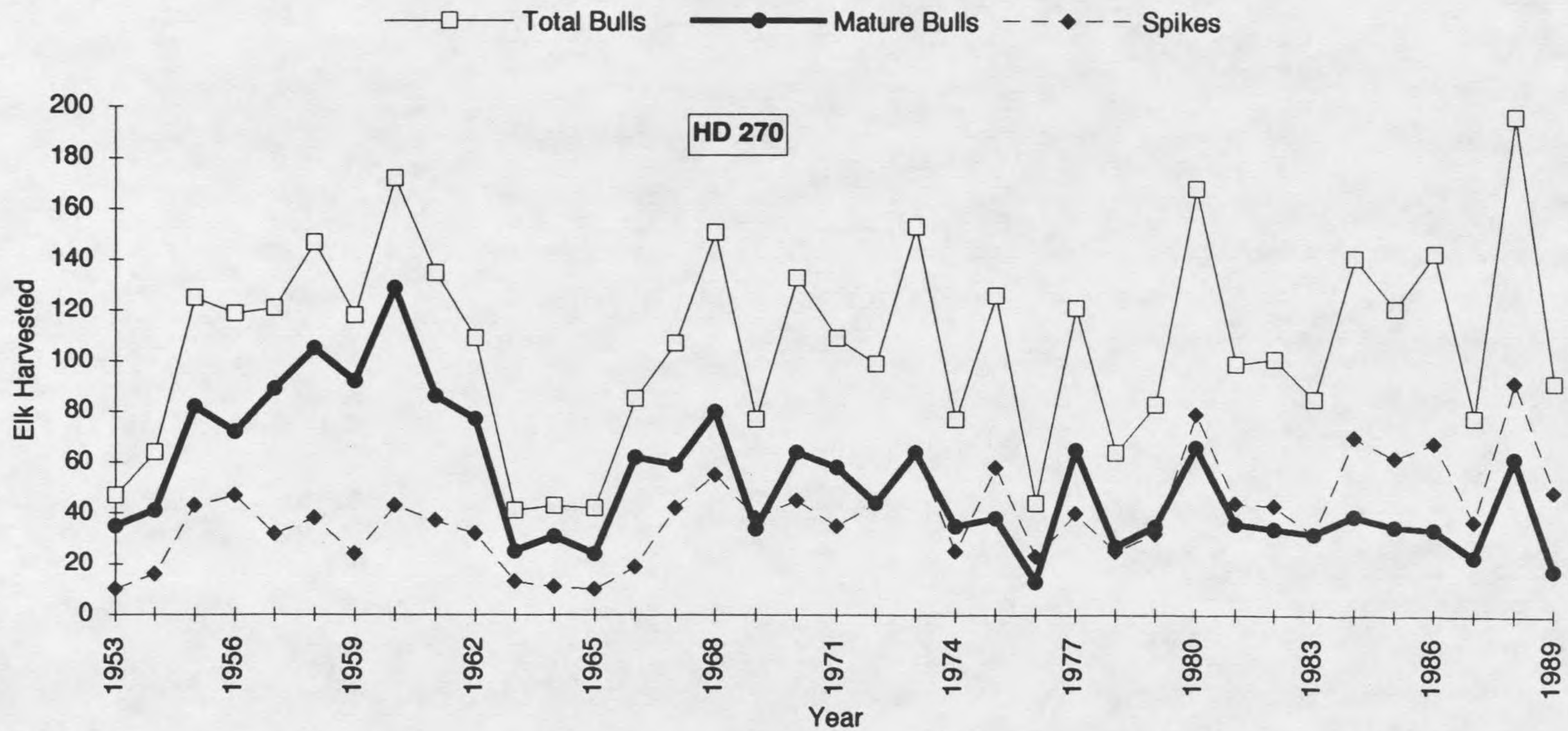

Figure 34. HD 270. Trend in annual harvest of antlered bull elk. Darby check station data results, upper Bitterroot, Ravalli Co., MT.

mature bull harvest does not increase commensurate with the total bull harvest during the last decade. Increases in recruitment appear to be counterbalanced by declines in survivorship of older bulls during this same time period. Population increases in HD 270 are less pronounced than in HD 250, which is reflected in the harvest.

The "signal to noise" ratio becomes a consideration if we rely solely on the mature bull harvest to assess vulnerability. Because the mature bull harvest is a subset to the total antlered bull harvest, the variance in the mature harvest is necessarily less. The small sample size attendant with the mature bull harvest lowers the signal to noise ratio, and less signal emerges from the data. Increasing our sample size to include the antlered bull harvest increases the signal to noise ratio, allowing insight into the influence of weather on the annual harvest. Therefore, we will want to track not only the change in the harvest of mature bulls, but also the antlered bull harvest.

Influence of Season Length

As discussed previously, season length in the upper Bitterroot has varied by an order of magnitude over the course of the last four decades. Figures 35 and 36 illustrate the trend in season length and the total and mature bull harvest while Figures 37 and 38 illustrate total mature bull harvest, season length and road density for HD 250 and HD 270, respectively. In HD 250, the closeness of the fit of mature bull harvest on season length is obvious (Figs. 35 and 37). Note that the trend in mature bull harvest exhibits little annual variation except during the sixties. The harvest rate of mature elk was

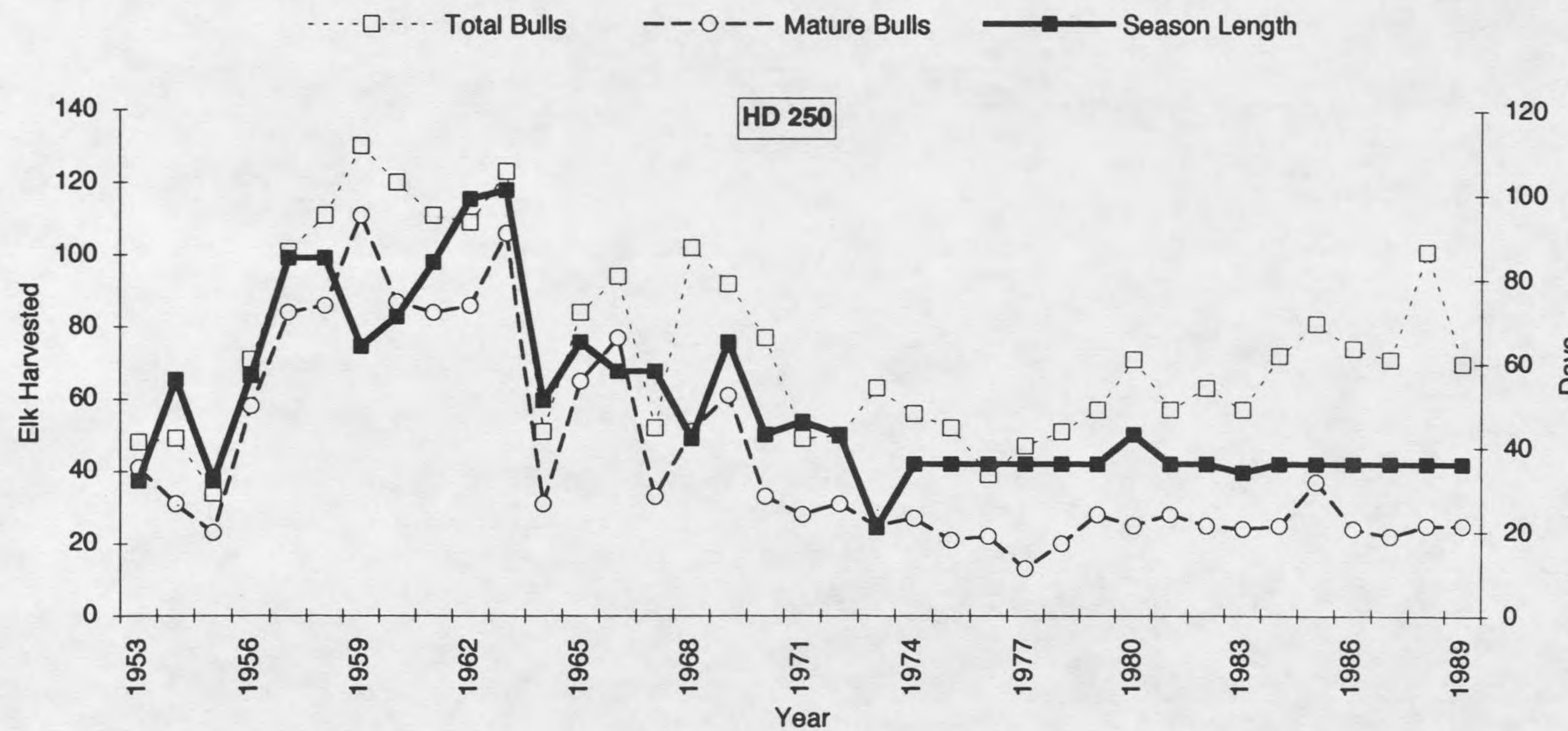

Figure 35. HD 250. Length of antlered bull season versus harvest of total and mature bulls. Darby check station results, upper Bitterroot, Ravalli Co., MT.

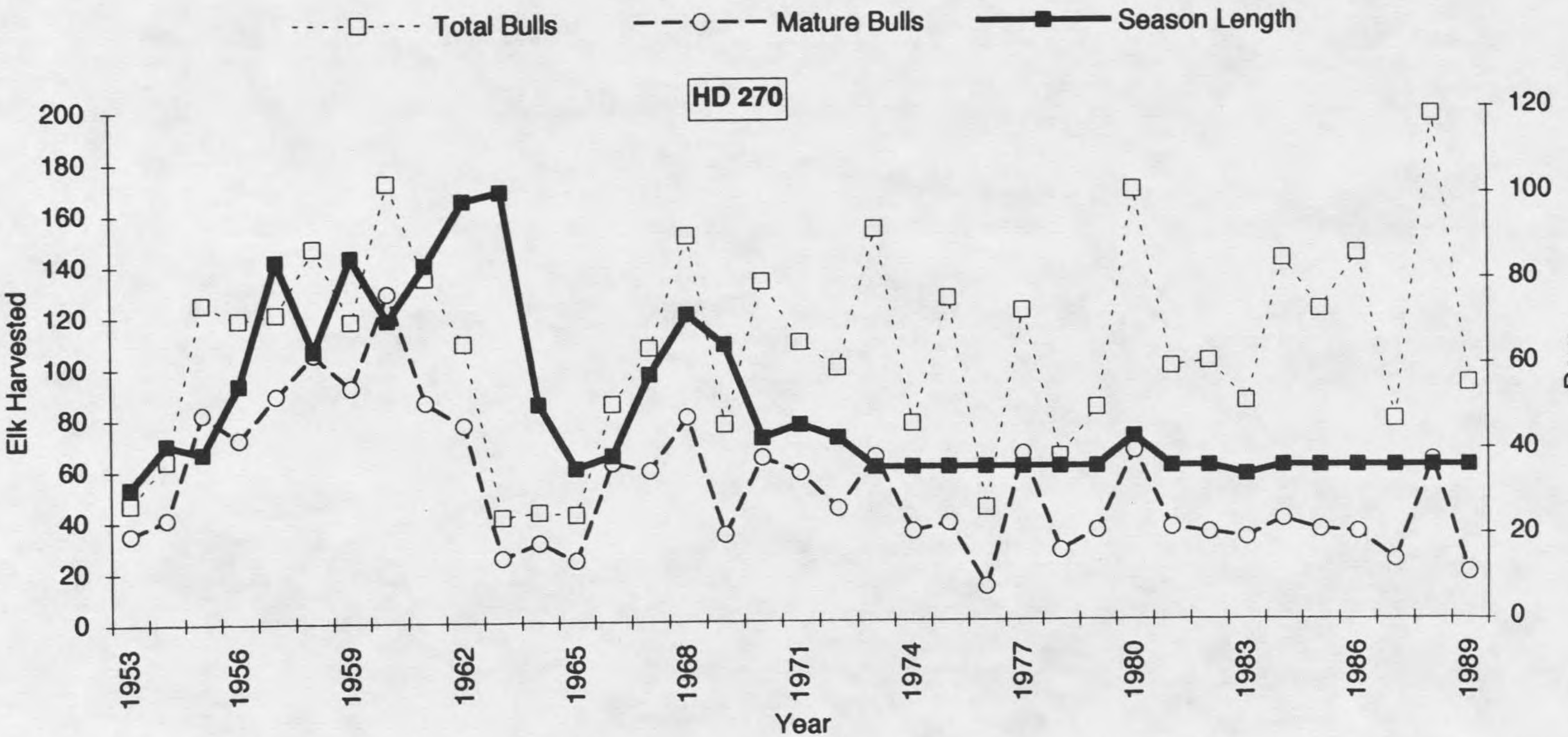

Figure 36. HD 270. Length of antlered bull season versus harvest of total and mature bulls. Darby check station results, upper Bitterroot, Ravalli Co., MT.

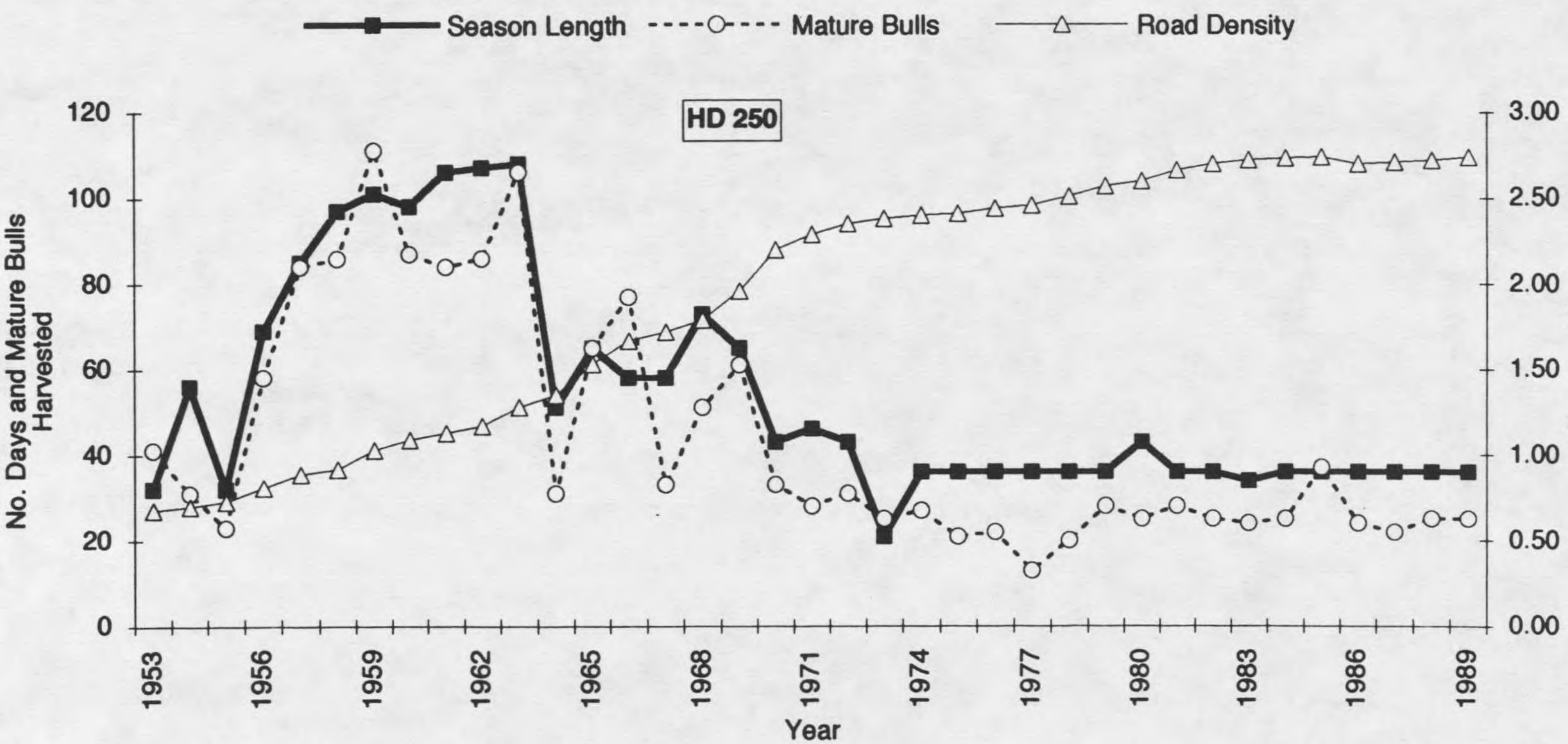

Figure 37. HD 250. Trend in length of antlered bull season, road density and harvest of mature bulls. Darby check station results, upper Bitterroot, Ravalli Co., MT.

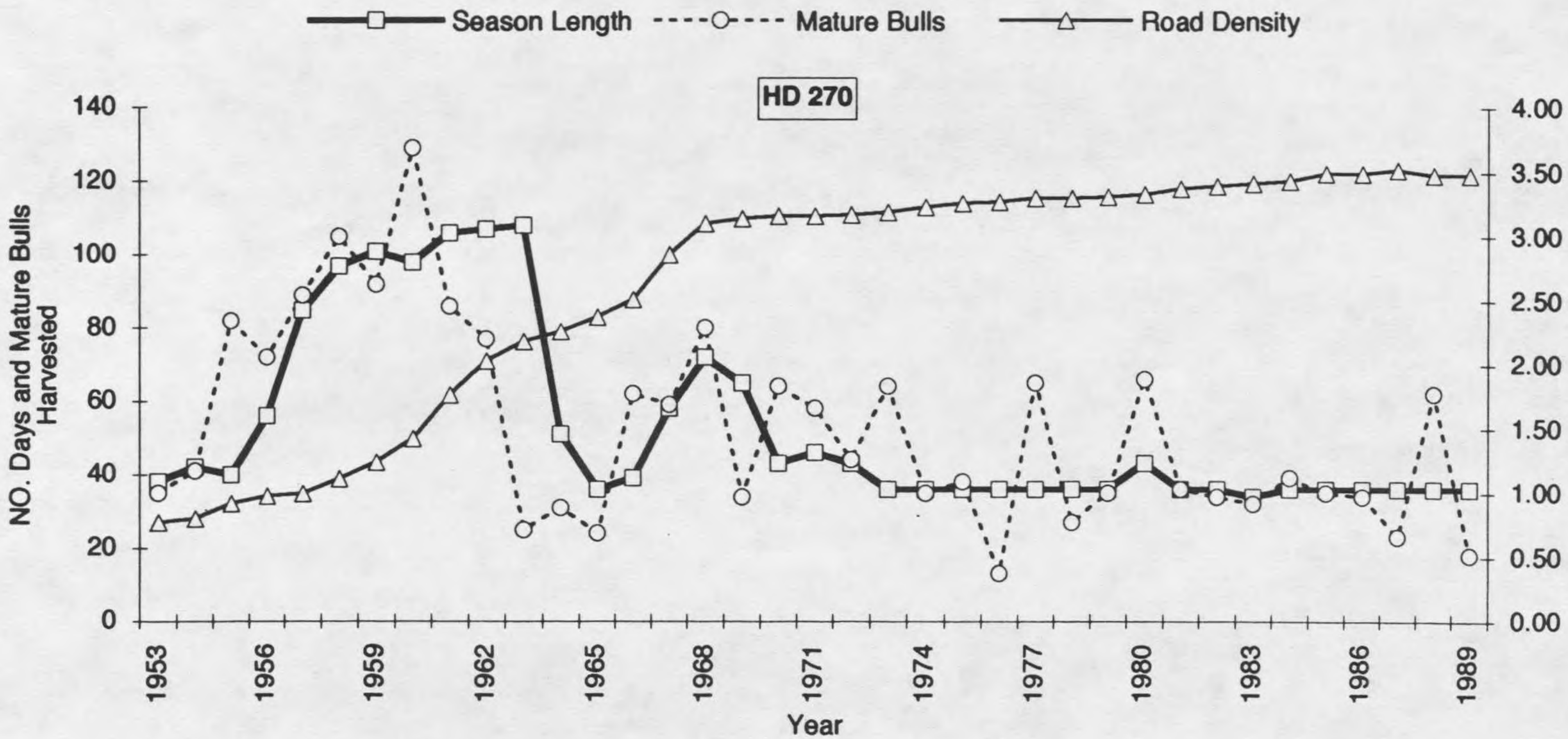

Figure 38. HD 270. Trend in length of antlered bull season, road density and harvest of mature bulls. Darby check station results, upper Bitterroot, Ravalli Co., MT.

about one per day in HD 250 during the first two decades. In the second two decades, the harvest rate of mature elk fell to about 0.5 elk/day (Fig. 37). It would be worthwhile to examine the daily harvest rate and its variance to see if there is a trend related to factors other than season length.

At the level of area and analysis unit, the decline in mature bull harvest also coincides with declines in season length. Figure 39 illustrates the trend in mature bull harvest against season length and trend in road density in the Triangle Area. At the analysis unit level, small sample size increases the "noise" in mature bull harvest data and confounds interpretation of results. However, with the exception of AU-W5, declines in mature bull harvest in HD 250 coincide fairly closely with reductions in season length. AU-W5 is a notable exception to this trend (Fig. 40). Approximately 51% of AU-W5 is located within the Selway-Bitterroot Wilderness. Small sample size increases the variance in the harvest from year to year in AU-W5, but it is clear that the mature bull harvest remained relatively constant during the first two decades and did not decline sharply when seasons were shortened (Fig. 40).

In HD 270, the mature bull harvest trend exhibits the same pattern as the trend in season length, but the mature bull harvest declines prior to reduced season length and appears to be out of phase with changes in season length (Fig. 38). Note also that annual variation in mature bull harvest is much greater than observed in HD 250, reflecting the influence of weather on the harvest. In August of 1961 the Sleeping Child fire burned approximately 11,736 ha, and road densities increased from 2.07 km/km^2 (1.29 mi/mi^2) in 1960 to 3.52 km/km^2 (2.19 mi/mi^2) in 1961. When individual analysis units in the East Fork and the Divide Areas are examined, season length does not appear to be nearly as important as weather variables in

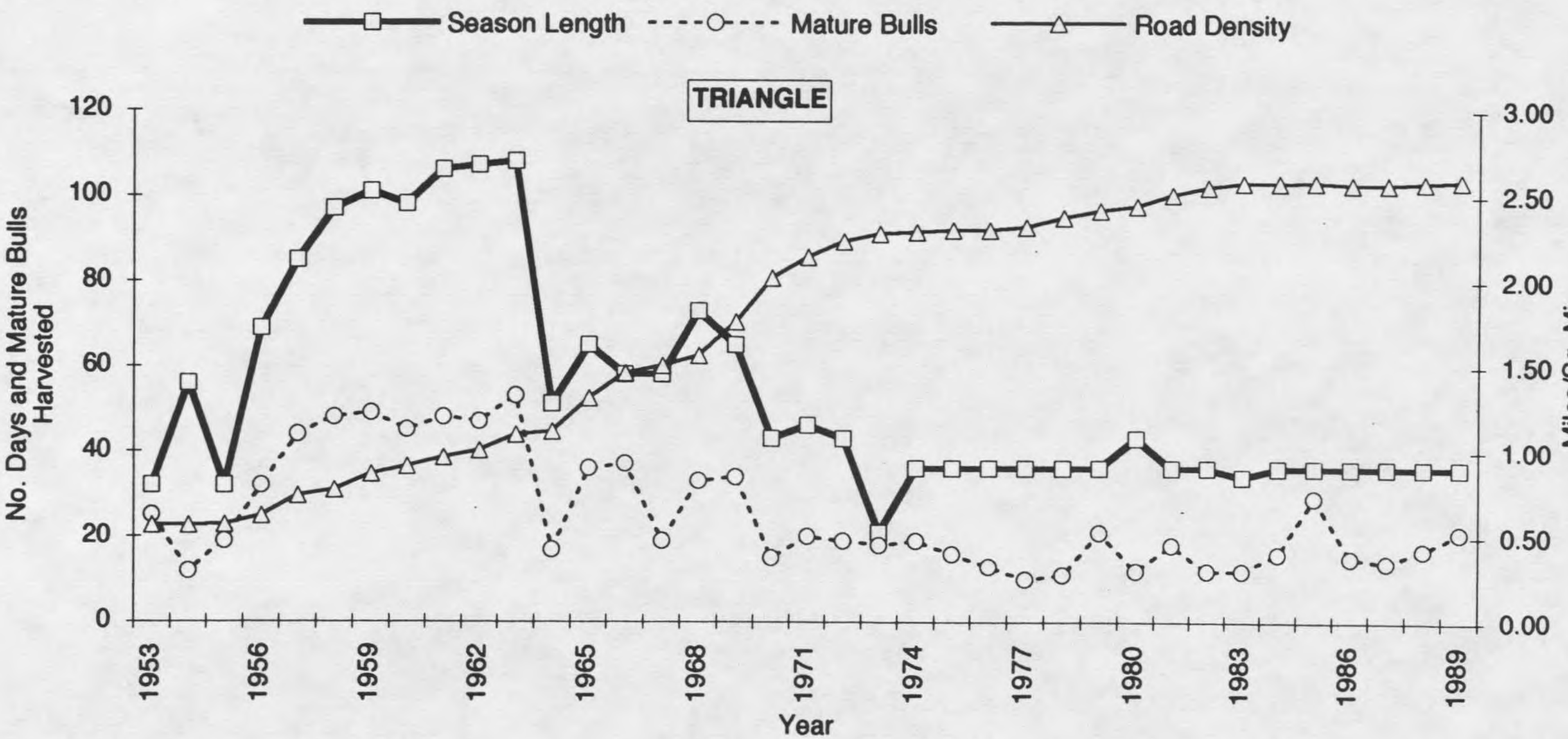

Figure 39. Triangle Area (HD 250). Trend in length of antlered bull season, road density and harvest of mature bulls. Darby check station results, upper Bitterroot, Ravalli Co., MT.

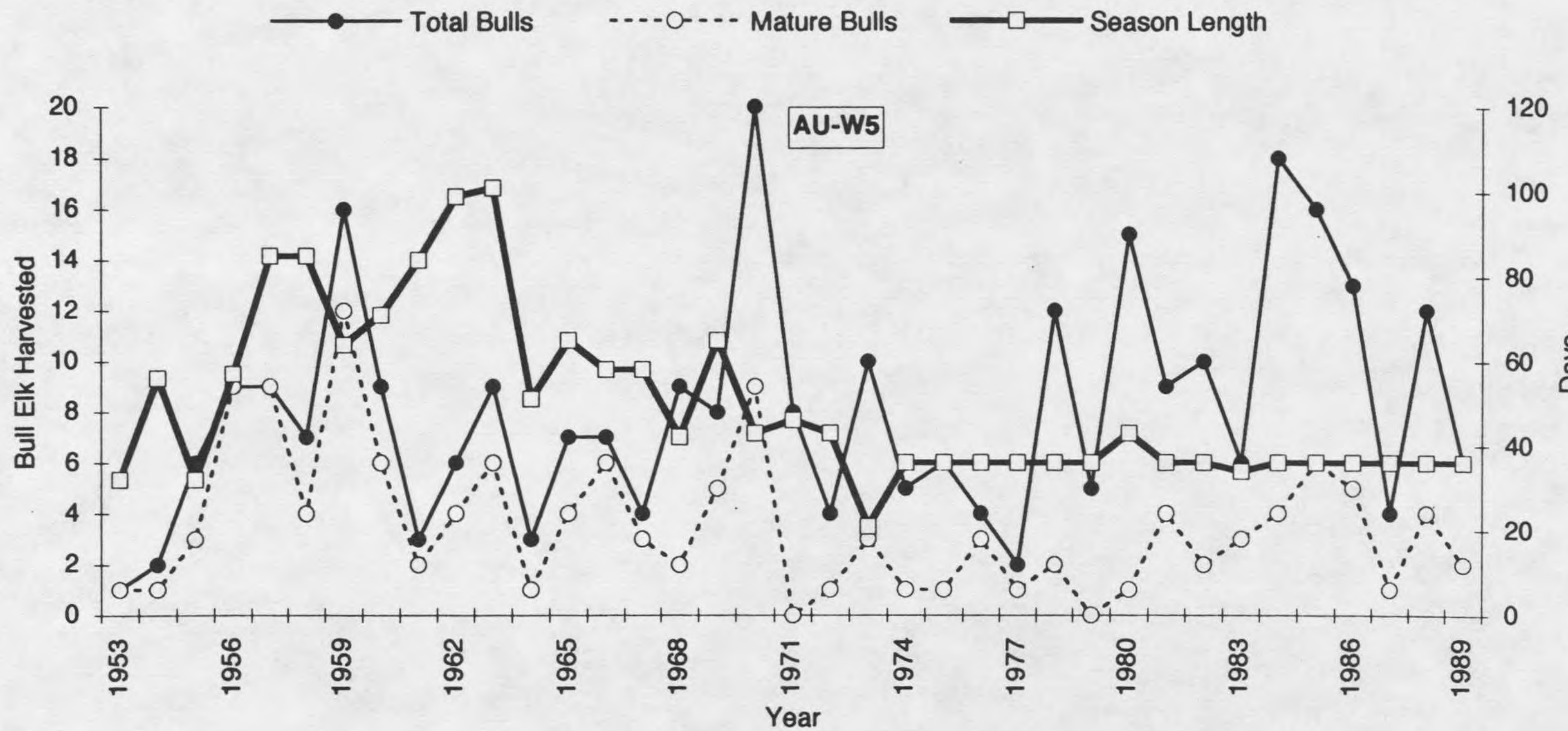

Figure 40. Analysis Unit W-5 (HD 250). Trend in length of antlered bull season, total and mature bull harvest. Darby check station results, upper Bitterroot, Ravalli Co., MT.

influencing the harvest of mature bulls. In AU-E5, the decline in mature bull harvest occurs prior to reductions in season length (Fig. 41). The majority of the acreage impacted by the Sleeping Child fire is within Analysis Unit E5.

The relationship between season length and mature bull harvest in HD 250 suggests that season length drives the mature bull harvest. Recall that seasons were shortened in response to a public perception of fewer elk (Cross 1965). It is unknown if elk numbers actually declined between 1961 and 1963 because spring census flights were not conducted. It is unknown if the mature bull harvest would have remained high in HD 250 if the season had not been shortened. It seems reasonable to argue that long seasons contributed to the decline in the mature elk harvest in HD 270. Given the decline in the mature bull harvest in HD 270, it is likely that a similar decline would have occurred eventually in HD 250 had season length remained long.

September Seasons and the Rut

While the influence of season length in HD 250 is clearly important, the timing of the season may also have contributed to the harvest of mature bulls during this same time interval. In HD 250, the longest seasons also opened in September, during the rut. The behavior of elk during the rut predisposes them to being shot because they are less alert to hunters and because they reveal their position when bugling. Artificial calls are most effective during the rut, however the most sophisticated of such calls are a relatively recent technology. When the total mature bull harvest in the first 36 days is plotted against the timing of the season (Fig. 42) more mature elk

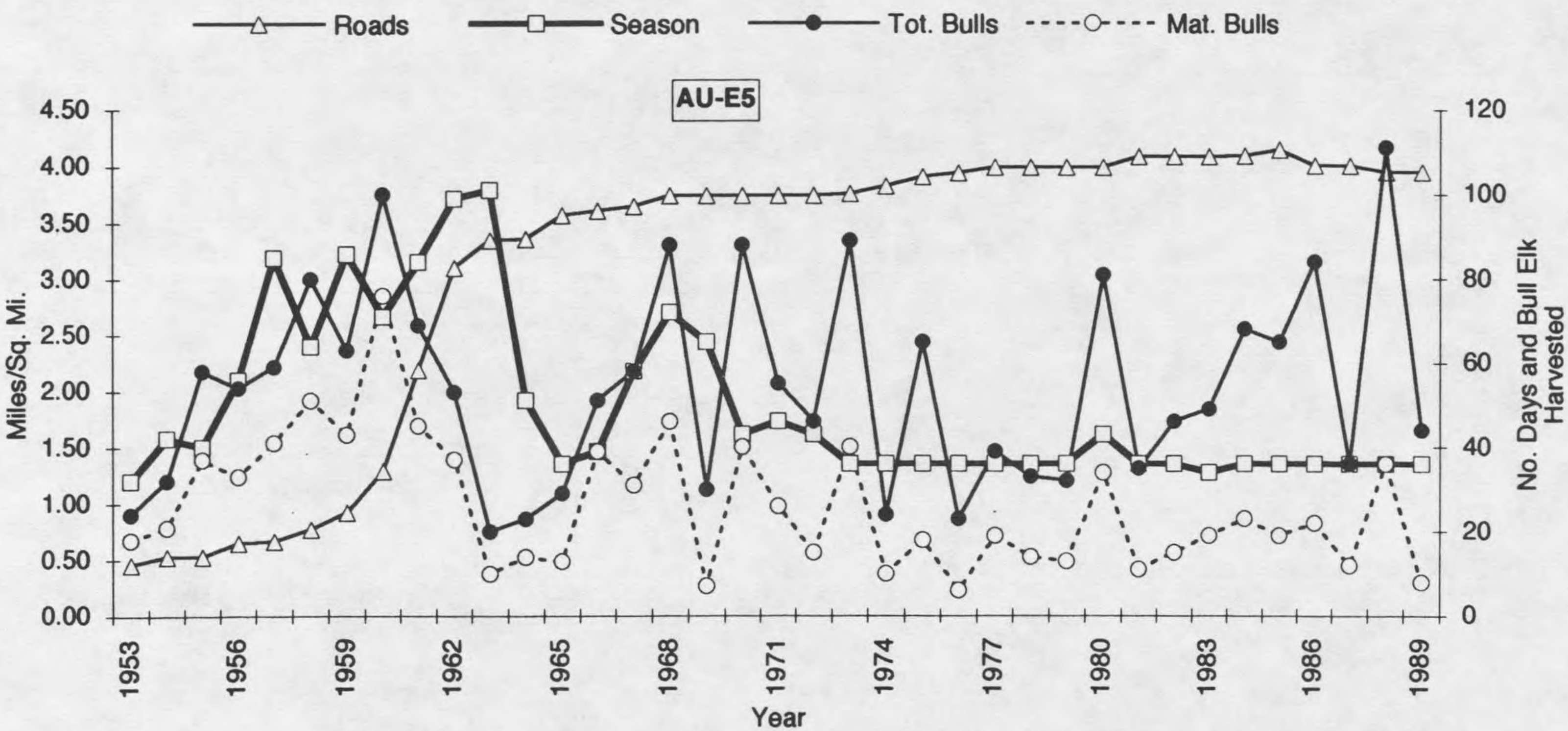

Figure 41. Analysis Unit E5 (HD 270). Trend in season length, total and mature bull harvest and road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

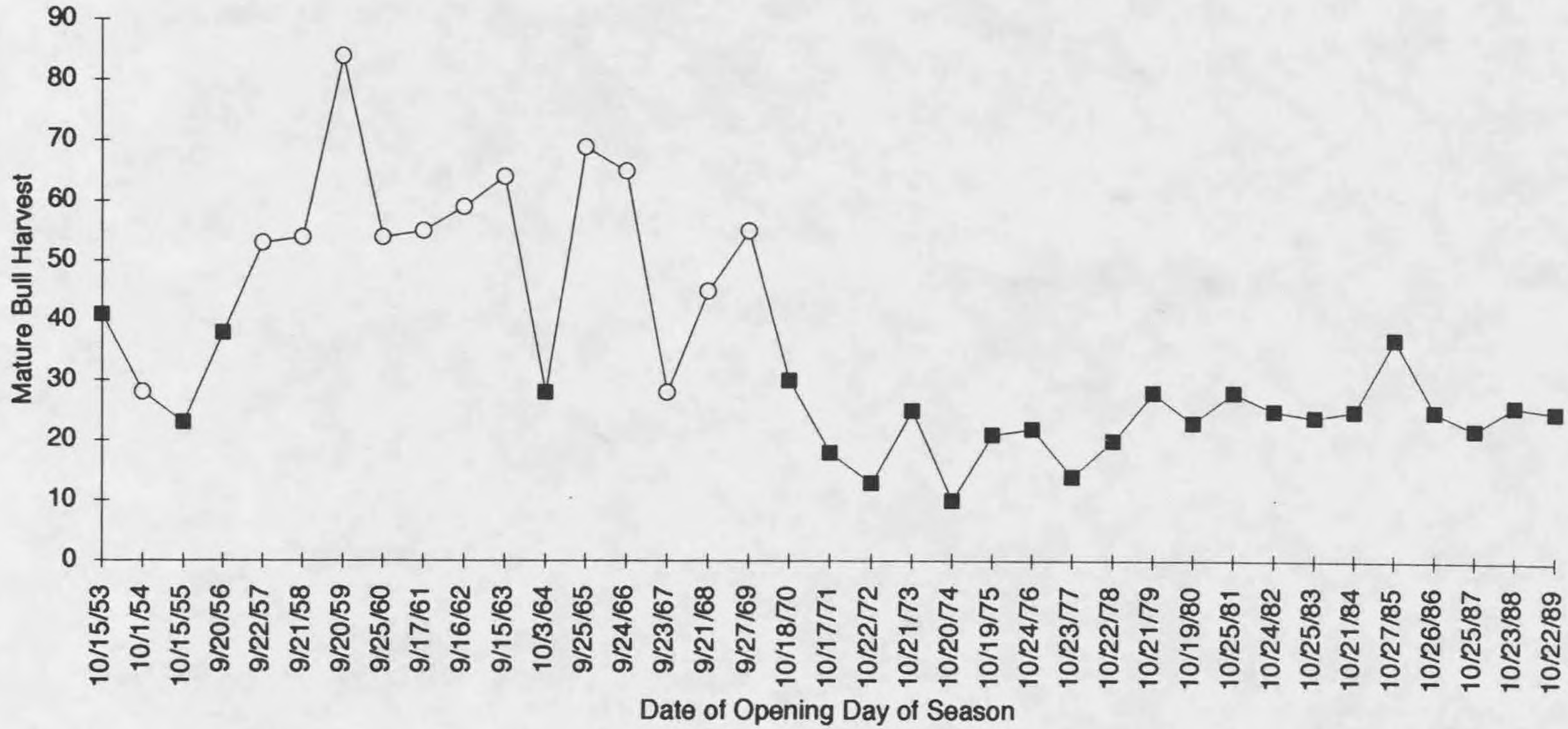

Figure 42. HD 250. Trend in 36-day mature bull harvest by month of opening day. Open circles represent September opener, filled squares are October openers. Darby Check Station, Ravalli Co., MT.

were killed in the first 36 days when the season opened in September than when the season opened in mid-October. Note that the decline in the 36-day mature bull harvest did not occur in 1964 when season length was shortened, but in 1970, when opening day of the season was changed to mid-October. Figure 42 suggests that the early September seasons may have contributed to the large harvest of mature bulls in HD 250 during the 1960s.

Harvest Rate and Vulnerability

Season length appears to be the most important variable influencing the number of bulls harvested each year in HD 250 but not in HD 270. It may be instructive to examine the apparent differences between hunting districts and the rather surprising stability of the annual harvest rate over time in HD 250.

To control for the influence of season length on the harvest, the elk harvest was scaled by season length to create a new variable: *elk harvested per day*. The rate at which bull elk are harvested has been shown to be a function of vulnerability (Lonner and Cada 1982; Vales et al. 1991). There are several approaches which can be used to examine the rate of harvest. The frequency histogram of the harvest over the course of the season was previously examined for all years and no obvious trend was observed. However, some years in the sixties exhibited a frequency histogram consistent with high levels of vulnerability, 1966 most notably (Fig. 15).

A plot of the daily accumulated elk harvest against accumulated snow reveals that in some years vulnerability increased dramatically in response to severe snow conditions (Fig. 24). Increased vulnerability is directly observable in the change in the slope of the accumulated harvest (average number of elk harvested per day).

The trend in harvest rates for mature and total antlered bulls in relation to road densities and habitat changes across 37 years for HD 250, HD 270 and the Triangle Area was examined. The trend of mature bull harvest rates was consistent with that observed for antlered bull harvest rates. Figure 43 contrasts harvest rates in the two hunting districts, illustrating the differential influence of weather. The differential influence of weather between hunting districts is apparent if the harvest rate in the first 36 days of the season is examined (Fig. 44). Mild weather in the first five weeks of the season reduced harvest rates in HD 270 but not HD 250 from 1957-1964 (Fig. 44). Figures 45 and 46 present trend in antlered bull harvest rates (mean and variance) for HD 250 and HD 270, respectively.

The peak harvest rate observed in 1973 is unprecedented for HD 250 (Fig. 45). Extreme snow depths early in the season apparently prevented West Fork Area elk from migrating into Idaho and forced them to congregate on accessible winter range in the Bitterroot (John Firebaugh, FWP, pers. comm.). Note also that annual variation in the harvest rate is relatively stable in HD 250 until the mid-sixties (Fig. 45). Following a period of large fluctuations in the mid-sixties, harvest rates stabilized again in the seventies (Fig. 45). Harvest rates increased gradually from 1976 to 1989, consistent with trends in elk population growth (Fig. 8). The variance in the daily harvest rate in HD 250 peaks during the mid-sixties. The four years with the greatest variance in the daily antlered bull harvest rate had the greatest opening day effect (> 25% total harvest on opening day). The large variances are the result of the harvest being strongly skewed toward opening day of the hunting

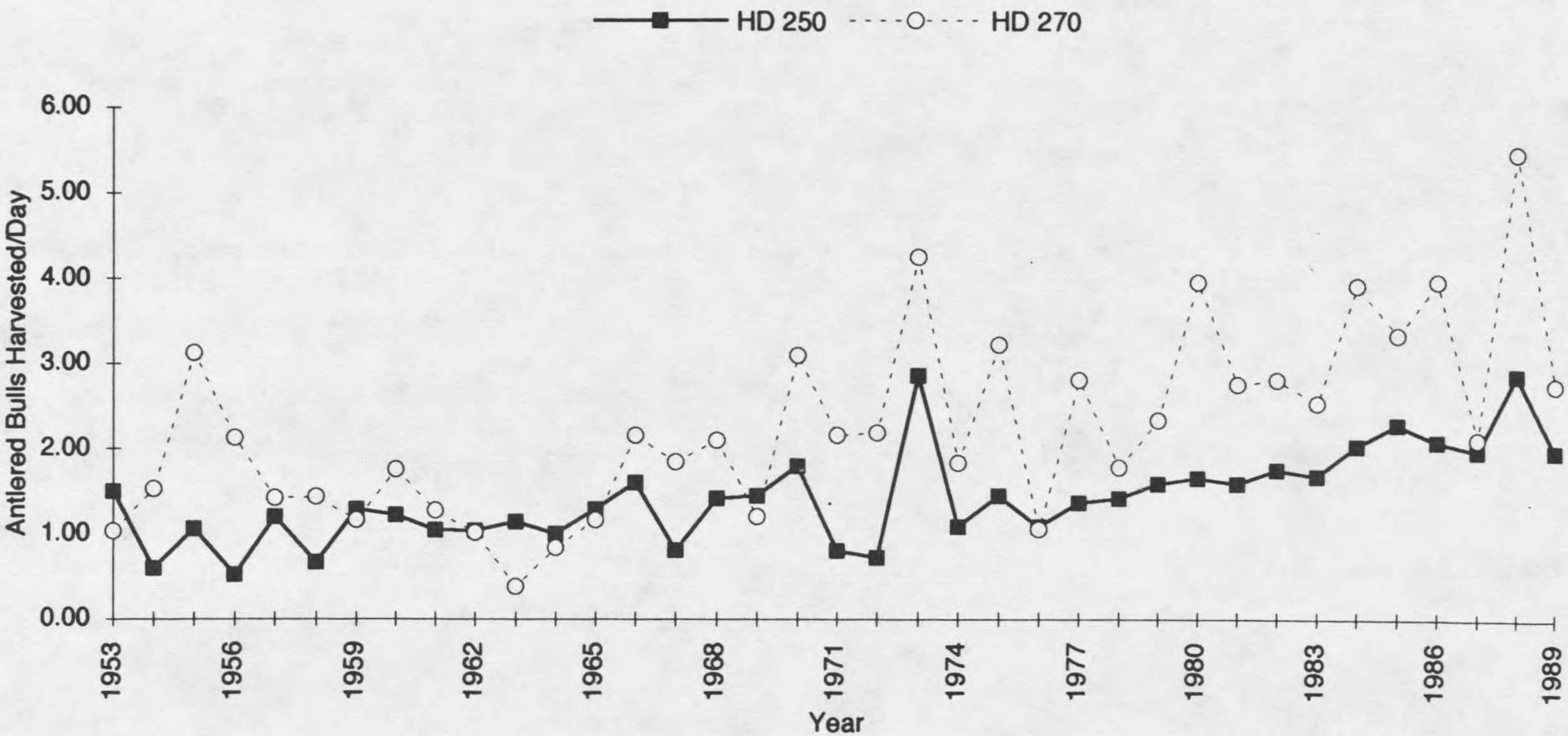

Figure 43. Trend in harvest rate of antlered bulls in HD 250 and HD 270. Darby check station results, upper Bitteroot, Ravalli Co., MT.

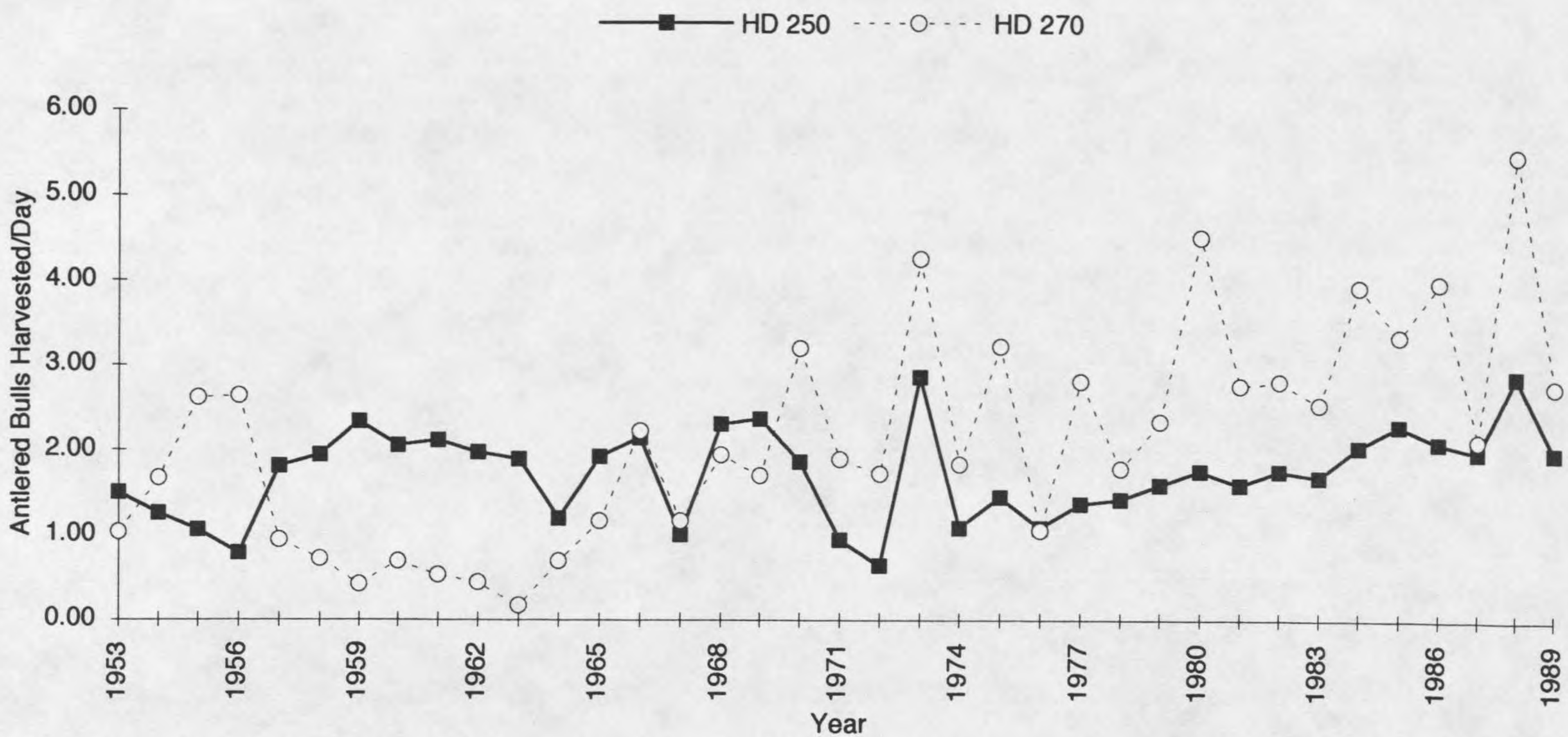

Figure 44. Trend in 36-day harvest rate of antlered bulls in HD 250 and HD 270. Darby check station results, upper Bitteroot, Ravalli Co., MT.

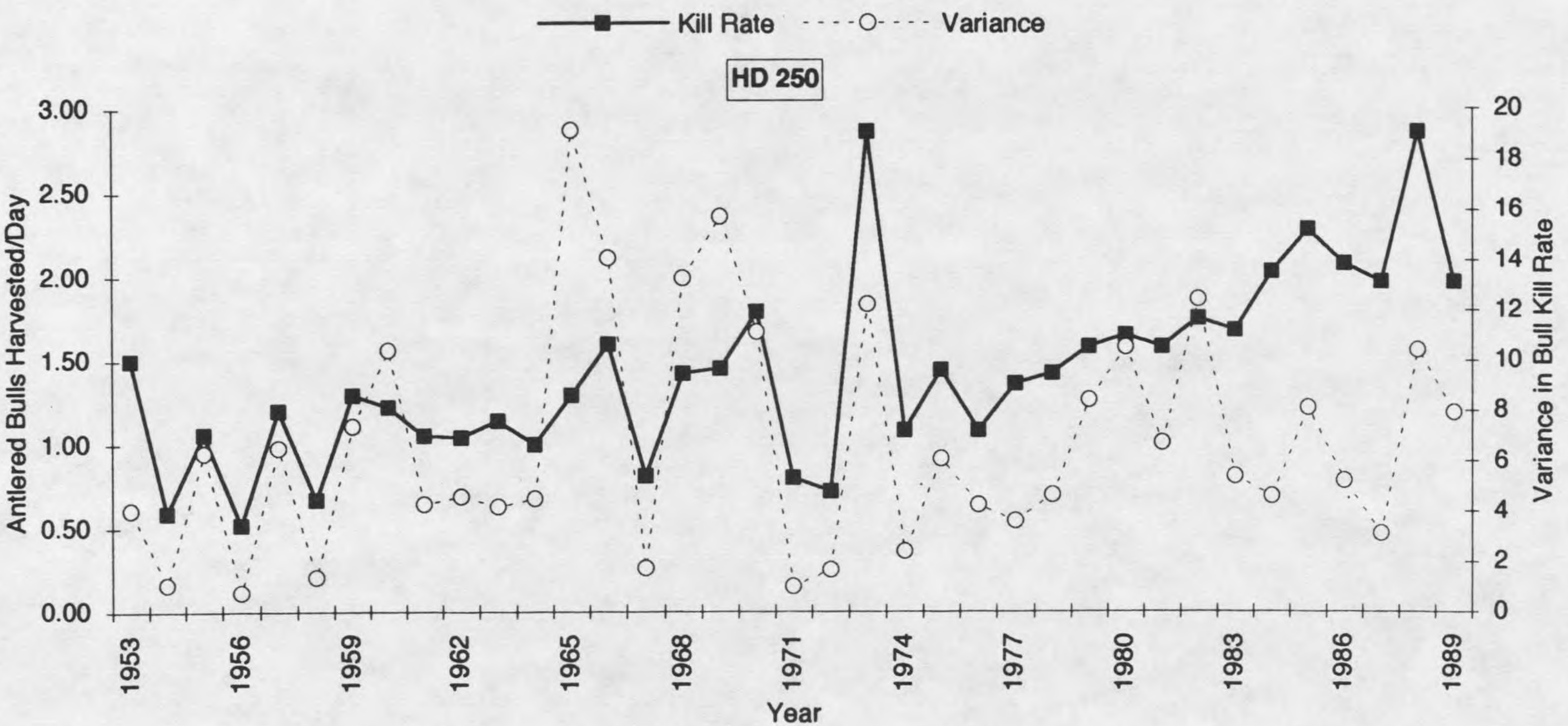

Figure 45. HD 250. Trend in mean and variance in antlered bull harvest rate over length of bull season. Darby check station results, upper Bitterroot, Ravalli Co., MT.

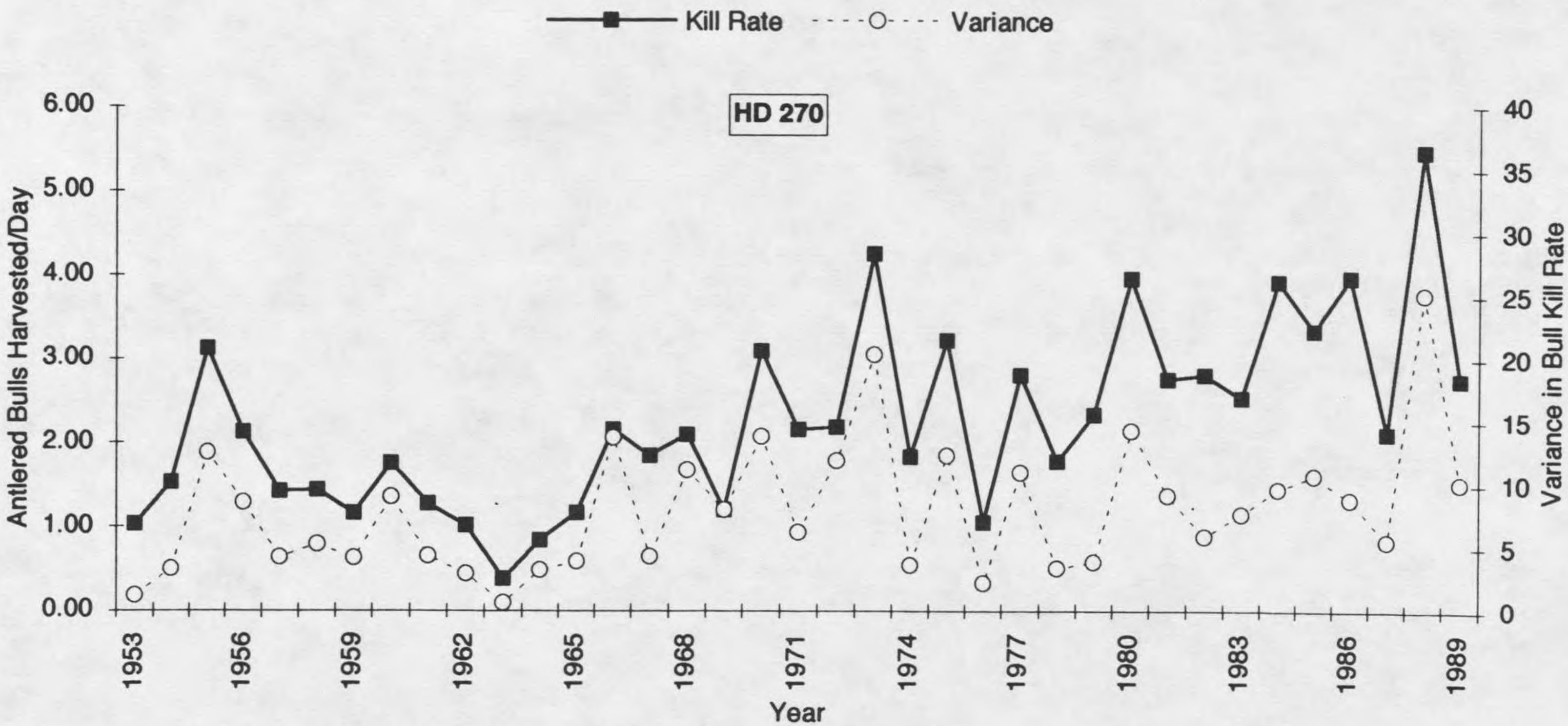

Figure 46. HD 270. Trend in mean and variance in antlered bull harvest rate over length of bull season. Darby check station results, upper Bitterroot, Ravalli Co., MT.

season. As discussed previously, these years were average to mild with respect to weather, and weather typically has little influence on elk harvest in HD 250, in contrast to HD 270.

In HD 270, note that the annual variation in the harvest rate increases during the second two decades (Fig. 46). This may be partially explained by change in weather patterns. Weather varied less during the first two decades than during the second two decades (Table 1). In the seventies, mild weather hunting seasons were often followed by severe weather seasons, generating the pronounced "saw-tooth" pattern observed during the seventies, and, to a lesser extent, the eighties. In contrast to HD 250, the variances in antlered bull harvest rate do not inflect during the mid-sixties (Fig. 46). This is consistent with the observations that the distribution of the harvest in HD 270 tends to be either uniform or skewed toward the latter part of the season and that elk are not vulnerable after the rut in the early part of the season if weather is mild or average.

Triangle Area

I examined the mean and variance in the bull harvest rate in the Triangle area to determine if the pattern observed in HD 250 is present at a smaller scale. The Triangle Area was selected because it is uniformly well sampled (because it lies entirely south of the Darby check station) and well delineated (located between the East and West Forks of the Bitterroot River). Analysis units in HD 270 do not correspond exactly with the East Fork and Rye Creek Areas as they do in the Triangle. Recall that Rye Creek and East Fork management areas were delineated during the early 1950s on the basis of geography and what was then known of elk herd movements. Individual analysis units in HD 270 do not exactly "fit" within each management area in HD 270 because they represent the current knowledge of elk herd movements. Because road densities were computed at the analysis unit level, it would have been difficult to compute road densities for either the East Fork Area or the Rye Creek Area. However for the Triangle Area, road density figures could be computed by simply combining results from individual analysis units.

In the Triangle Area, a peak in harvest rate coincides with the mid-point of road construction activity (Fig. 47). This peak harvest rate of antlered bulls was followed by a sharp decline (Fig. 47). In the eighties, the antlered bull harvest rate steadily increased (Fig. 47). However the harvest rate of mature bulls remained relatively constant (Fig. 47). Figure 48 is a plot of the variance of the daily antlered bull harvest against trend in road density for the Triangle Area. Note that the greatest variation in the antlered bull harvest rate coincided with peak road construction. These large variances in harvest rate capture opening day effect and are therefore attributed to increased vulnerability.

I was unable to extract and compile the daily elk harvest for each of the 17 analysis units under the time constraints of this study. However, the total number of elk harvested (by age class) for each analysis unit was extracted and compiled. A mean harvest rate (elk harvested/ day) can be obtained for each analysis unit by dividing elk harvest by the number of days of the hunting season. This method of deriving a harvest rate precludes computation of a variance for harvest rates.

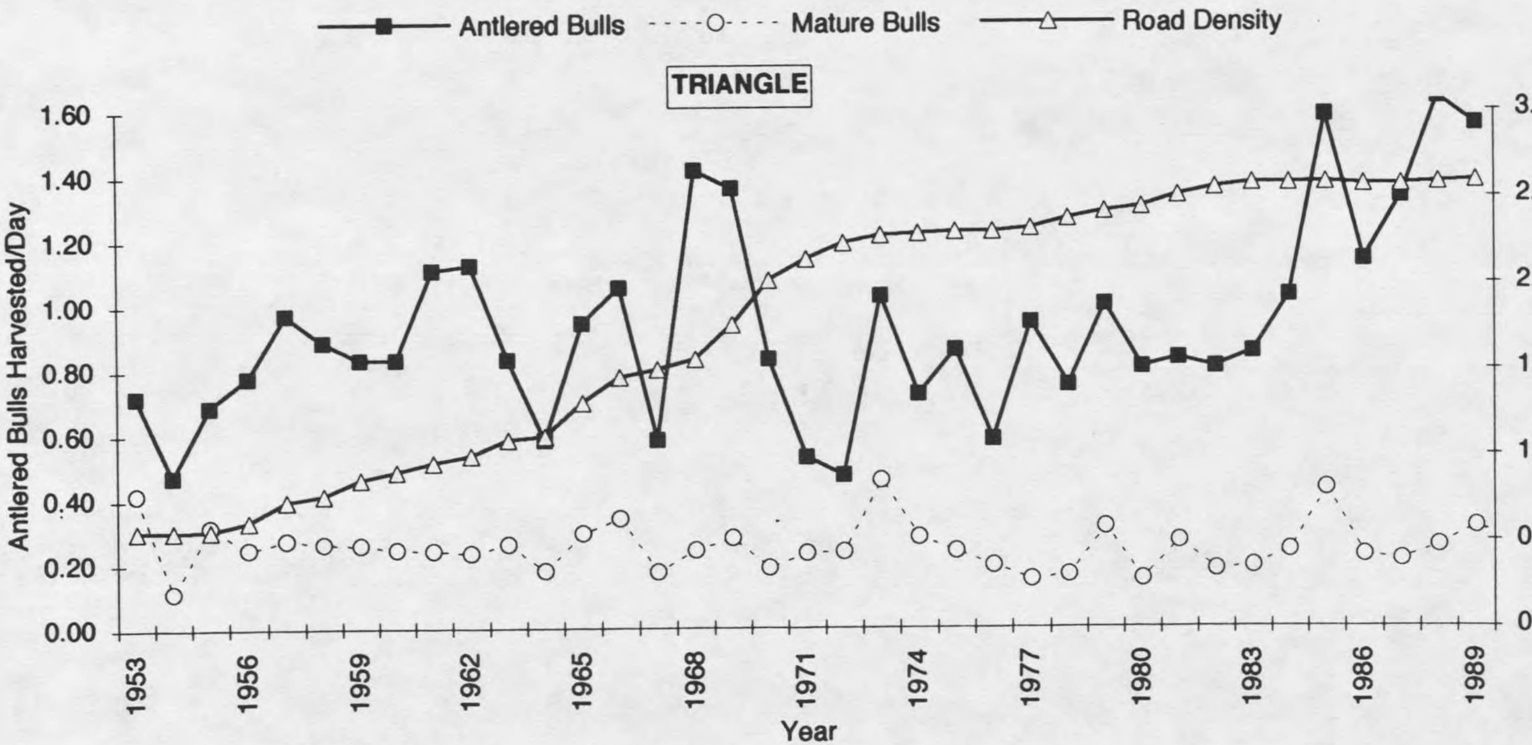

Figure 47. Triangle Area (HD 250). Trend in antlered bull and mature bull harvest rates against trend in Triangle Area road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

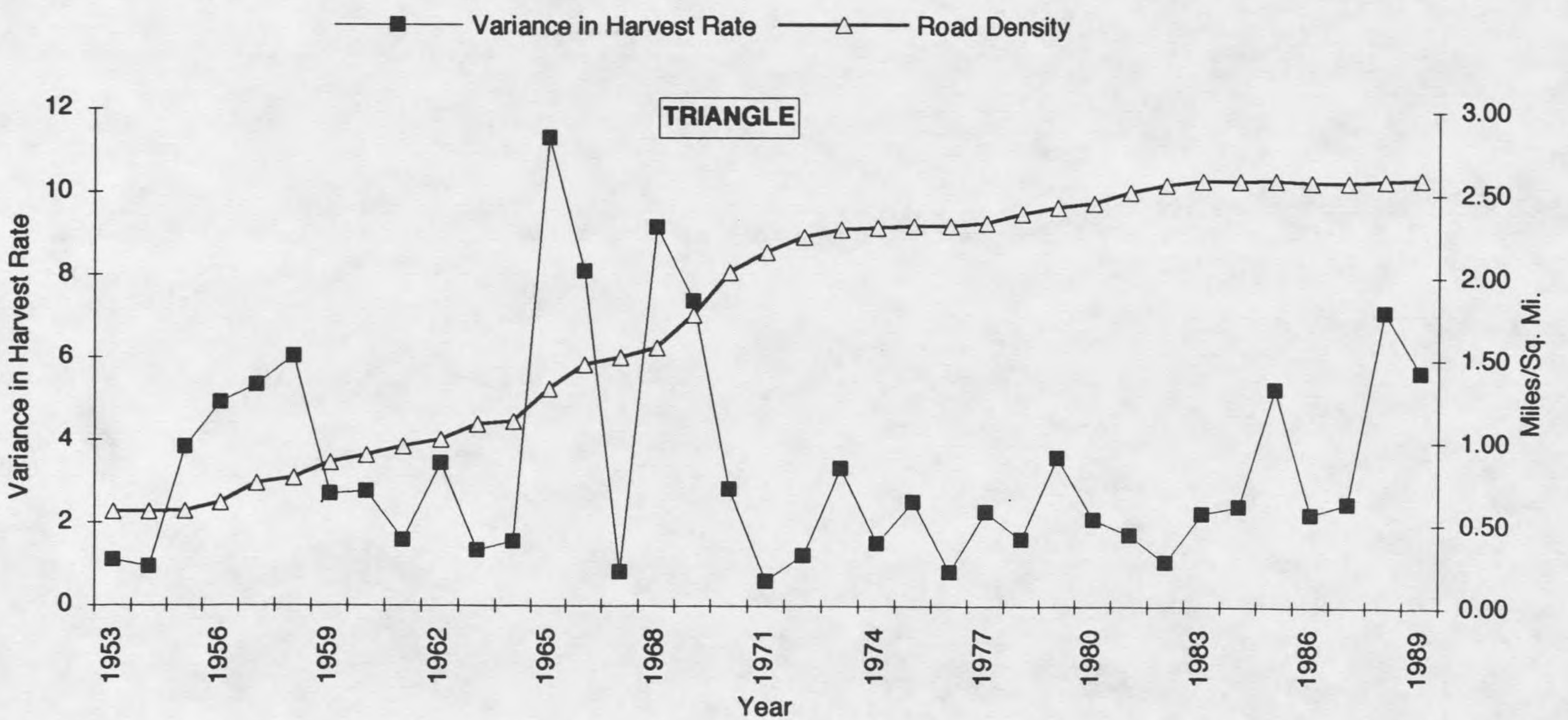

Figure 48. Triangle Area (HD 250). Trend in variance in antlered bull harvest rate against trend in road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

Analysis Units in HD 250

At the small scale of analysis unit, small sample size decreases the signal to noise ratio. However, in analysis units AU-T1 and AU-T3 in the Triangle (Fig. 10), there is evidence of inflections in the mature bull harvest rate coinciding with inflections in road miles (Fig. 49 and 50). In AU-T1 and AU-T3, sharp inflections in road construction result in elevated harvest rates followed by general decline in the harvest rate of mature bulls. In AU-T4, mature bull harvest rates are relatively constant until the period of peak road construction, at which point annual variation in the harvest rate increases dramatically (Fig. 51). It is unclear why harvest rates should become more variable, as the influence of weather is less evident in HD 250 than in HD 270.

Three of the five analysis units in the Triangle show changes in either the magnitude of the harvest rate coincident with peak roading (AU-T1 and AU-T3) or show dramatic increases in the annual variation in the harvest rate subsequent to peak roading (AU-T4). In the two analysis units where no inflection in the mature bull harvest rate occurred, road construction occurred much more gradually (Figs. 52 and 53). In particular, note the gradual slope of the accumulated road density line in AU-T2 and the corresponding lack of changes in magnitude in the harvest rate.

Sample size for two of the five analysis units in the West Fork Area (AU-W1 and AU-W2) is sufficient to examine trend in mature bull harvest rate without random sampling effects overwhelming the pattern. In AU-W1, the peak in the mature bull harvest rate coincides with the peak inflection in road construction (Fig. 54). Road construction begins much earlier in AU-W2 (Fig. 55) than other analysis units and the inflection in the harvest rate occurs

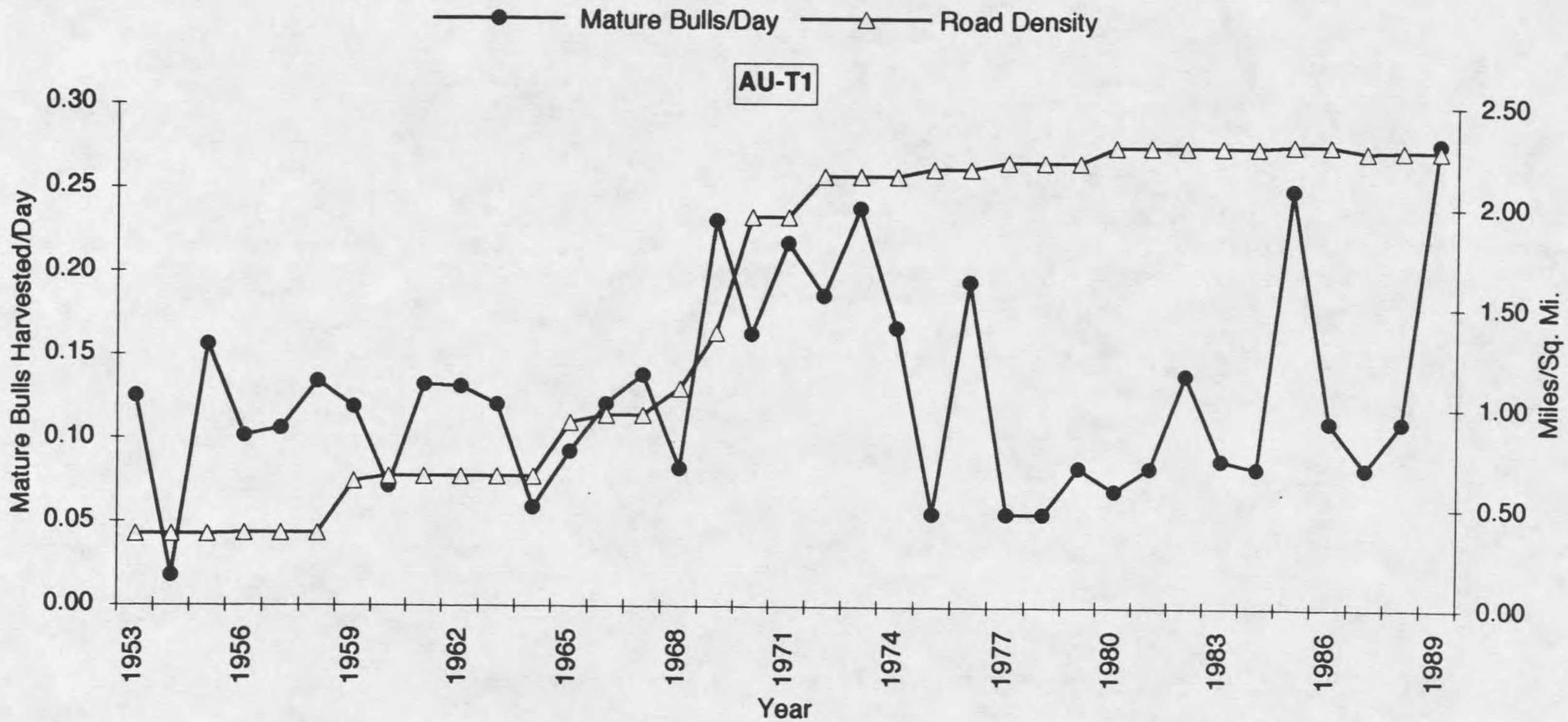

Figure 49. Analysis Unit T1, (Triangle Area; HD 250). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

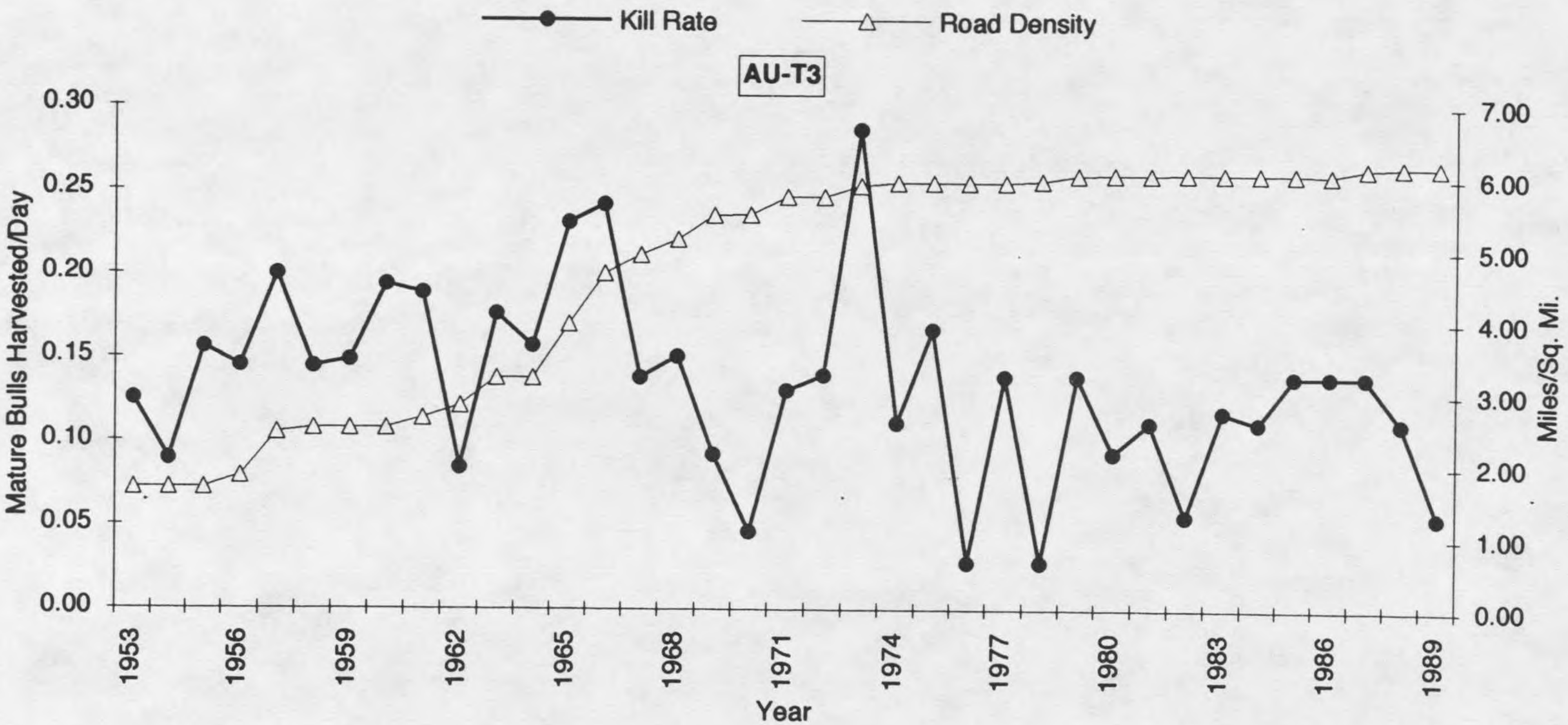

Figure 50. Analysis Unit T3, (Triangle Area; HD 250). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

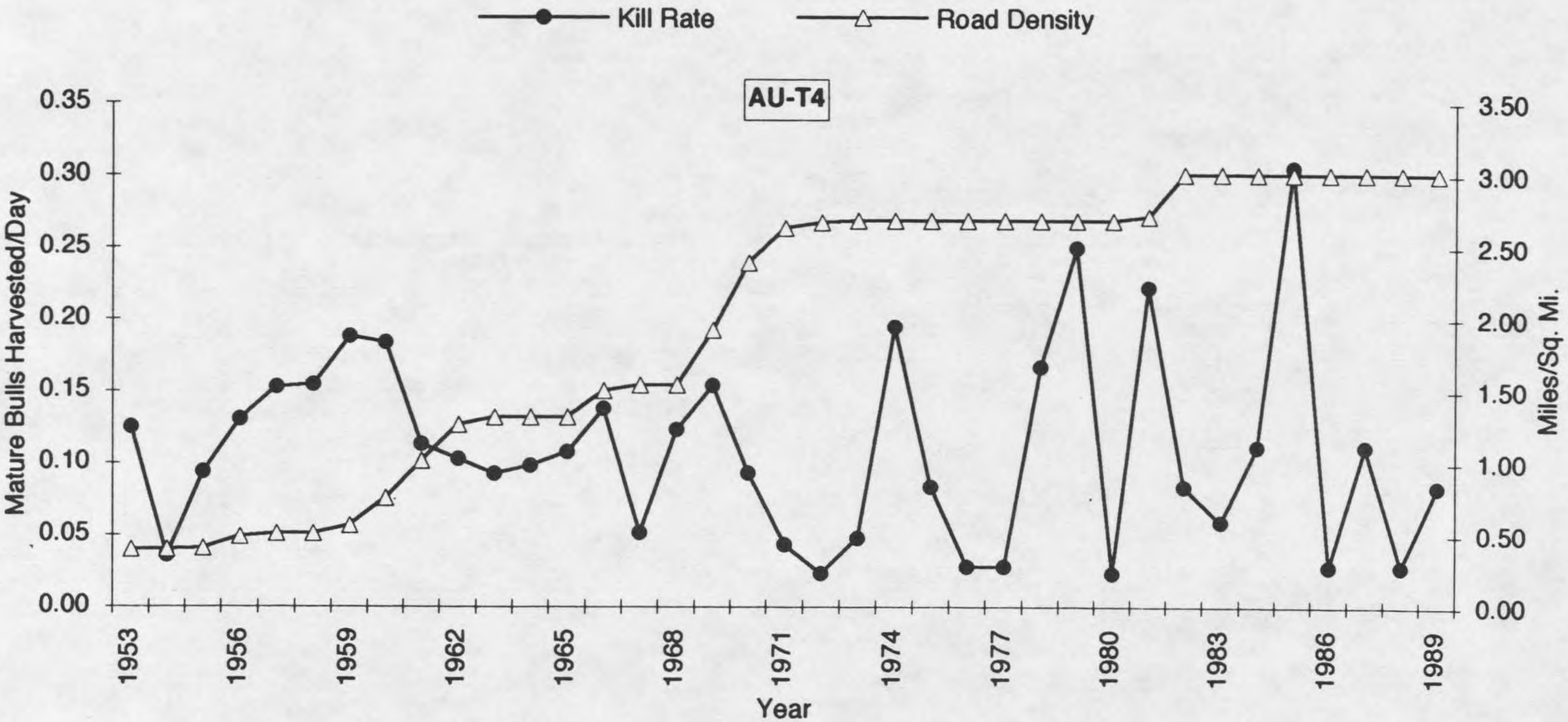

Figure 51. Analysis Unit T4, (Triangle Area; HD 250). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

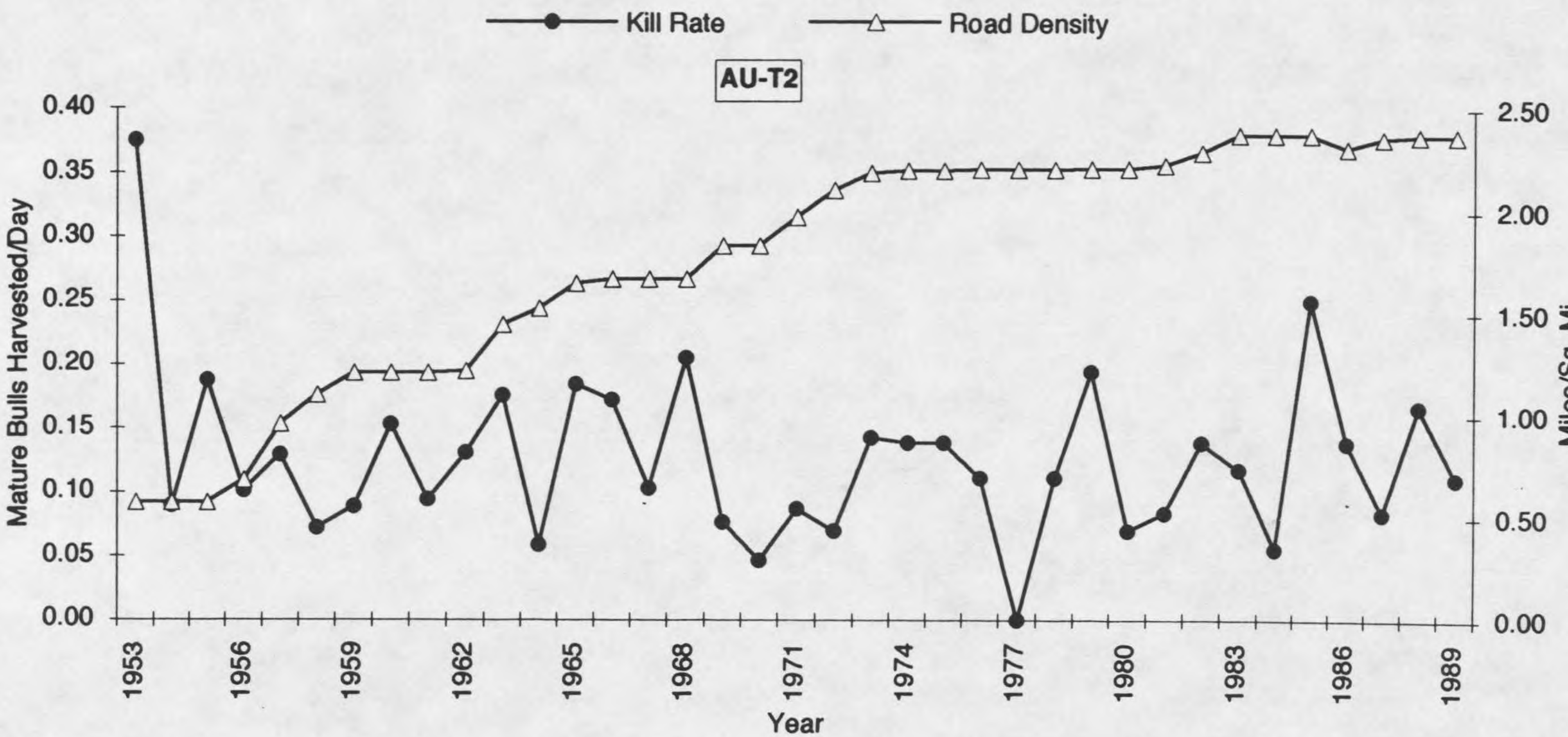

Figure 52. Analysis Unit T2, (Triangle Area; HD 250). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

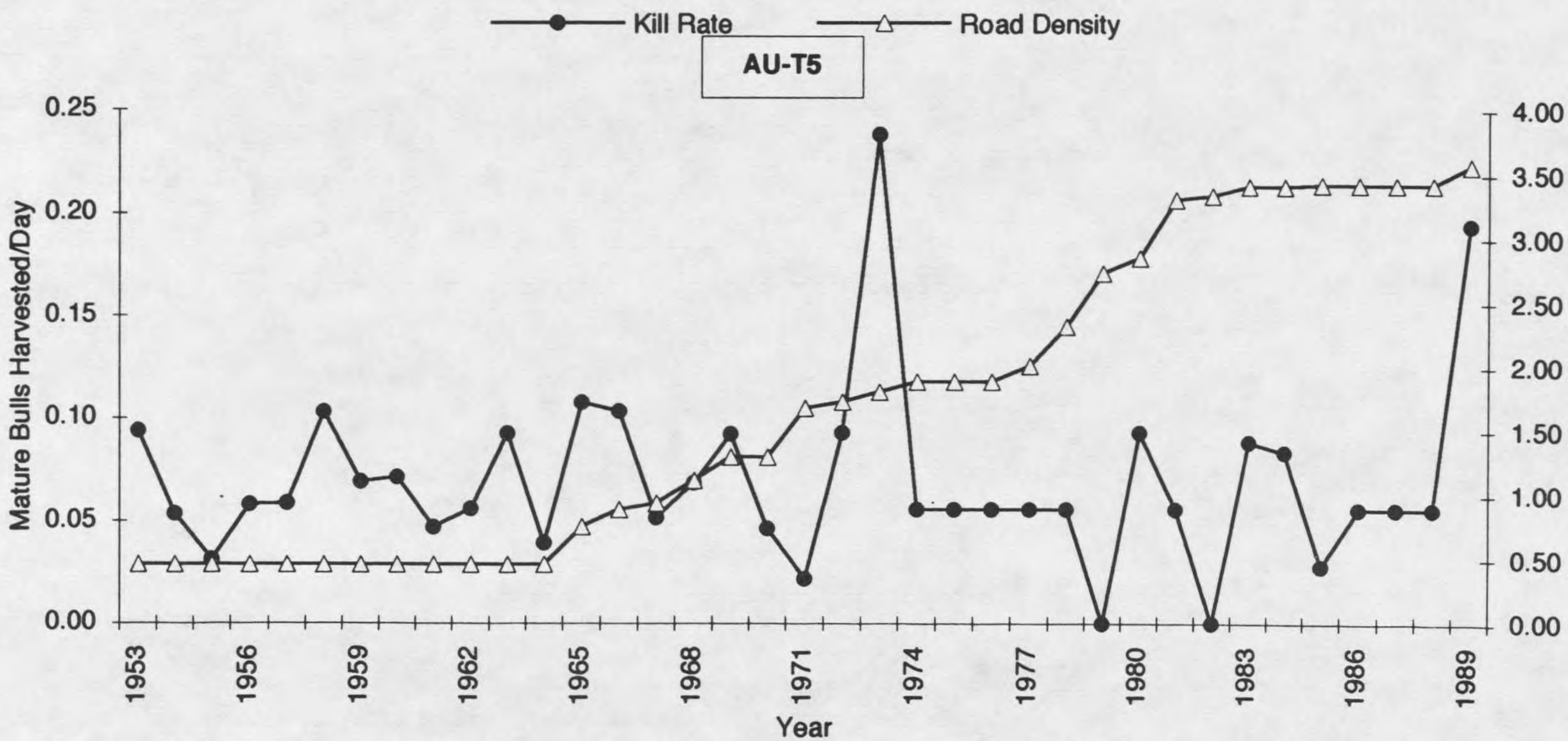

Figure 53. Analysis Unit T5, (Triangle Area; HD 250). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

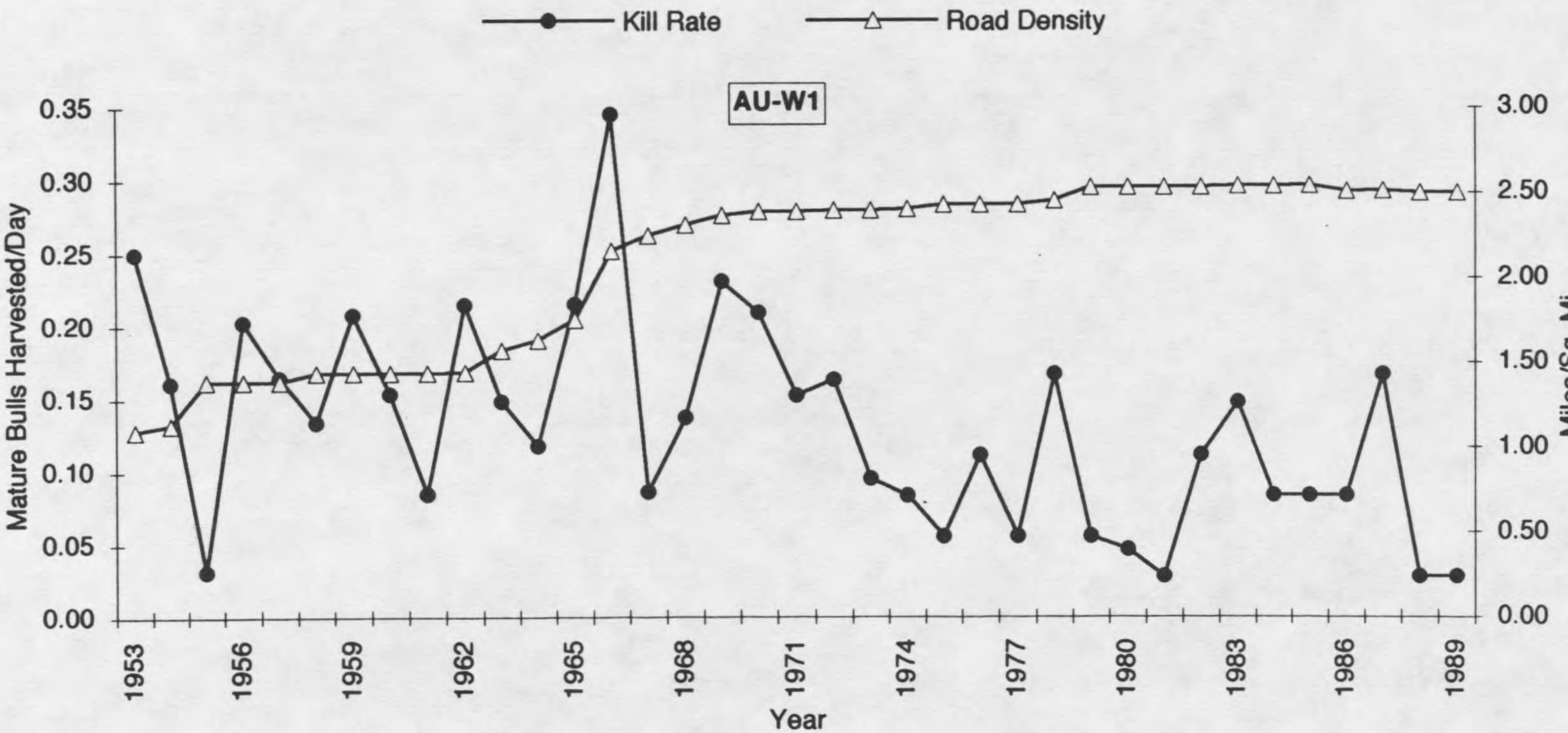

Figure 54. Analysis Unit W1 (West Fork Area; HD 250). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

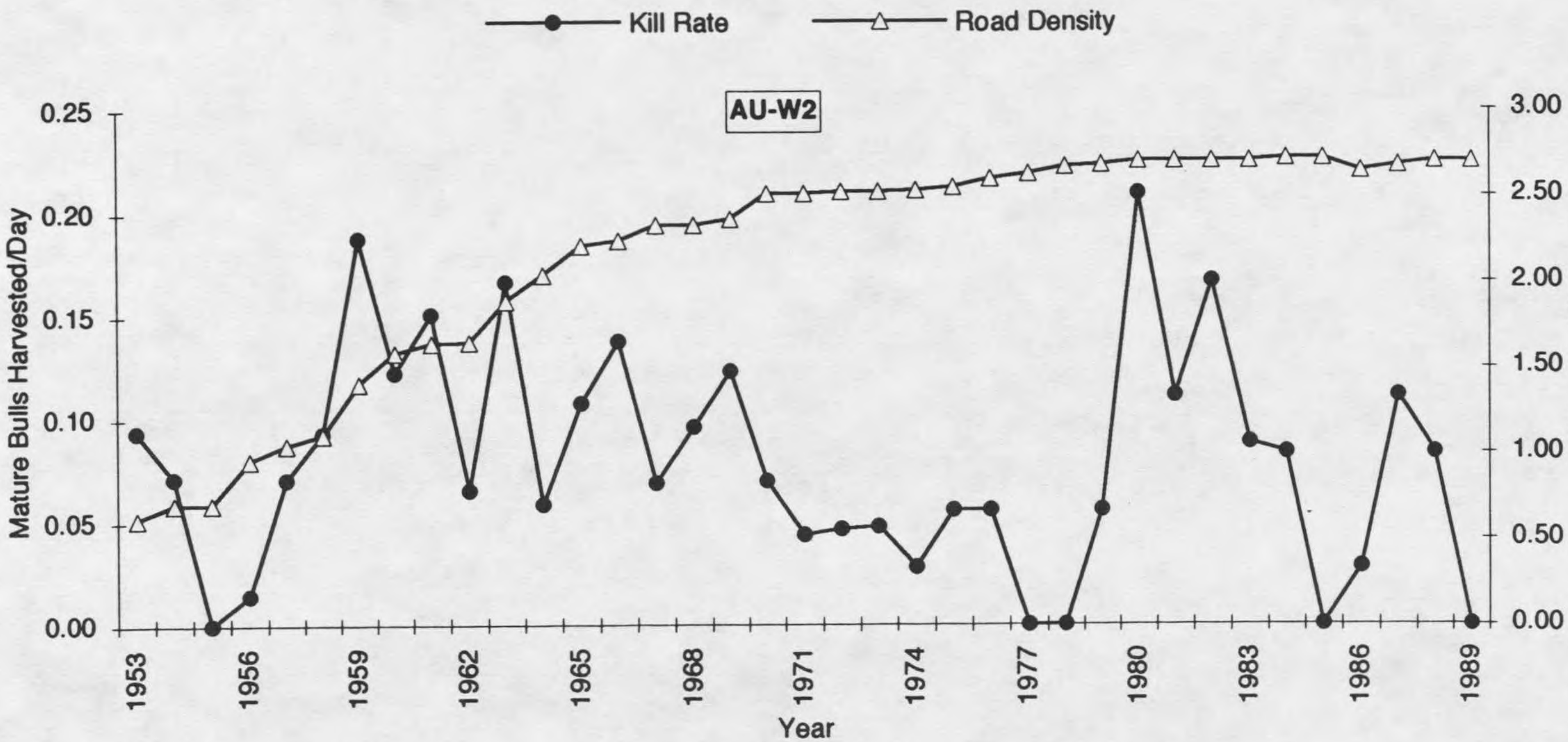

Figure 55. Analysis Unit W2 (West Fork Area; HD 250). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

earlier. Note also that a pattern of successively lower peaks in harvest rates follows this period of high harvest rates. Number of hunters was relatively constant during the period that inflections in harvest rate occurred.

Analysis Units in HD 270

As discussed previously, the trend in the harvest rate in HD 270 is largely obscured by weather effects. However, within individual analysis units some trend information does emerge that is consistent with the hypothesis that roading and loss of security cover have influenced bull harvest rate.

In Analysis Unit E-5, the harvest rate inflects, then dramatically declines, coincident with two events: initiation of roading and the 11,700 ha Sleeping Child fire in August of 1961 (Fig. 56). Note the large variance in the annual harvest rate in AU-E5 subsequent to roading and the fire and how the harvest rates have tended to dampen out during the last decade.

In the Divide Area, Analysis Unit D3 is notable in that 78% of the land area (41,162 acres) is part of the Anaconda-Pintler Wilderness. However, of the non-wilderness portion of the analysis unit, development has resulted in road densities of 5.5 miles/mi^2 with 24% of the non-wilderness habitat affected by logging. Figure 57 is a plot of the trend in road density against the mature bull harvest rate. Note that the first inflection in the harvest rate occurred in 1966, coincident with initiation of elevated rates of road building in the mid-sixties. As noted previously, 1966 was ranked as mild with respect to the winter severity index (Table 1). The second inflection in the harvest rate occurs in 1973, attributable to severe snow conditions that prompted elk to

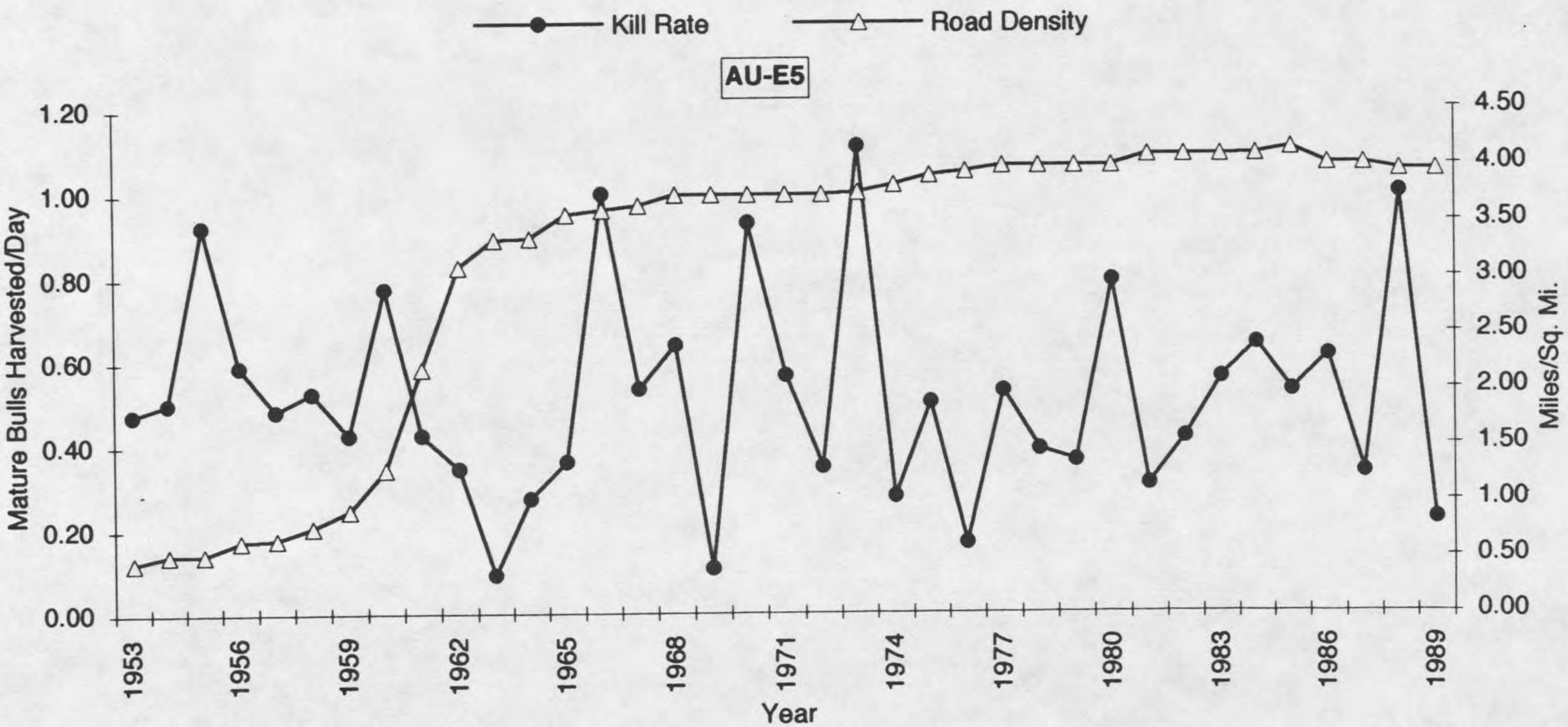

Figure 56. Analysis Unit E5 (HD 270). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

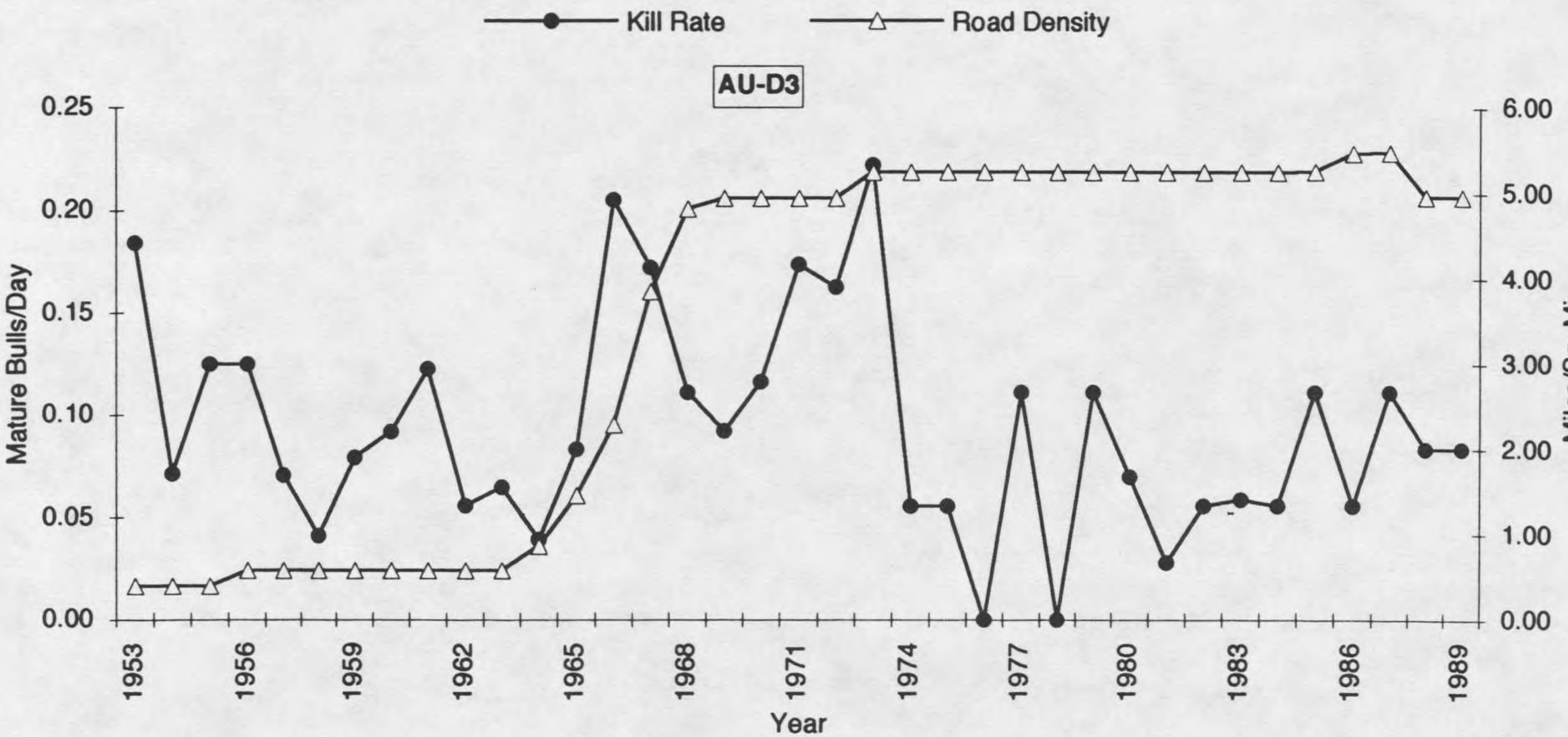

Figure 57. Analysis Unit D3 (HD 270). Trend in mature bull daily harvest rate versus road density. Darby check station results, upper Bitterroot, Ravalli Co., MT.

move from the wilderness to the developed portion of the analysis unit (Fig. 24). When mature bull harvest is plotted against season length in AU-D3 (Fig. 58) note that bull harvest is out of phase with season length and that unlike many analysis units, mature bull harvest remained higher for a longer period of time (to 1973). One possible explanation for the persistence of a relatively high bull harvest rate is a combination of high elk security in the wilderness portion of the analysis unit during mild years and the periodicity of weather, resulting in severe snow conditions and elevated harvest only every few years.

Analysis of Statistical Problems

Many of the variables examined thus far are closely correlated with each other, confounding interpretation of regression results. Season length, road density, logging and number of hunters are all partially correlated, as observed earlier in examination of the partial correlation matrices of selected variables. We have examined pattern for the data over time and observed that when mature bull harvest is plotted against the original variables (season length, road density, percent habitat affected and number of hunters) it is immediately apparent that a strong temporal or time series component is present. Coupled with the existence of a time trend is the problem of multicollinearity within the set of original variables. The correlation and partial correlation matrices of the original variables are presented in Tables 6 - 9.

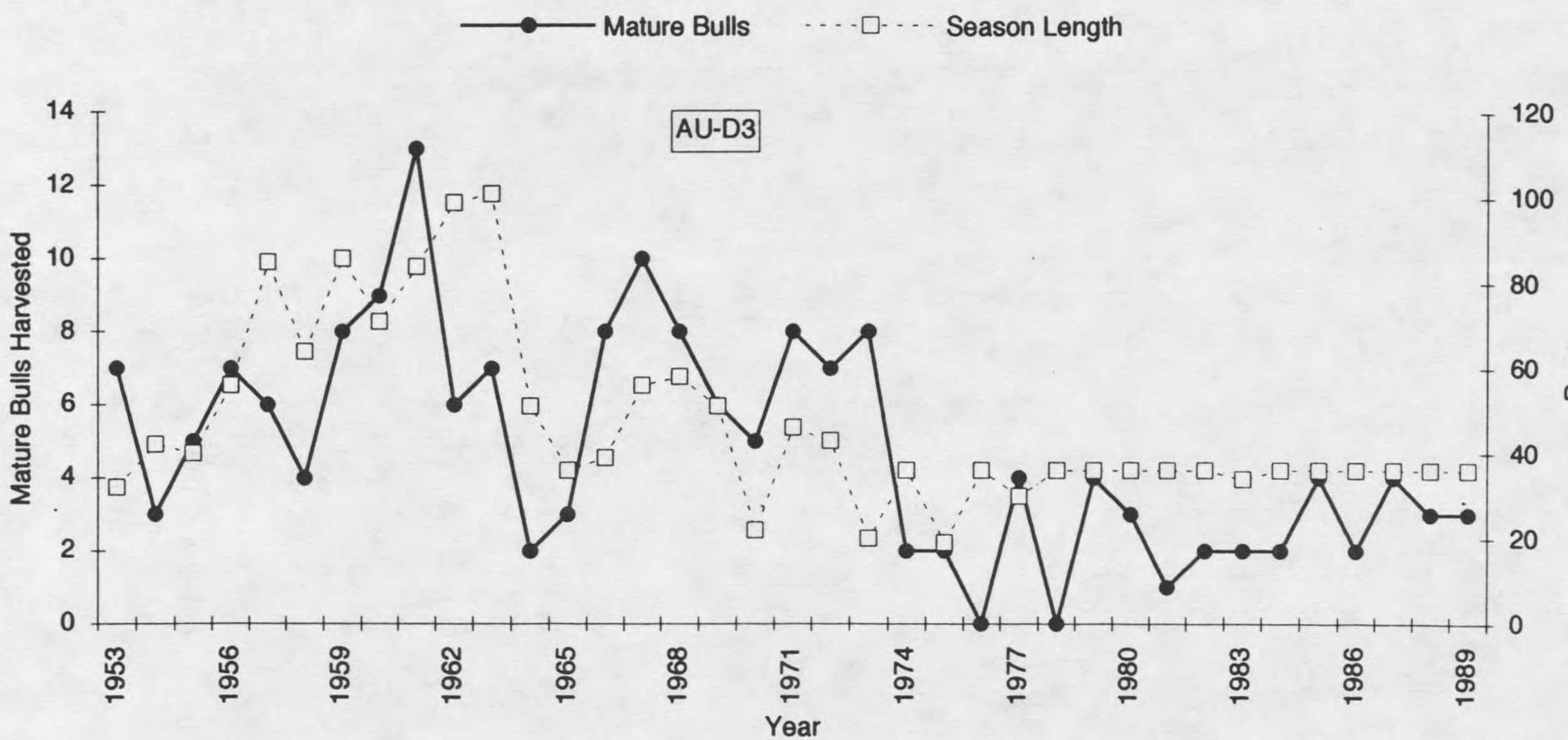

Figure 58. Analysis Unit D3 (HD 270). Trend in mature bull harvest versus either-sex season length. Darby check station results, upper Bitterroot, Ravalli Co., MT.

Table 6. Correlation matrix of selected variables for HD 250. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	Road Density	% Logging	Season Length	Hunters	Avg. IWS.
Year	1					
Road Density	0.9669	1				
% Logging	0.9913	0.9519	1			
Season Length	-0.6196	-0.6738	-0.6555	1		
Hunters	0.8957	0.9183	0.8826	-0.5275	1	
Avg. IWS.	0.2212	0.2212	0.2093	-0.1782	0.3004	1

Table 7. Partial Correlation matrix of selected variables for HD 250. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	Road Density	% Logging	Season Length	Hunters	Avg. IWS.
Year	.9922					
Road Density	.6724	.9687				
% Logging	.9361	-.4558	.9886			
Season Length	.5691	-.6035	-.5595	.6751		
Hunters	-.2144	.5771	.2351	.3944	.8767	
Avg. IWS.	.1762	-.2057	-.1769	-.2072	.3075	.1524

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 8. Correlation matrix of selected variables for HD 270. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	Road Density	% Logging	Season Length	Hunters	Avg. IWS.
Year	1					
Road Density	.9142	1				
% Logging	.9092	.9807	1			
Season Length	-.5828	-.5535	-.5461	1		
Hunters	.9049	.7667	.7396	-.4894	1	
Avg. IWS.	.2401	.2305	.2588	-.272	.1577	1

Table 9. Partial Correlation matrix of selected variables for HD 270.Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	Road Density	% Logging	Season Length	Hunters	Avg. IWS.
Year	.9488					
Road Density	.0246	.9663				
% Logging	.3722	.8749	.9684			
Season Length	-.2046	-.08	.0747	.3672		
Hunters	.8141	.1517	-.3534	.0933	.8647	
Avg. IWS.	.0657	-.2181	-.1306	-.1628	-.0747	.1152

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Two key variables, road density and logging, are cumulative functions that reflect an impact that has occurred over time on the Bitterroot National Forest. These two functions are positive and constantly increasing. More formally, the respective error terms of these two variables are correlated over time (autocorrelated). Hunter trips do not increase constantly, but there is an obvious temporal component to this variable (Fig. 11). Season length tends to have a strong temporal component from 1953 until 1963. In the early 1970s, season length converged on 36 days (Figs. 18 and 19).

There are problems associated with autocorrelation that deserve a brief discussion. In situations where the error terms in the regression are positively autocorrelated, the use of ordinary least squares procedures to construct a regression model has several important consequences that greatly reduce the utility of least squares regression (Neter et al., 1985). Autocorrelation problems also limit the utility of statistical methods such as path analysis to estimate model coefficients.

The consequences of multicollinearity are also substantial. The regression coefficient of any independent variable is dependent on which of the other independent variables are included in the model and which ones are excluded. Furthermore, there is not a unique sum of squares which can be ascribed to an independent variable (Neter et al. 1985).

If, within each analysis unit, the temporal sequence of road building and logging differed substantially, then sufficient variation would exist to estimate the relative contribution of each predictor variable in explaining variance in the response variable (an index of elk vulnerability). Although each of the 17 individual analysis units has its own unique history with respect to levels of road building and logging, there is little variation between analysis units in the timing of peak road construction and season length. The relatively uniform pattern in timing of road building, logging, and season length poses a serious (and potentially intractable) statistical problem. Figures 37 and 38 illustrate the confounding aspects of changes in season length and roading coincident with a general decline in the harvest of mature bulls.

Conceptual Models of Vulnerability

The problem of elk vulnerability may be addressed in two contexts: 1) a pure cumulative effects model and 2) a dynamic response model. In the case of a pure cumulative effects model, elk vulnerability increases monotonically as access, logging and number of hunters increase. Alternately, in a dynamic response model, elk are subjected to "shocks" of increased vulnerability as new roads and logging occur, and respond by adjusting movements to reduce vulnerability. In a pure cumulative effects context, incremental increases in access, logging and number of hunters contribute to an overall increase in vulnerability in subsequent years. In a dynamic response model, new roads and logging are more important than roading and logging in previous years. Both hypotheses have merits, and both may play a role in elk vulnerability; however, the "detrended" variables in a dynamic response model offer more potential for meaningful insight derived from exploratory multivariate statistical procedures.

Principal Components Analysis

Principal components analysis (PCA) is a multivariate procedure that is designed to reduce the dimensionality of a data set. It is routinely used as an exploratory analysis to create a few synthetic variables from many. For this study, the original analyses were limited to six variables (Tables 6 -7). Year was included as a variable to capture the influence of time trend. Road density is recorded in mi/mi^2. The "logging" variable is the cumulative percentage of total acreage logged or burned by the beginning of the hunting season in that year. This variable increases monotonically with time and does not include a regrowth provision for reasons discussed previously (see methods). Season length is the duration of the antlered bull season in days. Number of hunters was computed as described in the methods section. Average winter severity was computed as described previously in the methods section.

Most other candidate variables appeared to be redundant. For example, temperature and days of snow on ground were considered but excluded. Percent habitat affected and road miles may be expressed several different ways also. However, I chose to keep the analysis as simple as possible because adding redundant variables to the data set increases the percentage of the variance explained by the first principal component, which ultimately adds noise to the system with the result that interpretation becomes increasingly difficult (Johnson 1981).

The PCA results in this analysis are base on the correlation matrix structure, not the covariance matrix structure. PCA results presented in Table 10 illustrate the consequences of using variables which have a strong time-trend component.

In HD 250, the first principal components axis captures 73% of the variance in the original set of variables (Table 10). A greater dispersion of the proportion of the original variance accounted for among the principal components axes is clearly desirable. The first principal component (PC I) is composed of approximately equal weightings of the variables year, road density, logging and number of hunters (Table 10). The scores from this first axis constitute a new, independent "synthetic variable." Unfortunately, this

Table 10. Results of principal components analysis for HD 250 with selected variables. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Magnitude	Variance Prop.	Variable	PC I	PC II	PC III
Eigenvalue 1	4.3507	**.7251**	Year	**-0.4673**	-0.0909	-0.1827
Eigenvalue 2	.9324	**.1554**	Road Density	**-0.4697**	-0.0901	-0.0922
Eigenvalue 3	.5475	.0913	% Logging	**-0.4668**	-0.1055	-0.1122
	Sum	**.9718**	Season Length	0.3502	0.0758	**-0.9146**
			Hunters	**-0.4451**	0.0306	-0.3274
			Avg. IWS.	-0.1495	**0.9828**	0.0434

new independent variable is useless because the loadings of four of the original variables on PC I are nearly equal. Thus, we do not obtain a synthetic variable that captures the influence of any meaningful subset of our original variables, such as "roads and logging" or "number of hunters and season length." For HD 270, PC I and PC II capture 68% and 15% respectively of the original variance (Table 11). As was the case for HD 250, PC I is composed of nearly equal weightings of year, road density, logging and hunters .

For both hunting districts, axis PC II captures 15% of the original variance. Average winter severity loads as the dominant variable in PC II (Tables 10 and 11). However, in HD 270 season length has a somewhat larger weighting (-0.217) than obtained in HD 250 (0.075). Because the principal component scores from this second axis are uncorrelated (have zero covariance) with the scores from the first axis, PC II scores can be used as values of a new, independent weather variable. This independent weather variable may be regressed against a response variable to explore the relationship between weather and vulnerability. Several response variables

Table 11. Results of principal components analysis for HD 270 with selected variables. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Magn-itude	Variance Prop.	Variable	PC I	PC II	PC III
Eigen-value 1	4.0903	**.6817**	Year	**-.4802**	-.1164	-.1151
Eigen-value 2	.9525	**.1587**	Road Density	**-.4708**	-.1091	-.1498
Eigen-value 3	.5762	.096	% Logging	**-.4678**	-.0759	-.1686
	Sum	**.9364**	Season Length	.3403	-.2172	**-.914**
			Hunters	**-.4316**	-.1966	-.1383
			Avg. IWS.	-.1636	**.9397**	-.2854

were selected for this analysis based on results discussed previously. Total elk harvest and mature bull harvest were selected as response variables as was antlered bull harvest rate (antlered bull/day) and the variance in the antlered bull harvest rate. Mature bull harvest rate was not used, because the mature bull harvest rate is more subject to sample size effect (although it exhibits the same pattern as antlered bull harvest).

In HD 250, PC II scores do not correlate with the mature bull harvest ($r^2 = 0.003$, n = 37, P = 0.728) or with the total elk harvest ($r^2 = 0.045$, n = 37, P = 0.204). However, in HD 270 PC II scores are highly correlated with mature bull harvest ($r^2 = 0.46$, n=37, P = 0.0001) and total elk harvest ($r^2 = 0.5089$, n=37, P= 0.0001) (Fig. 59).

The mean and variance in antlered bull harvest rate is a measure of elk vulnerability and is correlated to season length because harvest rates are scaled by season length. In PC II, the weighting coefficient assigned season length is small for both HD 250 and HD 270, and thus the regression should

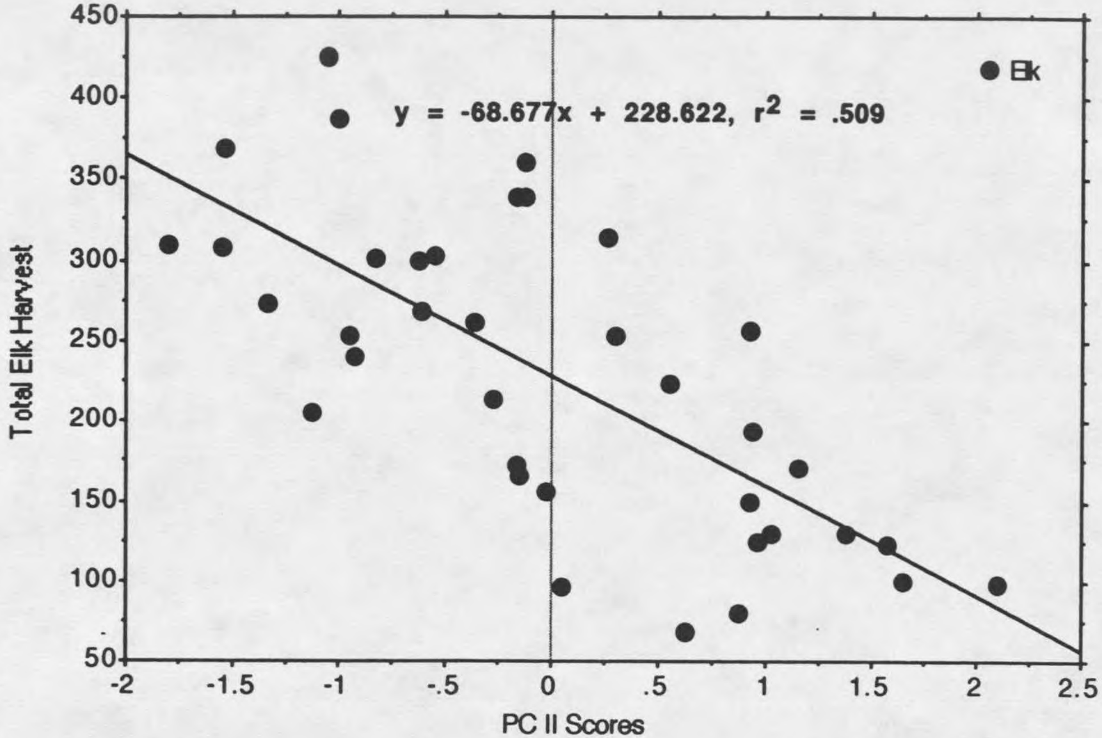

Figure 59. Scatterplot of regression of HD 270 PC II scores (synthetic weather variable) against the total elk harvest in each year. Darby check station results, upper Bitterroot.

be unaffected (Tables 10 and 11). For HD 250, PC II scores do not correlate significantly with either antlered bull harvest rate or the variance in the antlered bull harvest rate. For HD 270, PC II scores correlate significantly with the variance in antlered bull harvest rate (r^2=0.14, n=37, P= 0.018), but not with antlered bull harvest rate.

Section Summary

The strong time-trend component in road density, logging and number of hunters severely limit the utility of PCA results to produce a usable independent variable other than weather. The second PC axis (PC II) for both HD 250 and HD 270 captures the influence of weather. Scores from PC II do not correlate significantly with the elk harvest in HD 250; however, for HD 270, PC II scores correlate significantly with the total elk harvest and with the variance in the harvest rate of antlered bulls.

Detrended Variables

The time-series trend in roading and logging can be eliminated by limiting PCA analysis to miles of new road constructed and the percent of the total acreage impacted by logging or fire during each year individually. Road construction in the upper Bitterroot varied annually but the annual timber volume (board feet) and number of acres logged were fairly constant following passage of the Multiple Use Sustained Yield Act (MUSY) in 1966 (Figs. 6 and 7). Under the Resource Planning Act (RPA) of 1974, Congressionally mandated timber volume objectives required each National Forest to meet an

Annual Sales Quota (ASQ) (timber volume target). The ASQ requirement is responsible for the fairly uniform rate of timber harvest over time in the upper Bitterroot.

Tables of correlation and partial correlation coefficients for detrended variables are presented in Tables 12 -17.

Table 12. Correlation matrix of detrended variables for HD 250. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	New Miles	New Logging	Season Length	Hunters	Avg. IWS.
Year	1					
New Miles	-.3379	1				
New Logging	.4437	.2757	1			
Season Length	-.6196	.322	-.2629	1		
Hunters	.8957	-.352	.3977	-.5275	1	
Avg. IWS.	.2212	-.0468	.0061	-.1782	.3004	1

Table 13. Partial Correlation matrix of detrended variables for HD 250. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	New Miles	New Logging	Season Length	Hunters	Avg. IWS.
Year	.8424					
New Miles	-.0899	.3873				
New Logging	.2085	.5248	.4249			
Season Length	-.3633	.1918	-.0931	.4136		
Hunters	.7975	-.1854	.1186	.1262	.8213	
Avg. IWS.	-.094	.1509	-.1697	-.1	.2635	.1372

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 14. Correlation matrix of detrended variables for HD 270. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	New Miles	New Logging	Season Length	Hunters	Avg. IWS.
Year	1					
New Miles	-.4635	1				
New Logging	-.1367	.551	1			
Season Length	-.5828	.6653	.3923	1		
Hunters	.9049	-.552	-.1461	-.4894	1	
Avg. IWS.	.2401	-.2821	-..2113	-.272	-.1577	1

Table 15. Partial Correlation matrix of detrended variables for HD 270. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Year	New Miles	New Logging	Season Length	Hunters	Avg. IWS.
Year	.8764					
New Miles	.3964	.682				
New Logging	-.0298	.4371	.3479			
Season Length	-.5048	.5322	.0558	.609		
Hunters	.8945	-.5227	.1335	.3702	.8741	
Avg. IWS.	.2367	-.1781	-.0533	.024	-.2142	.1469

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

PCA results for the "detrended" variables of road miles and acres logged for HD 250 and HD 270 are presented in Tables 16 and 17., respectively.

Table 16. Results of principal components analysis for HD 250 with detrended variables. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Magnitude	Variance Prop.	Variable	PC I	PC II	PC III
Eigenvalue 1	2.8324	**.4721**	Year	**-.5591**	-.0493	-.0912
Eigenvalue 2	1.286	**.2143**	New Miles	-.2502	**-.703**	.2486
Eigenvalue 3	.9467	**.1578**	New Logging	-.2817	**-.6983**	-.1266
	Sum	**.8422**	Season Length	.451	-.0786	.125
			Hunters	**-.5465**	-.0133	.0144
			Avg. IWS.	-.2083	.0969	**.9477**

Table 17. Results of principal components analysis for HD 270 with detrendFed variables. Darby check station results, upper Bitterroot, Ravalli County, MT.

	Magnitude	Variance Prop.	Variable	PC I	PC II	PC III
Eigenvalue 1	3.1405	**.5234**	Year	**-.4663**	**-.4529**	.0749
Eigenvalue 2	1.1748	**.1958**	New Miles	**.4684**	-.253	.2016
Eigenvalue 3	.8483	**.1414**	New Logging	.2894	**-.6468**	.3161
	Sum	**.8606**	Season Length	**.4607**	-.0969	.0997
			Hunters	**-.4604**	**-.4582**	-.0408
			Avg. IWS.	-.235	.3055	**.9177**

Note that compared to previous PCA results, a greater dispersion of the proportion of the original variance accounted for among the principal components axes is achieved for both HD 250 and HD 270. In HD 250 PC II, new road miles and new logging are the important variables (Table 16). Scores from PC II may thus be used as values for a new, independent variable that captures the influence of new road construction and new logging in HD 250. In HD 270, PC II variables load in a less interpretable fashion (Table 17) but PC II is clearly dominated by new logging/fire (particularly the Sleeping Child fire) and includes contributions from year and hunters. The third PCA axis in both HD 250 and HD 270 is dominated by the weather severity index variable (Table 16 and 17). However in HD 270, new miles and new logging also contribute to explaining the variance captured in PC III (Table 16).

In HD 250, scores from PC II (new roads and logging) do not correlate with mature bull harvest ($r^2 = 0.0318$, n=37, P = 0.29) nor with total harvest ($r^2 = 0.0608$, n=37, P=0.141). The low weighting given season length in PC II indicates that the new synthetic variable is relatively independent of season length. Scores from PC II do not correlate significantly with the antlered bull harvest rate ($r^2 = 0.007$, n=37, P=0.1727).

As discussed previously, the variance in the antlered bull harvest rate captures the pattern or "evenness" of the distribution of the harvest over the length of the hunting season. During the period of the mid-sixties, variances in the antlered and mature bull harvest rate were larger than at any other time (Fig. 45). This variance was the result of the distribution of the harvest being heavily skewed toward the opening few days of the season (and opening day effect) and is a measure of vulnerability. Scores from PC II correlate significantly with the variance in the antlered bull harvest rate ($r^2 = 0.3463$, n=37, P=0.0001). In HD 250, scores from PC I and PC III do not correlate significantly with either antlered bull harvest rate or with the variance in the antlered bull harvest rate.

For HD 270, PC II is dominated by logging/fire, with contributions from number of hunters and year (Table 17). Scores from PC II do not correlate significantly with any variable relating to elk vulnerability (mature bull harvest, antlered bull harvest rate or the variance in the antlered bull harvest rate). Principal component axis III is dominated by weather, with small contributions from new road miles and new logging/fire. Scores from PC III correlate significantly with both the absolute number of elk harvested, the rate of harvest, and the variance in the antlered bull harvest. The greatest amount of variance is captured in a regression of total elk harvest versus PC III scores ($r^2 = 0.4365$, n=37, P = 0.0001). While PC III scores significantly correlate with antlered bull harvest rate (r^2= 0.112, n=37, P= 0.04) the variance in the antlered bull harvest rate has a stronger correlation ($r^2 = 0.21$, n=37, P = 0.003).

Section Summary

Use of the detrended variables of new road miles and new logging provides for a greater dispersion of the original variance among the three component axes. In HD 250, PC II captures the influence of road construction and logging while PC III captures the influence of weather. The new "roading and logging" variable formed from PC II scores correlate significantly with the variance in the antlered bull harvest rate, but not with other harvest-related response variables. The new weather variable formed from PC III scores did not correlate significantly with any of the harvest-related response variables. In HD 270, PC II captures the influence of logging and fire but PC II scores do not correlate significantly with any harvest-related response variable. HD 270 weather is captured in PC III. Scores from PC III correlate significantly with all harvest-related response variables, however the highest correlation is with the total elk harvest.

Daily Weather in Relation to Elk Harvest

We have examined the influence of weather with respect to the harvest of elk (total number and mature bulls) and with respect to the mean and variance of the harvest rate (antlered and mature bulls/day). This analysis has provided us understanding of the relationship between average winter severity indices during the hunting season and the harvest of elk on an annual scale. However, we would like to explore the relationship between daily indices of weather severity, number of hunters and the harvest. This smaller temporal scale analysis allows us to look for trend in the relationship between weather factors and the harvest and provides a larger sample size for statistical analysis. To do this, I partitioned day of season, day of week, daily elk harvest, daily number of hunters, daily minimum temperatures, daily precipitation, daily snow pillow and daily IWS into four decades: 1953-1960, 1961-1970, 1971-1980, 1981-1989. Partial correlation coefficients were then computed on a decade by decade basis.

Partial correlation coefficient matrices for each decade are presented in Tables 20 - 35, Appendix B, for HD 250 and HD 270. Partial correlation coefficients between weather variables and elk harvest are consistently much lower in HD 250 than in HD 270. In HD 270, accumulated snow pillow has the highest partial correlation coefficient with the daily harvest during all decades.

The daily winter severity index does not perform well with respect to predicting the daily harvest in either hunting district. This is not surprising because actual daily weather, unlike interpolated daily IWS values, is nonlinear.

Partial correlation coefficients between the daily harvest and daily number of hunters are higher for HD 250 than for HD 270 for all decades. In both hunting districts, partial correlation coefficients between daily harvest and daily number of hunters are highest in the decade of the sixties. For both hunting districts, partial correlation coefficients between day of the week and the number of hunters were comparable in the first two decades and increased markedly beginning in the decade of the seventies. This suggests that although more hunters may be hunting on weekdays than in previous decades, the proportion of hunters hunting on weekends (relative to total hunters) has actually increased.

Section Summary

Matrices of partial correlation coefficients are examined with respect to daily weather variables, number of hunters, day of week, and total elk harvest. The correlations between daily weather variables and daily elk harvest are highest for HD 270. The daily IWS does not correlate as highly as daily snow pillow because it is less sensitive to daily changes in weather than is snow pillow data. Temperature was not highly correlated with the daily harvest or with number of hunters. The highest partial correlation coefficients between daily number of hunters and the daily elk kill occurred in the sixties. Correlation between daily number of hunters and day of week indicate the proportion of hunters hunting on weekends has increased over previous decades.

Discussion on Weather and Elk Vulnerability

Winter weather conditions are known to influence strongly movements and habitat selection of elk (Brazda 1953, Murie 1956, Picton 1960, Dalke et al. 1965, Knight 1970, Lovaas 1970, Beall 1974, Picton and Picton 1975, Sweeney and Steinhoff 1976, Leege and Hickey 1977, Lyon 1979). Adams (1982) states: "weather-specifically snow depth-is one of the most important and probably the major factor influencing the timing and rate of autumn elk migration. "Winter weather is known to be an important regulating mechanism in large mammal populations (Martinka 1967, Meagher 1971, Peek et al. 1976, Picton 1978, Picton 1979, Barrett 1982). The increased metabolic costs of locomotion and foraging in snow (Verme 1968, Parker et al. 1984, Wickstrom et al. 1984,) and ungulate adaptations to snow (Pruitt 1959, Pruitt 1960, Pruitt 1979, Kelsall 1969, Telfer and Kelsall 1984) have also been researched.

Quantitative indices have been developed for winter weather variables to measure effects of winter weather on ungulate distribution, survivorship, reproduction and observability (Picton and Knight 1971, Verme 1968, Pruitt 1979, Picton 1979, Picton 1989, Farnes 1991). Measurement of the thickness, hardness, and density of snow cover have been used to predict reindeer *(Rangifer tarandus)* response to snow conditions (Pruitt 1979). Picton and Knight (1971) integrated daily maximum temperatures with "snow on ground" data (from standardized Weather Bureau measurements) to arrive at a numerical index relating to elk observability. Sign counts of standard deviations from mean monthly temperature and precipitation (Lamb 1963) and modifications of this method (Picton 1979) have been used to evaluate influences of weather on survival of mule deer fawns (Picton 1979), litter size in grizzly bears *(Ursus arctos horribilis)* (Picton 1978) and lamb survival of big horn sheep *(Ovis canadensis nelsoni)* (Douglas et al. 1986). Values within one standard deviation of the long-term mean are considered within the biometerological norm (Baranaowski and Gabryl 1981, Picton and Knight 1983). Farnes (1991) developed a scaled index of winter severity (IWS) to predict ungulate survivorship and reproduction in Yellowstone National Park. This index is based on the probability distribution of minimum temperatures and snow water equivalent measurements (SWE) over time. The IWS can be used to quantify the severity of any given winter or portion of winter (Farnes 1991). In this study, temperature variables were excluded, and the IWS was computed strictly on the basis of SWE probability of non-exceedence. Temperature was excluded because there was no evidence of a relationship between daily minimum temperature and daily elk harvest.

The importance of weather in triggering elk migration and subsequent increased elk vulnerability to hunters has long been recognized (Lovaas 1970, Knight 1970, Picton and Picton 1975, Adams 1982, MDFWP 1985). However, quantitative analysis of the influence of snow on vulnerability has focused on enhanced predation efficiency of large carnivores in certain snow conditions (Mech et al. 1971, Peterson and Allen 1974, Nelson and Mech 1981, Gasaway et al. 1983). Hansen et al. (1986) examined the influence of weather conditions on daily harvest of white-tailed deer *(Odocoileus virginianus)*. Hansen et al. (1986) regressed synthetic variables generated from principal components analysis against daily deer harvest using step-wise multiple regression analysis. They found that daily deer harvest was related negatively to precipitation in 3 of 4 regions and that day of season strongly affected daily harvest in all regions. No long-term studies have been conducted on the influence of snow (as measured by a winter severity index) on elk vulnerability.

In this study, consistent differences in the influence of weather on the elk harvest were observed between HD 250 and HD 270. Cross (1965) suggests that differences between the physiography of the East Fork (HD 270) and West Fork (HD 250) account for the disproportionate influence of weather in the former. Cross (1965) suggests that higher elevations and more precipitous terrain in HD 250 result in earlier snow accumulation and lower temperatures than in HD 270. Differences in winter phenology noted by Cross (1965) suggest that HD 250 elk are more accessible to hunters early in the season than are elk in HD 270. If weather alone is responsible for differences in elk vulnerability, it is unclear why opening day effect should be so prevalent in HD 250 for even the most mild early September seasons, unless the IWS does not reliably capture weather patterns in the West Fork. Comparison of 11 years (1977 to 1989, 1979 data missing for Nez Perce Camp) of SNOTEL data from Nez Perce Camp SNOTEL station (elev. 1722 m; 5650 ft) in the West Fork with the Saddle Mountain SNOTEL station (elev. 2420 m; 7940 ft), indicates comparable phenology of snow events for the East Fork and West Fork (Fig. 60). Saddle Mountain SNOTEL is located between HD 250 and HD 270 in AU-T4. Regression analysis of Saddle Mountain (East Fork) snow water equivalents against Nez Perce Camp (West Fork) snow water equivalents pillow indicates Nez Perce Camp is about 46% of that measured

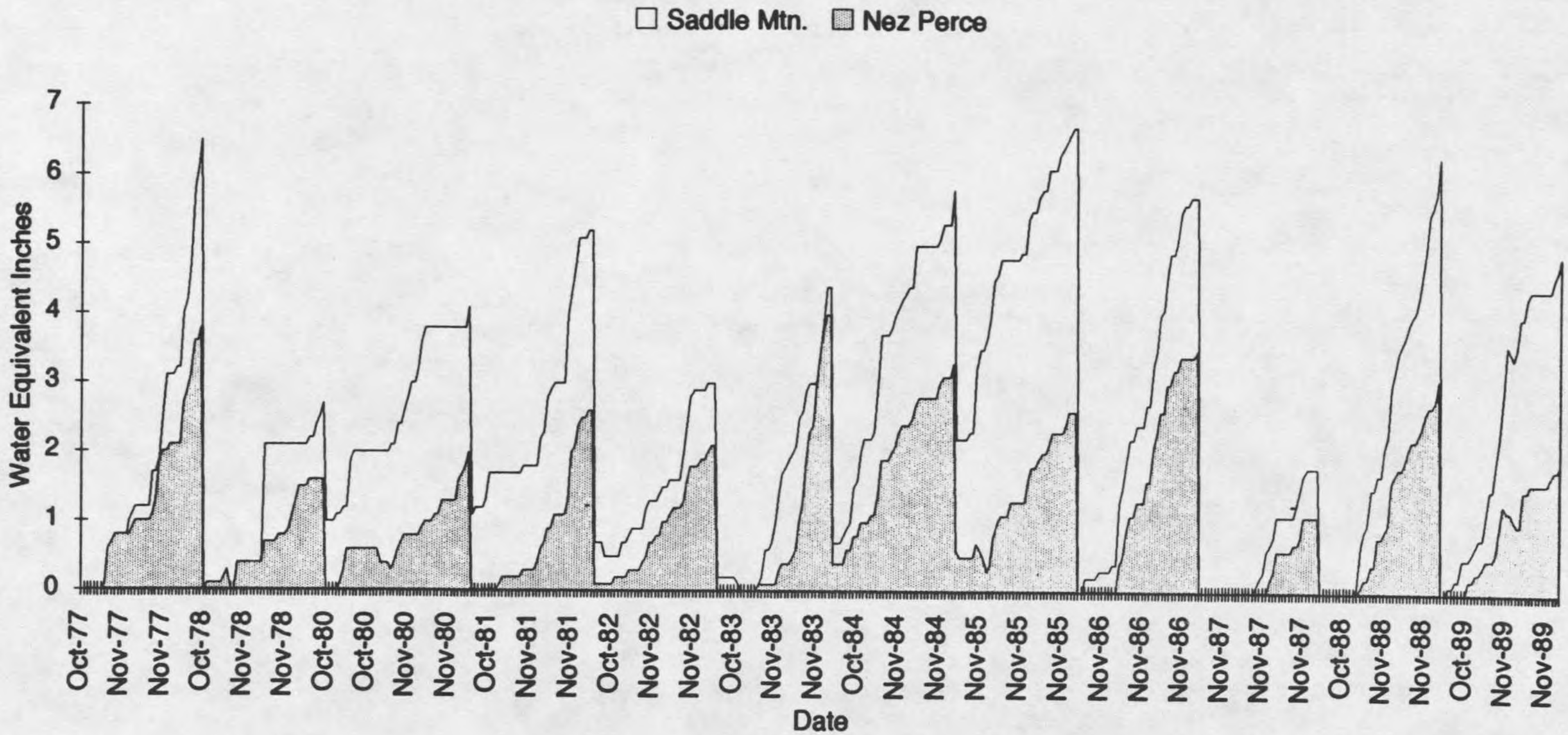

Figure 60. Comparison of snow pillow readings between Saddle Mtn. and Nez Perce SCS SNOTEL stations, upper Bitterroot, Ravalli Co., MT.

at Saddle Mountain ($Y = .4671x - .0304$, $r^2 = .75$, $n = 437$, $P = 0.0001$). An elevation difference of 697 m (2290 ft) likely accounts for the difference in magnitude of snow pillow measurements recorded at the two stations. However, it is also clear that the Saddle Mountain site is representative of the snow conditions in the West Fork. Thus, differences in weather phenology are too small to account for different harvest patterns in HD 250 and HD 270. Elk in the two hunting districts are apparently responding differently to the same weather patterns.

Radio telemetry studies indicate that elk in HD 270 are more migratory and move longer distances on average than elk in HD 250 (FWP Region 2 Job Progress Reports 1955-1989). In HD 250, elk movements tend to be more along elevational gradients within individual analysis units. A comparison of the size and shape of analysis units within each of the two hunting districts helps illustrate differences in movements of elk herds. Recall that analysis units were delineated on the basis of elk herd movements as determined by radio-telemetry data. In HD 270, analysis units are elongated from east to west, capturing the longer distances traveled by elk during seasonal migrations (Fig. 10). Note that AU-D2 and AU-D3 were partitioned to examine different logging and roading treatments but that each should be considered part of one analysis unit with respect to elk herd movements.

Differences in migration with respect to distance and plane (vertical versus horizontal) exist between HD 250 and HD 270. Migration with both horizontal and vertical components, involving movement up or down major topographical features is defined as altitudinal migration (Baker 1978). In the more precipitous terrain of the West Fork, migration is primarily vertical (due to the elevational gradient), and the horizontal component of this altitudinal migration is typically much less than observed in HD 270 (Cross 1965). Comparable snowfall apparently has very different consequences in each hunting district with respect to vulnerability. In the steeper terrain of the West Fork, elk may be "funnelled" into more constricted ranges at lower elevations earlier in the season. Greater elk densities at lower elevation result in higher encounter rates with hunters and proportionately greater vulnerability. Changes in habitat and access that foster increased encounter rates would further increase vulnerability. Topographic diversity has been found to reduce the influence of roads and human disturbance on elk (Edge and Marcum 1991); however, young timber stands offer reduced hiding cover in steep topography because of the effect of viewing angle (Canfield et al. 1986). Thus, logging in steep terrain may have a disproportionate influence on elk vulnerability over other less steep - yet topographically diverse - areas.

In contrast to the West Fork, terrain in HD 270 is less precipitous (Cross 1965), and the plane of migration movement has a strong horizontal component. Under average to mild weather conditions, elk in HD 270 remain widely dispersed, and many elk that winter in HD 270 are in remote portions of adjacent hunting districts. This dispersion results in proportionately lower encounter rates with hunters. In years with severe snow conditions, elk migration occurs early, resulting in dramatic increases in vulnerability and hence harvest rates. Until elk initiate migration from higher elevation summer and fall ranges, they remain widely dispersed in relatively large tracts of timber. Low elk density results in correspondingly low encounter rates and low vulnerability. Following initiation of migration, elk become more vulnerable as they move to and congregate on more fragmented habitats. An example of the dramatic change in vulnerability as a result of movement to lower elevation would be the contrast between elk security in the wilderness portion of AU-D3 (Anaconda-Pintler Wilderness) and the developed portion (24% of the total habitat affected by logging) bordering the wilderness which has a road density of 5.5 miles/square mile. In HD 270, hunters also key in on snow conditions, leading to strong correlations between number of hunters and snow conditions.

Annual variation in weather among years was greatest during the decade of the seventies. In particular, the difference between 1 November IWS values in adjacent years was extreme (Fig. 29). The consequences of such a large variation in weather in the seventies resulted in the large fluctuations in both the total harvest and the harvest rate of elk from year to year. In the eighties, more restrictive antlered bull general seasons reduced the variance in the harvest rate among years in both hunting districts, most dramatically in HD 250 (Fig. 45). When all 15-day periods are included in the computation of variance in IWS, differences between decades are not apparent. Indeed, the overall variance in winter severity is greater for the eighties. This result underscores the importance of 15-day IWS values in capturing differences in weather severity.

Management Implications

HD 250

In HD 250, weather is clearly less influential in determining elk harvest than in HD 270. However, severe weather, such as occurred in 1955, 1967, and 1973 substantially increased elk vulnerability. As is the case in HD 270, a downward trend in mean age of branch-antlered bulls has occurred in HD 250 in the last decade along with a reduction in the absolute number of older age bulls harvested (Table 2). This trend has occurred during a period of relatively stable number of hunters, increased spike recruitment, and in comparison to other decades, during a period of relatively low rates of road construction and logging.

Check station data do not provide sufficient resolution to capture increases in vulnerability as a linear response to roading and logging over time. Problems of insufficient variation with respect to roading and logging (road access occurred at about the same time in all analysis units) and autocorrelation (due to time trend) severely constrain statistical analysis of the data. However, several lines of evidence indicate that elk vulnerability dramatically increased coincident with peak roading and logging in the mid-sixties. Inflections in antlered bull harvest rates, dramatic opening day effects, and large variances in the daily antlered bull harvest all occurred concurrent with the period in HD 250 when 25% of the existing roads were constructed. During this period, hunters enjoyed record levels of success at a time when weather conditions were mostly average to mild. For similar weather years, the correlation between daily number of hunters and elk harvested increased from the fifties to the sixties.

With the exception of the period of the mid-sixties, the mature bull harvest rate has remained surprisingly uniform across 37 years. It may be hypothesized that the "system" in HD 250 received "shocks" in the mid-sixties which resulted in a period of disequilibrium. This disequilibrium was reflected in the variation in harvest rate among years and in within-year variance in the daily antlered bull harvest rate. Stability in the year-to-year harvest rate returned shortly after the period of peak roading and logging. The return to an equilibrium harvest rate suggests that elk adjusted to roads with the result that vulnerability was reduced. This result is consistent with the hypothesis that incremental increases in vulnerability may not be detectable as a gradual cumulative response, at least by check station results. However large "shocks" which result in large deviations from the response norm can be captured by check station data. A return to a new, lower equilibrium appears to have occurred following an adjustment period, and, again, check station data provide insufficient resolution to capture incremental increases in vulnerability.

Figures 33 and 35 illustrate the trend in numbers of mature bulls harvested per day in HD 250. Note that following the large variance in the harvest rate during the mid-sixties the harvest rate stabilized at a lower level than observed prior to the sixties. The dynamic response model assumes that by adjusting home range movements, elk can compensate to new roads and logging. At some level of development, such an assumption is no longer valid. Once some threshold of roading and logging is reached, adjustments by elk would not be sufficient to reduce encounter rates with hunters. At this threshold level of fragmentation, hunter density becomes the driving variable in the system (Vales et al., 1991).

The most obvious impact of vulnerability in HD 250 is the pronounced opening day effect. Picton (1991) suggests that opening day vulnerability has a strong behavioral component. Elk have not made the behavioral adjustments from natural predator capture limits to human predator capture limits (Picton 1991), nor have elk moved to more secure habitats that reduce encounter rates with hunters (Lyon and Canfield 1991). Hunters turn out in large numbers opening day, compounding elk vulnerability. One solution would be to open a permit-only cow season several days prior to the general bull season. This would allow bulls adequate time to adjust behavior and reduce vulnerability.

HD 270

Weather factors clearly "drive" the system in HD 270 and overwhelm our ability to isolate the contribution of other variables to elk vulnerability, at least at the level of resolution afforded by check station data. Dramatic increases in logging and roading in the sixties occurred; yet, of the response variables examined, only opening day effect indicated corresponding increases in elk vulnerability may have occurred. A dramatic decline in the mature bull harvest did follow the 1961 Sleeping Child fire in AU-E5. Analysis of scattergrams between hunters and elk harvest in HD 270 indicates that the harvest has been largely independent of number of hunters, especially early in the season. This low level of association between number of hunters and the harvest, coupled with the general absence of opening day effect, indicate that elk experienced a relatively high level of security during mild/average weather years for three decades, independent of roading and logging. This security continued through the decade of the seventies. However, the pattern of opening week harvest versus number of hunters shows that the variance among years in the first week antlered bull harvest has declined during the eighties. The variance among years in the total harvest rate has also declined. The decline in the annual variance in the harvest in HD 270 appears to be due to a combination of more restrictive hunting regulations and less variation in winter severity between adjacent years during the most recent decade.

In HD 270 the principal component scores from the synthetic weather variable accounts for over 50% of the annual variation in total elk harvest. Near catastrophic increases in elk vulnerability have accompanied early severe snow conditions in HD 270 at least three times (1955,1973, 1991). Vulnerability in HD 270 is still strongly influenced by weather conditions, as indicated by the annual variation in the total harvest (Fig. 38). Moving the season forward to reduce the possibility of such dramatic increases in vulnerability deserves serious consideration. If predictability in harvest from year to year is desirable, earlier seasons would reduce the influence of weather from year to year and allow closer examination of the influence of other variables on elk vulnerability.

The declining age of bulls checked at Darby and a reduction in the absolute number of older age bulls harvested has occurred in the most recent decade. This decline in age of bulls cannot be directly attributed to increases in either number of hunters or to reduced recruitment of bulls. Check station data do not provide sufficient resolution to distinguish weather-related vulnerability from habitat-related vulnerability. Detailed information on mortality rates and number of hunters at the analysis unit level is required if this question is to be resolved.. Where possible, analysis units selected for comparison should vary with respect to road densities and logging.

In many respects, this analysis may be considered the "before treatment" portion of an on-going experiment on elk vulnerability. Large blocks of roadless land remain in the upper Bitterroot (Fig. 3), but are currently under consideration for development. As these last blocks of unroaded, high elevation forests are accessed and logged, changes in elk vulnerability will occur. The relatively high level of security afforded elk early in the season in HD 270 may be expected to be reduced as these lands are developed. Reliable information on variables relating to elk vulnerability thus becomes even more critical.

CONCLUSIONS

Long-term check station data from the Darby check station do not offer sufficient resolution to estimate the effect of incremental increases in road densities and logging on elk vulnerability. Site-specific information on survivorship of bulls in different "treatment" levels of road density, logging and hunter density would be required to obtain such information. Information on daily hunter numbers and the location of the kill proved to be the most useful information in this analysis. Specific information on hunter numbers at the analysis unit level would have allowed estimation of changes in hunter efficiency in response to changes in roading and logging.

The timing of road access in the upper Bitterroot severely reduced the range of "treatment effects" in which to look for differences in the harvest as a result of varying degrees of roading or logging. As nearly all analysis units were accessed at about the same time, it was difficult to isolate which variables were most important. However, in HD 250, hunter numbers are clearly more a factor in increasing the harvest than in HD 270, where weather is most important. Peak roading and logging in the sixties did lead to changes in the distribution of the harvest and to increased opening day effect in HD 250. This occurred during a period when hunter numbers were relatively constant, suggesting that dramatic increases in logging and road construction were responsible for a period of extremely high elk vulnerability.

Snow conditions and elk migratory behavior interact in HD 270 so as to produce dramatic increases in vulnerability when snowstorms trigger early elk migration. In the absence of snow, elk remain dispersed in large, contiguous blocks of forest and enjoy relatively high security as a result. Annual variation in the weather accounts for as much as 50% of the total variation in the elk harvest in HD 270. This large weather influence severely constrains the use of linear models to estimate the incremental influence of increases in road densities and logging on elk vulnerability. As the last roadless lands along the Sapphire Divide are accessed and logged, weather influences should be expected to become less important in determining the harvest in HD 270.

REFERENCES CITED

REFERENCES CITED

Adams, A. W. 1982. Migration. Pages 301-321 in J. W. Thomas and D. E. Toweill, eds. Elk of North America. Ecology and management. Stackpole Books, Harrisburg, Pa.

Baker, R. R. 1978. The evolutionary ecology of animal migration. Holmes & Meier Publishers, Inc., New York. 1012 pp.

Baranowski, M. and B. Gabryl. 1981. Biometerological norm as tolerance interval of man to weather stimuli. Int. J. Biometeor. 25:123-126.

Barrett, M. W. 1982. Distribution, behavior, and mortality of pronghorns during a severe winter in Alberta. J. Wildl. Manage. 46: 991-1002.

Beal, R. C. 1974. Winter Habitat Selection and Use by a Western Montana Elk Herd. PhD. Diss., University of Montana, Missoula. 197 pp.

Brazda, A. R. 1953. Elk migration patterns and some of the factors affecting movements in the Gallatin River drainage, Montana. J. Wildl. Manage. 17(1):9-23.

Canfield, J.E., L.J. Lyon and J.M. Hillis. 1986. The influence of viewing angle on elk hiding cover in young timber stands. USDA For. Ser. Res. Pap. INT-371. 5 pp.

Carpenter, L.H. 1991. Elk hunting regulations, the Colorado experience. Pages 16-22 In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

Christensen, A. G., L. J. Lyon and T. N. Lonner. 1991. Proceedings of a Symposium on Elk Vulnerability. Bozeman, MT Ap. 10-12, 1991. 330 pp

Coop., K. L. 1973. Habitat use and behavior of elk in relation to hunting. Pages 97-100 In: Proceeding of the biennial conference of the western states elk workshop. Allen, E.O. and H.R. Chrest (Chairmen). Bozeman, MT. Feb. 20-21.

Cross, H. J. 1965. The elk herd of the East Fork of the Bitterroot River. Unpublished M.S. thesis. University of Montana, Missoula. 95 p.

Dalke, P. D., R. D. Beeman, F. J. Kindel, R. J. Robel, and T. R. Williams. 1965. Seasonal movements of elk in the Selway River Drainage, Idaho. J. Wildl. Manage. 29(2):333-338.

Douglas, C. L. and D. M. Leslie. 1986. Influence of weather and density on lamb survival of desert mountain sheep. J. Wildl. Manage. 50:153-156.

Edge. D.W. and C.L. Marcum. 1991. Topography ameliorates the effects of roads and human disturbance on elk. Pages 132-137 In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

Farnes, Phillip E. 1991. A Scaled Index of Winter Severity. Presented at the 59th Western Snow Conference, April 12-15, 1991, Juneau, Alaska. Available from author, P. O. Box 691, Bozeman, MT 59715

Gasaway, W. C., R. O. Stephenson, J. L. Davis, P. E. K. Shepherd, and O. E. Burris. 1983. Interrelationships of wolves, prey and man in interior Alaska. Wildl. Monogr. 84. 50pp.

Hansen, L. P., C. M. Nixon, and F. Loomis. 1986. Factors affecting daily and annual harvest of white-tailed deer in Illinois. Wildl. Soc. Bull. 14: 368-376.

Hillis, J., M. Thompson, J. Canfield, L. Lyon, C. Marcum, P. M. Dolan and D. McCleerey. 1991. Defining Elk Security: The Hillis Paradigm. Pages 38-43 In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

Hollibaugh, George W. 1942. Winter game study, 1941-42 (Bitterroot) Montana Fish and Game Department, 22 pp.

Irwin, L.L. and J.M. Peek. 1983. Elk habitat use relative to forest succession in Idaho. J. Wildl. Manage. 47: 664-672.

Johnson, Douglas H. 1981. The use and misuse of statistics in wildlife habitat studies. Pages 11-19 In: Caspen, David E., ed. The use of multivariate statistics in studies of wildlife habitat. USDA Forest Service General Technical Report RM-87, 249 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Kelsall, J. P. 1969. Structural adaptations of moose and deer for snow. J. Mammal. 50: 302-310.

Knight, R. R. 1970. The Sun River elk herd. Wildl. Monogr. No. 23. 66 pp.

Lamb, H. H. 1963. On the nature of certain climatic epochs which differed from the modern (1900-39) normal. Symp. on changes of climate. Arid Zone Res. (Paris), 20: 125-150.

Leckenby, D., C. Wheaton and L. Bright. 1991. Elk vulnerability - The Oregon situation. Pages 89-93, In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

Leege, T. A. and W. O. Hickey. 1977. Elk-snow-habitat relationships in the Pete King Drainage, Idaho. Wildl. Bull. #6. Idaho Dept. Fish and Game, Boise. 23 pp.

Leptich, D. J. and P. Zager. 1991. Road access management effects on elk mortality and population dynamics. Pages 126-131, In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

Lonner, T. N., and J. D. Cada. 1982. Some effects of forest management on elk hunting opportunity. Proc. 1982 Western States Elk Workshop, Phoenix, Arizona: pp.119-128.

Lovaas, A. L. 1970. People and the Gallatin elk herd. Helena: Montana Fish and Game Dept. 44 pp.

Lyon, L. J. 1979. Influences of logging and weather on elk distribution in western Montana. U.S. Forest Service. Res. Paper. INT-236. 11 pp.

Lyon, L. J. 1983. Road density models describing habitat effectiveness for elk. J. For. 81: 592-595.

Lyon, L. J., D. W. Edge, L. Kuck, T. A. Leege, T. N. Lonner, C. L. Marcum, M. D. Scott, R. E. Escano, J. T. Light, R. D. Pfister. A conceptual Model of elk habitat selection and use. Pages 117-130 In: Proceedings of the 984 western states and provinces elk workshop. April 17-19, 1984, Edmonton, Alberta, Canada.

Lyon, L. Jack and A. Christensen. 1990. Toward a Workable Glossary of Elk Management Terms-Results of a Workshop. Western States and Provinces Elk Workshop, Eureka, CA. May 15-17. 1990.

Lyon, L. Jack and J. Canfield. 1991. Habitat selections by Rocky Mountain elk under hunting season stress. Pages 99-105 In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

Marcum, C. L. and M. D. Scott. 1985. Influences of weather on elk use of spring-summer habitat. J. Wildl. Manage. 49: 73-76.

Martinka, C. J. 1967. Mortality of northern Montana pronghorns in a severe winter. J. Wildl. Manage. 31:159-164.

Martinka, C. J. 1969. Population ecology of summer resident elk in Jackson Hole, Wyoming. J. Wildl. Manage. 32: 558-565.

Mech, L. D., L. D. Frenzel, Jr., and P. D. Karnes. 1971. The effect of snow conditions on the vulnerability of white-tailed deer to wolf predation. Pages 51-59 in L. D. Mech. and L. D. Frenzel, Jr. ed. Ecological studies of the timber wolf in northeastern Minnesota. USDA Forest Service Research Paper 52.

Mohler, Levi L. and Dale E. Toweill (Ed.) Elk of North America, Ecology and Management. Stackpole 698 pp.

Montana Department of Fish, Wildlife and Parks, 1985. Antlered elk and deer management in Montana: past trends and current status. A special report for the fish and game commission. Prepared by the Wildlife Division, FWP, Helena, MT 68 p.

Montana Department of Fish, Wildlife and Parks. Region 2 big game job progress completion reports (annual Pittman-Robertson reports) for 1955-1989. Montana Department of Fish, Wildlife and Parks, Helena, MT.

Montana Historical County Census Data, 1910-1970 In: Montana State, Regional and County Estimates: 1950-1975 with city population estimates 1970-1975. Prepared by Richard Dodge, statistician. Division of Resources and Information Systems, MT Dept. of Community Affairs. Oct. 1976.

Murie, O. J. 1956. The elk of North America. The Stackpole Co., Harrisburg, PA. 376 pp.

Nelson, M. E. and L. D. Mech. 1981. Deer social organization and wolf predation in northeastern Minnesota. Wildl. Monogr. 77. 53 pp.

Neter, J. W. Wasserman, and M. Kutner. 1985. Applied linear statistical models, Richard D. Irwin, Inc., Homewood, Ill. 1,127 pp.

Parker, K. L., C. T. Robbins and T. A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. J. Wildl. Manage. 48: 474-488.

Peek, J. M., D. L. Urich, and R. J. Mackie. 1976. Moose habitat selection and relationships to forest management in northeastern Minnesota. Wildl. Monogr. 48. 65pp.

Peterson, R. O. and D. L. Allen. 1974. Snow conditions as a parameter in moose-wolf relationships. Nat. Can. (Que.) 101:481-492.

Picton, H. D. 1960. Migration patterns of the Sun River elk herd, Montana. J. Range Manage. 24(3): 279-290.

Picton, H. D. 1978. Climate and reproduction of grizzly bears in Yellowstone National Park. Nature (Lond.), 274: 888-889.

Picton, H. D. 1979. A climate index and mule deer fawn survival in Montana. Int. J. Biometeor. 23(2): 115-122.

Picton, H. D. 1991. Elk on the defense: an evolutionary context. Pages 82-84, In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

Picton, H. D. and R. R. Knight. 1971. A numerical index of winter condition of use in big game management. pp. 29-83. In: Proc. Symp. on snow and ice in relation to wildlife and recreation, Ames, Iowa. 280 pp.

Picton, H. D., and I. E. Picton. 1975. Saga of the sun--a history of the Sun River elk herd. Helena: Montana Dep. Fish and Game. 55 pp.

Picton. H. D. and R.L. Knight. 1989. Using climate to predict grizzly bear litter size. Int. Conf. Bear Res. and Manage. 6:41-44.

Pruitt, W. O. Jr. 1959. Snow as a factor in the winter ecology of the barren-ground caribou (Rangifer arcticus). Arctic 12 (3): 158-179.

Pruitt, W. O. Jr. 1960. Animals in the snow. Scient. Amer. 202 (1):60-68.

Pruitt, W. O. Jr. 1979. A numerical "Snow Index" for reindeer (Rangifer tarandus) winter ecology. Ann. Zool. Fennici. 16:271-280. 1979.

Rognrud, M. J. 1955. A study of Big Game and Land Management in the Bitterroot Unit. Job Completion Report, Project No. W-60-R-2, Vol. VI, No. 2. July 15, 1955. pp 280-324

Sweeney, J. M. and H. W. Steinhoff. 1976. Elk movements and calving as related to snow cover. In: Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. ed. H. W. Steinhoff and J. D. Ives, pp. 415-436. Fort Collins: Colorado State Univ. Publ.

Sylvester, James T. An economic profile of Ravalli County. Montana Business Quarterly 19(3): 35-40; 1981.

Telfer, E. S. 1970. Winter habitat selection by moose and whitetailed deer. J. Wildl. Manage. 34: 553-559.

Telfer, E. S. and J. P. Kelsall. 1984. Adaptation of some large north American mammals for survival in snow. Ecol. 65(6): 1828-1834.

Thomas, J. W. 1991. Elk vulnerability - a conference perspective. Pages 318-319 In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

U.S. Bureau of the Census. 1981. 1980 census of population for governmental units: Montana. Chapter A, Inhabitants of Montana, Table 4.

U.S. Bureau of the Census. 1991. 1990 census of population for governmental units: Montana.

Unsworth, J.W. and L. Kuck. 1991. Bull elk vulnerability in the Clearwater Drainage of north-central Idaho. Pages 85-88 In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

USDA Forest Service. 1986. Concepts in managing elk hunting opportunity. Forest Service memo, Available from Region One, USDA Forest Service, Missoula, MT. 9 p.

USDA Forest Service. 1987. Final environmental impact statement, Bitterroot National Forest plan. Vol. II. appendices.

Vales, D.J. and V.L. Coggins, P. Matthews and R. A. Riggs. Analyzing options for improving bull:cow ratios of rocky mountain elk populations in northeast Oregon. Pages 174-181 In: Proceedings of a Symposium on Elk Vulnerability. Christensen, A.G., T.N. Lonner and L.J. Lyon, (eds.), Bozeman, MT Ap. 10-12, 1991. 330 pp.

Verme, L. J. 1968. An index of winter severity for northern deer. J. Wildl. Manag. 32: 566-574.

Wickstrom, M. L., C. T. Robbins, T. A. Hanley, D. E. Spalinger and S. M. Parish. 1984. Food intake and foraging energetics of elk and mule deer. J. Wildl. Manage. 48: 1285-1301.

Wisdom, M. J., L. R. Bright, C. G. Carey, W. W. Hines, R. J. Pedersen, D. A. Smithey, J. W. Thomas, and G. W. Witmer. 1986. A model to evaluate elk habitat in western Oregon. Publication No., R6-F&WL-216-1986. USDA Forest Service, Pacific Northwest Region, Portland, OR. 36 p.

Youmans, C. C., and P. F. Brussard. 1986. Habitat insularization on the managed forest: Assessing its impacts on the future of elk hunting. Unpubl. manuscript. 18 pp.

APPENDICES

APPENDIX A

ROAD CONSTRUCTION SUMMARIES

Table 18. HD 250. Summary of road construction by year in the upper Bitterroot, Ravalli Co., MT.

Year	Total Mi	Rd. Density	New Mi.	%Total-Date	% Total Mi.
1953	380.09	0.68	10.00	2.63%	0.65%
1954	392.01	0.70	11.20	2.86%	0.73%
1955	411.06	0.73	19.50	4.74%	1.27%
1956	454.01	0.81	42.50	9.36%	2.77%
1957	498.02	0.89	44.10	8.85%	2.87%
1958	517.10	0.92	18.90	3.65%	1.23%
1959	577.61	1.03	60.51	10.48%	3.94%
1960	611.41	1.09	33.80	5.53%	2.20%
1961	636.31	1.13	24.90	3.91%	1.62%
1962	657.71	1.17	21.40	3.25%	1.39%
1963	717.61	1.28	59.90	8.35%	3.90%
1964	756.91	1.35	39.30	5.19%	2.56%
1965	859.46	1.53	102.55	11.93%	6.68%
1966	940.06	1.67	80.60	8.57%	5.25%
1967	967.26	1.72	27.20	2.81%	1.77%
1968	1003.66	1.79	36.40	3.63%	2.37%
1969	1102.86	1.96	99.20	8.99%	6.46%
1970	1232.86	2.20	130.00	10.54%	8.47%
1971	1285.46	2.29	52.60	4.09%	3.43%
1972	1319.86	2.35	34.40	2.61%	2.24%
1973	1334.76	2.38	14.90	1.12%	0.97%
1974	1345.56	2.40	10.80	0.80%	0.70%
1975	1351.56	2.41	6.00	0.44%	0.39%
1976	1368.66	2.44	17.10	1.25%	1.11%
1977	1381.46	2.46	12.80	0.93%	0.83%
1978	1407.06	2.51	25.60	1.82%	1.67%
1979	1441.36	2.57	34.30	2.38%	2.23%
1980	1461.71	2.60	20.35	1.39%	1.33%
1981	1492.81	2.66	31.10	2.08%	2.03%
1982	1515.51	2.70	22.70	1.50%	1.48%
1983	1525.61	2.72	10.10	0.66%	0.66%
1984	1530.31	2.73	4.70	0.31%	0.31%
1985	1536.91	2.74	6.60	0.43%	0.43%
1986	1515.81	2.70	0.00	0.00%	0.00%
1987	1522.61	2.71	6.80	0.45%	0.44%
1988	1526.61	2.72	4.00	0.26%	0.26%
1989	1535.61	2.74	9.00	0.59%	0.59%

Total Mi = Total miles of road
Rd. Density = Total road Density
New Mi. = Miles of new road constructed
% Total -Date= Percent of total miles constructed to date
% Total Mi. = Percent of total miles constructed to 1989

Table 19. HD 270. Summary of road construction by year in the upper Bitterroot, Ravalli Co., MT.

Year	Total Mi	Rd. Density	New Mi.	%Total-Date	%Total Mi.
1953	326	0.77	10	3.07%	0.68%
1954	341	0.80	15.3	4.48%	1.03%
1955	390	0.92	48.3	12.40%	3.26%
1956	416	0.98	26.9	6.46%	1.82%
1957	424	1.00	7.4	1.75%	0.50%
1958	470	1.11	46.1	9.81%	3.12%
1959	526	1.24	56.4	10.72%	3.81%
1960	601	1.42	75.1	12.49%	5.08%
1961	747	1.76	145.7	19.50%	9.85%
1962	864	2.03	116.6	13.50%	7.88%
1963	926	2.18	62.5	6.75%	4.22%
1964	960	2.26	33.9	3.53%	2.29%
1965	1008	2.37	48.3	4.79%	3.26%
1966	1067	2.51	58.2	5.46%	3.93%
1967	1215	2.86	148.1	12.19%	10.01%
1968	1318	3.10	103.4	7.84%	6.99%
1969	1336	3.14	18.2	1.36%	1.23%
1970	1341	3.16	4.5	0.34%	0.30%
1971	1345	3.16	3.9	0.29%	0.26%
1972	1347	3.17	2.2	0.16%	0.15%
1973	1357	3.19	10.3	0.76%	0.70%
1974	1372	3.23	14.8	1.08%	1.00%
1975	1384	3.26	12.2	0.88%	0.82%
1976	1389	3.27	4.4	0.32%	0.30%
1977	1403	3.30	14.1	1.01%	0.95%
1978	1403	3.30	0.5	0.04%	0.03%
1979	1405	3.31	2	0.14%	0.14%
1980	1414	3.33	9	0.64%	0.61%
1981	1432	3.37	18.2	1.27%	1.23%
1982	1440	3.39	7.5	0.52%	0.51%
1983	1450	3.41	10.1	0.70%	0.68%
1984	1459	3.43	9.4	0.64%	0.64%
1985	1484	3.49	24.7	1.66%	1.67%
1986	1484	3.49	0	0.00%	0.00%
1987	1497	3.52	12.5	0.84%	0.84%
1988	1480	3.48	0	0.00%	0.00%
1989	1480	3.48	0	0.00%	0.00%

Total Mi = Total miles of road
Rd. Density = Total road Density
New Mi. = Miles of new road constructed
% Total -Date= Percent of total miles constructed to date
% Total Mi. = Percent of total miles constructed to 1989

APPENDIX B

CORRELATION MATRICES

Table 20. HD. 250 (1953-1960). Correlation matrix of selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	1							
WKDAY	-.0095	1						
TKFRQ	-.2721	.2108	1					
HNTRS	-.3771	.3423	.7282	1				
TMIN	-.436	.0199	.1261	.2643	1			
NSNOW	.0572	.0397	.0251	-.0573	.086	1		
ANSNO	.8648	-.0001	-.1794	-.2799	-.4002	.1271	1	
WSEV	-.204	.0041	.0933	.185	.1549	-.1727	-.4653	1

Day # = Day of hunting season
WKDAY = Day of week
TKFRQ = Total daily elk harvest
HNTRS = Total unsuccessful hunters
TMIN = Minimum temperature (Darby 1953-56; Sula 1957-89)
NSNOW = New snow
ANSNO = Accumulated snow pillow in inches of snow
WSEV = Daily weather severity index

Table 21. HD. 250 (1953-1960). Matrix of partial correlation coefficients among selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	.8289							
WKDAY	.1089	.1473						
TKFRQ	-.0356	-.0719	.5477					
HNTRS	-.224	.3224	.6835	.6362				
TMIN	-.1399	-.0449	-.1192	.1739	.2343			
NSNOW	-.0438	.0691	.1073	-.1256	.1572	.0712		
ANSNO	.872	-.0664	.0173	.1531	-.0454	.0857	.8444	
WSEV	.4798	-.0681	-.0214	.1747	.0352	-.08	-.5947	.411

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 22. HD. 250 (1961-1970). Correlation matrix of selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	1							
WKDAY	.0101	1						
TKFRQ	-.2573	.2159	1					
HNTRS	-.2827	.3772	.7323	1				
TMIN	-.2686	-.0484	.0786	.147	1			
NSNOW	.1742	.0566	-.0421	-.0682	.037	1		
ANSNO	.8253	.0203	-.1163	-.1656	-.3229	.2454	1	
WSEV	-.2153	.0065	.0576	.1158	.2549	-.1714	-.4612	1

Day # = Day of hunting season
WKDAY = Day of week
TKFRQ = Total daily elk harvest
HNTRS = Total unsuccessful hunters
TMIN = Minimum temperature (Darby 1953-56; Sula 1957-89)
NSNOW = New snow
ANSNO = Accumulated snow pillow in inches of snow
WSEV = Daily weather severity index

Table 23. HD. 250 (1961-1970). Matrix of partial correlation coefficients among selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	.7484							
WKDAY	.0963	.1787						
TKFRQ	-.1317	-.0881	.5506					
HNTRS	-.1337	.3566	.6845	.6109				
TMIN	-.0117	-.1049	-.0512	.1251	.1548			
NSNOW	-.0448	.0895	.0154	-.0692	.1473	.0921		
ANSNO	.8315	-.0593	.0992	.0803	-.1261	.1533	.784	
WSEV	.3499	-.0195	.0152	.0816	.1276	-.0632	-.4889	.3266

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 24. HD. 250 (1971-1980). Correlation matrix of selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	1							
WKDAY	.0786	1						
TKFRQ	-.404	.2345	1					
HNTRS	-.3763	.4689	.6595	1				
TMIN	-.312	-.0356	.0175	.08	1			
NSNOW	.1053	-.0195	-.0147	-.0478	.0904	1		
ANSNO	.712	.0563	-.2074	-.3231	-.2355	.2443	1	
WSEV	-.075	-.0073	.012	.1822	.0498	-.1424	-.6478	1

Day # = Day of hunting season
WKDAY = Day of week
TKFRQ = Total daily elk harvest
HNTRS = Total unsuccessful hunters
TMIN = Minimum temperature (Darby 1953-56; Sula 1957-89)
NSNOW = New snow
ANSNO = Accumulated snow pillow in inches of snow
WSEV = Daily weather severity index

Table 25. HD. 250 (1971-1980). Matrix of partial correlation coefficients among selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	.8162							
WKDAY	.1966	.3104						
TKFRQ	-.2627	-.0503	.5008					
HNTRS	-.1358	.4869	.5516	.6015				
TMIN	-.1738	.0158	-.1221	.0244	.1308			
NSNOW	-.128	-.0292	-.0031	.0108	.1367	.1049		
ANSNO	.8487	-.0546	.17	.0088	.0008	.2384	.8761	
WSEV	.7242	-.1119	.0663	.1406	.0205	.1299	-.8462	.7408

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 26. HD. 250 (1981-1989). Correlation matrix of selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	1							
WKDAY	.1168	1						
TKFRQ	-.2044	.346	1					
HNTRS	-.1172	.6268	.605	1				
TMIN	-.3405	-.0051	-.0307	.0381	1			
NSNOW	.1886	.0846	.0832	-.0169	.0883	1		
ANSNO	.7532	.087	-.0369	-.0348	-.3724	.2388	1	
WSEV	-.2126	-.0173	-.0849	-.021	.1701	-.1556	-.7335	1

Day # = Day of hunting season
WKDAY = Day of week
TKFRQ = Total daily elk harvest
HNTRS = Total unsuccessful hunters
TMIN = Minimum temperature (Darby 1953-56; Sula 1957-89)
NSNOW = New snow
ANSNO = Accumulated snow pillow in inches of snow
WSEV = Daily weather severity index

Table 27. HD. 250 (1981-1989). Matrix of partial correlation coefficients among selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	.8312							
WKDAY	.1618	.4382						
TKFRQ	-.1726	-.0099	.4228					
HNTRS	-.0918	.5711	.4999	.5809				
TMIN	.0198	.0137	-.1335	.0738	.0738	.2132		
NSNOW	-.0101	.0883	.1569	-.1362	.2198	.1268		
ANSNO	.8753	-.0625	.063	.063	-.2167	.1304	.9184	
WSEV	.7428	-.0306	.0124	.0506	-.1437	.0592	-.89	.8104

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 28. HD. 270 (1953-1960). Correlation matrix of selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	1							
WKDAY	.0115	1						
TKFRQ	.0957	.2773	1					
HNTRS	.0518	.5079	.5916	1				
TMIN	-.3762	.0261	-.2391	.0028	1			
NSNOW	.0397	.0529	.1103	.0477	.103	1		
ANSNO	.8453	.0208	.263	.1393	-.403	.1296	1	
WSEV	-.1218	-.0086	-.2171	-.0912	.1442	-.1595	-.4336	1

Day # = Day of hunting season
WKDAY = Day of week
TKFRQ = Total daily elk harvest
HNTRS = Total unsuccessful hunters
TMIN = Minimum temperature (Darby 1953-56; Sula 1957-89)
NSNOW = New snow
ANSNO = Accumulated snow pillow in inches of snow
WSEV = Daily weather severity index

Table 29. HD. 270 (1953-1960). Matrix of partial correlation coefficients among selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	.8017							
WKDAY	.0594	.2652						
TKFRQ	-.1905	-.0104	.4542					
HNTRS	-.0092	.4371	.5382	.4963				
TMIN	-.0903	-.0015	-.2645	.18	.2481			
NSNOW	-.0576	.0487	.0954	-.0671	.1815	.0735		
ANSNO	.8747	-.0726	.1867	.0489	-.1017	.109	.8428	
WSEV	.4893	-.0091	-.0101	.034	.0045	-.0561	-.5876	.4007

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 30. HD. 270 (1961-1970). Correlation matrix of selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	1							
WKDAY	.0159	1						
TKFRQ	-.1524	.2881	1					
HNTRS	-.1257	.4901	.6518	1				
TMIN	-.2338	-.0486	-.074	4.8E-5	1			
NSNOW	.145	.0413	-.0107	-.0067	.0109	1		
ANSNO	.8561	.0283	.0187	-.0149	-.3573	.2267	1	
WSEV	-.329	-.0076	-.1177	-.0484	.2985	-.1731	-.4193	1

Day # = Day of hunting season
WKDAY = Day of week
TKFRQ = Total daily elk harvest
HNTRS = Total unsuccessful hunters
TMIN = Minimum temperature (Darby 1953-56; Sula 1957-89)
NSNOW = New snow
ANSNO = Accumulated snow pillow in inches of snow
WSEV = Daily weather severity index

Table 31. HD. 270 (1953-1960). Matrix of partial correlation coefficients among selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	.772							
WKDAY	.1131	.2582						
TKFRQ	-.2365	-.0197	.4684					
HNTRS	-.0616	.4229	.5784	.53				
TMIN	.1533	-.0775	-.0337	.0797	.1931			
NSNOW	-.1301	.0664	-.0464	-.0252	.1376	.0907		
ANSNO	.8493	-.0827	.188	.0428	-.2777	.2127	.7956	
WSEV	-.0153	.0501	-.094	-.0064	.1805	-.1131	-.1577	.2227

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 32. HD. 270 (1971-1980). Correlation matrix of selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	1							
WKDAY	.082	1						
TKFRQ	-.0207	.3049	1					
HNTRS	.0583	.5935	.4846	1				
TMIN	-.3182	-.0284	-.1592	-.0724	1			
NSNOW	.1191	-.0165	.0416	-.0256	.0672	1		
ANSNO	.7143	.0625	.1236	-.0091	-.2428	.2542	1	
WSEV	-.125	-.0126	-.1297	.1096	.065	-.156	-.6858	1

Day # = Day of hunting season
WKDAY = Day of week
TKFRQ = Total daily elk harvest
HNTRS = Total unsuccessful hunters
TMIN = Minimum temperature (Darby 1953-56; Sula 1957-89)
NSNOW = New snow
ANSNO = Accumulated snow pillow in inches of snow
WSEV = Daily weather severity index

Table 33. HD. 270 (1971-1980). Matrix of partial correlation coefficients among selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	.7821							
WKDAY	.0579	.3622						
TKFRQ	-.2012	.0215	.3128					
HNTRS	.0366	.5338	.4176	.4821				
TMIN	-.1727	.0471	-.1703	.0064	.1451			
NSNOW	-.1313	-.0199	.0229	-.0161	.1216	.1034		
ANSNO	.8622	-.0306	.1508	-.0047	.0016	.2334	.8823	
WSEV	.7032	-.0728	.0218	.1114	.0102	.1315	-.8508	.7512

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.

Table 34. HD. 270 (1981-1989). Correlation matrix of selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	1							
WKDAY	.1168	1						
TKFRQ	.3211	.4105	1					
HNTRS	.1916	.7033	.6425	1				
TMIN	-.3405	-.0051	-.1374	-.0588	1			
NSNOW	.1886	.0846	.1617	.0521	.0883	1		
ANSNO	.749	.0866	.405	.2063	-.3759	.2363	1	
WSEV	-.2128	-.0172	-.2523	-.1014	.1701	-.1557	-.7386	1

Day # = Day of hunting season
WKDAY = Day of week
TKFRQ = Total daily elk harvest
HNTRS = Total unsuccessful hunters
TMIN = Minimum temperature (Darby 1953-56; Sula 1957-89)
NSNOW = New snow
ANSNO = Accumulated snow pillow in inches of snow
WSEV = Daily weather severity index

Table 35. HD. 270 (1981-1989). Matrix of partial correlation coefficients among selected variables from daily weather and Darby check station results, upper Bitterroot, Ravalli Co., MT.

	Day #	WKDAY	TKFRQ	HNTRS	TMIN	NSNOW	ANSNO	WSEV
Day #	.8177							
WKDAY	.0553	.5056						
TKFRQ	-.051	-.0553	.4983					
HNTRS	-.0112	.6287	.5196	.6493				
TMIN	.0571	.004	-.0032	.0206	.2054			
NSNOW	-.0176	.0915	.0945	-.1046	.2038	.1113		
ANSNO	.874	-.0645	.1585	.0185	-.2407	.1201	.9214	
WSEV	.7599	-.0276	.06	.0219	-.1625	.0521	-.8901	.816

Diagonal elements are multiple r^2 values, off-diagonals are partial correlation coefficients.