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Gene Byrne

SUMMARY PROGRESS REPORT ON THE UPPER EAGLE VALLEY ELK STUDY

The Effects of Ski Area Expansion on Elk

Accuracy of 2 Telemetry systems in Mountainous Terrain

Summer Data - 1991

Summary Report 1988-1991

Conducted for:

Colorado Division of Wildlife
Vail Associates
Arrowhead at Vail
The Rocky Mountain Elk Foundation
U. S. Forest Service

By:

James R. Morrison
Graduate Research Assistant

and

A. William Alldredge
Professor, Wildlife Biology

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Fort Collins, Colorado 80523

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Report Format

The majority of work included in this report was conducted by James Robert Morrison as partial fulfillment of the requirements for a Master of Science degree in the Department of Fishery and Wildlife Biology. Morrison's thesis is appended to this report in its entirety. A bibliography relevant to effects of ski area development on the environment is provided at the end of Morrison's thesis. Recommendations from Morrison's work led to development of an intensive pellet plot survey in Pete's Bowl at Vail, and continuation of observations of elk use of habitats in the Back Bowls at Vail and in the Mud Springs/McCoy Park area at Beaver Creek. We include a summary of data collected during summer 1991 from that work.

ACKNOWLEDGEMENTS

Initial impetus for this study came from Colorado Division of Wildlife employees Bill Andree and Gene Byrne. Bill de Vergie initiated the involvement of Colorado State University, acquired funding for the first phases of the study and completed a Master of Science degree thesis entitled, "Elk Movements, Dispersal, and Winter Range Carrying Capacity in the Upper Eagle River Valley, Colorado" (de Vergie 1989). de Vergie's work developed the foundation for remainder of our work.

Financial support for this phase of our work was provided by Vail Associates, Arrowhead at Vail, The Rocky Mountain Elk Foundation, and The National Wildlife Federation. The Colorado Division of Wildlife made this project possible by contributing manpower, equipment, vehicles, aircraft and flight time. The US Forest Service provided manpower assistance and lodging for personnel during field work.

Persons too numerous to name have facilitated our work by volunteering time in all important phases of the project from trapping elk to editing documents. These many and varied contributions are warmly acknowledged.

Drs. Bruce Wunder and Gary White, from Colorado State University, served on Morrison's graduate committee and provided design, analytical, and editorial advice. Colorado Division of Wildlife employees contributing to this phase of our work include Bill Andree, Gene Byrne, Bill de Vergie, Joe Frothingham, Bill Heicher, and Craig Wescoatt. Jan Alldredge and Mathew Alldredge helped collect data during summer 1991.

Throughout our work, the interest, cooperation and support of Mr. Larry Lichliter, of Vail Associates, has been sincerely appreciated. Our best wishes are extended to Larry in his new business venture; the "elk study" will miss him.

EXECUTIVE SUMMARY

Elk in the Upper Eagle River Valley, Colorado, migrate seasonally to and from summer and winter ranges. The timing of migration to summer ranges appears to be correlated with receding winter snows. Movement toward winter ranges is influenced by weather, but also by other factors including mating activities. In the Upper Eagle River Valley, significant amounts of elk winter range has been altered for housing, commercial, and recreational development. Additionally, recreation, timber, and livestock activities occur on habitats used by elk in summer. The purpose of our work has been to elucidate habitat use patterns and responses of elk to these activities and developments and to evaluate potential impacts to resident elk populations. The first phase of this work reported on elk movements, dispersal and winter range carrying capacity (de Vergie 1989). In this report, we discuss work conducted from 1988 through 1991, which was designed to document responses of elk to expansion of ski areas and human activities in summer habitats.

We have used radio-telemetry as a means of ascertaining locations of elk as well documenting elk mortality. Telemetry has numerous advantages; primarily, an animal equipped with a telemetry device can almost always be relocated. A major disadvantage of telemetry, especially when it is employed in mountainous terrain is, that the accuracy of locations may be inadequate to make specific inferences regarding habitat use patterns. In the early phases of our work, when we had fewer telemetered elk, we could visually locate each animal after general locations were obtained using telemetry. As sample sizes increased, visual locations of all telemetered elk became infeasible, and we relied more on triangulation and aerial estimates to determine locations of telemetered elk. Reliance on this approach necessitated evaluation of system accuracy.

Triangulation using bearings defined with a hand-held antenna resulted in errors that ranged from 609 to 1,105 meters. When we used an airplane with a belly-mounted antenna system, errors ranged from 409 to 1081 meters. Errors are influenced by the abilities of observers and, more significantly, by signal bounce in mountainous terrain. We concluded that both systems we tested were adequate for making inferences regarding gross changes in geographic use patterns, but these systems were inadequate for ascertaining specific habitat use patterns. Our accuracy was as good or better than the few published studies that have evaluated accuracy. Because of the error associated with telemetry locations we are now using visual locations of elk to evaluate specific habitat use patterns. Telemetry is still a valuable tool for monitoring gross movements and animal survival. The reader is referred to Chapter 1 of Morrison's thesis appended to this report for specific details regarding our assessment of the accuracy of the telemetry systems we employed.

When we utilized only telemetry data to evaluate changes in elk habitat use associated with expansion of ski facilities in the Back Bowls of Vail, we could detect no statistically significant changes in use patterns. We attribute this result to the failure of our telemetry system to accurately determine specific locations of elk. Using visual observations of elk in the Back Bowls and comparing data before and after development, we measured an 11-fold decrease in the number of elk using China Bowl. This reduction may be associated with: 1. China Bowl was more developed than other the other bowls. 2. Development in China Bowl occurred at lower elevations than development in other bowls. 3. China Bowl was the only area with a new chair lift.

Elk seemed to avoid China Bowl the first year following development, but use appeared to increase during and after the second year following development. Elk did not abandon the Back Bowls, but merely shifted their use patterns, avoiding areas of recent development. The effects of physical disturbance on elk may have been minimized because human activity was excluded from the Bowls during periods of concentrated elk use. Specifics for this segment of our work are included in Chapter 2 of the appended thesis. Monitoring of elk use in the Back Bowls is continuing, and we recommend that human activity in this area be minimized or excluded from 15 May to 1 July.

We also used observational data to evaluate changes in use patterns for elk associated with development in McCoy Park and Mud Springs. Development included physical disturbance from ski runs built at Arrowhead and Beaver Creek ski areas, and a cabin at McCoy Park, and the human activity associated with these developments. We documented no change in the number of elk observed in McCoy Park following development, but a 46-fold decrease in elk use at Mud Springs occurred post-development. Further analysis indicated that elk decreased their use of both McCoy Park and Mud Springs drainages during mid to late summer after development occurred. Elk use began to increase following post-development lows during the second and third years after development. Details on this segment of our study are included in Chapter 3 of the appended thesis. We continue to monitor elk use in both the Mud Springs and McCoy Park drainages.

Results of our work indicate that elk respond to physical disturbances and human activities by altering their habitat use patterns. Avoidance of the disturbances that we evaluated was greatest during the first year following the activity, but animals appeared to acclimate to disturbances during and after the second year of disturbance. In areas where ample, undisturbed habitat exists, elk may respond to disturbance by merely changing habitat use patterns with no measurable impacts to population sizes or performance. Our studies were not designed to measure reductions in populations, but we recommend that future work evaluate population performance. Quite likely, elk calf survival would be the most sensitive and realistic parameter to measure for this type of study. Albeit extremely valuable, a study of this type would also be significantly more costly than the work we report herein.

At the request of the Colorado Division of Wildlife and Vail Associates we developed an intensive pellet plot survey in Pete's Bowl at Vail, and continued to monitor elk use in the Back Bowls and at Mud Springs and McCoy Park. Data from Pete's Bowl will provide a less expensive, indirect measure of elk use in this area that can be compared to similar data obtained after projected development occurs. We will use observational data from the Back Bowls and McCoy Park/Mud Springs to evaluate the suggested trends of elk acclimation to disturbance.

We implemented our pellet plot study during summer 1990. A pellet plot study measures the number of animal droppings, in this case concentrating on deer and elk, found on representative plots in a study area. Pete's Bowl was selected because it is slated for future development. By evaluating plots, pre- and post-development, changes in animal use can be inferred. We implemented 175, 4 X 15 meter plots, which were all randomly located in Pete's Bowl. This design enables us to detect small changes in pellet distributions with good statistical power. Once plots were established (summer 1990) approximately 140 man-hours are required to collect field data each year.

Plots established during summer 1990 were located and cleared of all animal evidence (fecal pellets, etc.). During summer 1991, we surveyed all plots. We were unable to locate 2 plots; possibly they were lost in an avalanche that appeared to have swept the slope where the plots were supposed to be. Evidence of all wildlife use was recorded on the remaining 172 plots. Because this is the first year of actual data collection, we have no comparisons with prior years data. Because of the large number of plots containing deer and elk pellets, our study will have good statistical power. On the 172 monitored plots, we found 144 elk fecal groups and 303 deer fecal groups. Some of our interpretations are confounded because domestic sheep droppings were found on plots in the upper reaches of Pete's Bowl. Domestic sheep droppings are easily confused with deer droppings. Domestic sheep are not supposed to be using this area and we anticipate that in the future they will not be allowed to graze here.

Also summarized in this report are observational data for elk use of the Back Bowls and McCoy Park/Mud Springs collected during summer 1991. These data are currently being analyzed by Jim Morrison for inclusion in a publication with data he collected from 1988 through 1990. Preliminary examination of 1991 data suggests that elk are using both study areas. Elk continue to use the Back Bowls including China Bowl, although few elk were observed there in 1991. Most elk had migrated from the Back Bowls by early July. Elk were observed at both McCoy Park and Mud Springs, although numbers do not approach pre-development levels. Late summer use of these areas continues to be low. We last observed elk in the McCoy Park/Mud Springs areas on 17 July and saw no elk there during 2 visits after that time.

Because of increased overhead rates at Colorado State University, the continuation of our work (pellet plots and observations for the Back Bowls and McCoy Park\Mud Springs) will be conducted by A. W. Alldredge and Jan P. Alldredge through RFL Environmental. RFL Environmental is a small, DBE Certified firm owned by Jan Alldredge specializing in environmental consulting.

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SUMMARY OF ELK STUDIES SUMMER 1991

During summer 1991, we continued to make observations on elk in the Back Bowls at Vail and at McCoy Park and Mud Springs. Our purpose is to continue evaluation of trends in elk use following disturbance from both habitat alterations and human activities. Observational data were obtained by Bill de Vergie and Mathew Alldredge from 22 May through 29 July. Pellet plots were evaluated during 9-11 August, by Gene Byrne, Bill Andree, Bill Heicher, Craig Wescoatt, Bill de Vergie, Jan Alldredge and Bill Alldredge.

Elk Observation Data Summer 1991

Observational data are summarized in Table 1. Although statistical analysis of these data are pending, elk continue to use both study areas. Elk were observed in the Back Bowls on 10 out of 12 visits from 22 May through 25 June. No elk were observed in the Back Bowls after 25 June, although some telemetered elk were still known to be in the general vicinity until 18 July. Elk were recorded in China Bowl on only 1 occasion when 3 animals were observed. Elk were, however frequently observed in the bowls adjacent to China Bowl.

Observers recorded elk in the McCoy Park/Mud Springs areas on 7 out of 13 visits. Group sizes for these observations ranged from 1 to 8 animals, and large numbers of animals were never observed. No elk were seen in the area on 2 visits made after 17 July.

Because of differences in observers and frequencies of observations, it is difficult for us to interpret these observational data. We are currently evaluating this information and comparing it to previously collected data. Results of this work will be presented in a publication authored by Jim Morrison.

Table 1. Elk observation data for the Back Bowls at Vail and McCoy Park/Mud Springs, Summer 1991.

Date	Location	Elk Present	No. Observed
5/22/91	Back Bowls	No	
	Game Creek	Yes	50+
	Beaver Creek	Yes	10-15
	Mud Springs	No	
5/23/91	Mud Springs	Yes	3
	McCoy Park	No	
	Game Creek	Yes	75+
	Lower Sunup	Yes	1 (radio)
5/28/91	Back Bowls	Yes	ND
	Game Creek	Yes	30+
5/31/91	Mud Springs	Yes	2
	McCoy Park	No	
	Siberia Bowl	Yes	7
	Lower Teacup	Yes	15+
	China Bowl	No	
	Game Creek	Yes	20
6/4/91	McCoy Park	No	
	Mud Springs	No	
6/5/91	Mud Springs	Yes	9-11
	McCoy Park	No	
	Teacup Bowl	Yes	8
	China Bowl	No	
6/6/91	Game Creek	Yes	1
6/7/91	China Bowl	No	
	Siberia Bowl	Yes	ND
	Game Creek	Yes	3
6/10/91	Super Bowl	Yes	3
	Teacup Bowl	Yes	3
6/11/91	Sundown Bowl	Yes	6
	China Bowl	No	
	Teacup Bowl	Yes	5
	Mud Springs	No	
	McCoy Park	No	

6/14/91	Siberia Bowl China Bowl Teacup Bowl Sundown Bowl	Yes Yes Yes Yes	15 3 4 4
6/17/91	Mud Springs McCoy Park No Name Road Commando Bowl China Bowl Teacup Bowl Siberia Bowl Pete's Bowl	Yes No Yes Yes No Yes No Yes	3 20 20+ 3 1
6/21/91	No Name Road McCoy Park Mud Springs	Yes Yes No	42 7
6/25/91	Siberia Bowl China Bowl Teacup Bowl Sundown Bowl	No No No No	
7/1/91	McCoy Park Mud Springs	Yes No	3
7/2/91	Back Bowls	No	
7/9/91	Back Bowls	No	
7/10/91	McCoy Park Mud Springs No Name Road	Yes No No	2
7/18/91	Back Bowls	No	
7/23/91	Back Bowls	Yes	1 radio sign.
7/24/91	McCoy Park Mud Springs	No No	
7/28/91	Back Bowls	No	
7/29/91	McCoy Park Mud Springs	No No	

Data collection for summer 1992 will be more standardized and will conform with the approach used by Morrison for collection during the period 1988-1990.

Conclusions that can be drawn from data collected during summer 1991 are that elk continue to use the Back Bowls and McCoy Park/Mud Springs. Elk use in China Bowl still appears to be low when compared to adjacent Back Bowls and to data for pre-development use in China Bowl. Numbers of elk observed in McCoy Park/Mud Springs remain lower than pre-development observations; however, use may be increasing. Prior to development elk used this area throughout summer (Andree personal communication), but with the increase in development and human activity in the area, elk have not been observed in the area after late July. Elk appear to have been displaced from areas of development, but impacts on population size and performance are unknown.

Pete's Bowl Pellet Plot Study

We implemented our pellet plot study during summer 1990. A pellet plot study measures the number of animal droppings, in this case concentrating on deer and elk, found on representative plots in a study area. Pete's Bowl was selected because it is slated for future development. By evaluating plots, pre- and post-development, changes in animal use can be inferred. This study is designed to extend for a 10-15 year period and will provide data on elk use pre- and post-development. Both the opportunity and our approach are unique for this type of study. Results will allow indirect inferences to be drawn regarding elk (and deer) use. Pete's Bowl was selected, because it would not be fiscally possible to monitor all of the 4 bowls that might be developed south of Two Elk Creek. Pete's Bowl will likely be the first bowl developed and it may receive the largest amount of development, thus it was the logical candidate for monitoring.

Analysis of data from this work will provide an indirect index of elk and deer use. Our approach will be to use negative binomial statistics and the Multi-Response Permutation Procedures (MRPP). Negative binomial statistics will be used to ascertain changes in pellet densities between years. The MRPP approach will allow us to detect changes in the distribution of pellet groups between years, even if the total pellet densities are constant across years. This analysis could offer insights in the location of use by elk. The MRPP approach is currently in planning stages and, although we believe that it offers good potential, it may prove infeasible for our work.

We implemented 175, 4 X 15 meter plots, which were all randomly located in Pete's Bowl. This design enables us to detect small changes in pellet distributions with good statistical power. Once plots were established (summer 1990) approximately 140 man-hours are required to collect field data each year.

Plots established during summer 1990 were located and cleared of all animal evidence (fecal pellets, etc.). During summer 1991, we surveyed all plots. We were unable to locate 2 plots; possibly they were lost in an avalanche that appeared to have swept the slope where the plots were supposed to be. Evidence of all wildlife use was recorded on the remaining 172 plots. Because this is the first year of actual data collection, we have no comparisons with prior years data. Because of the large number of plots containing deer and elk pellets, our study will have good statistical power.

On the 172 monitored plots, we found 144 elk fecal groups and 303 deer fecal groups, with an average of 0.84 elk groups and 1.76 deer groups per plot. Some of our interpretations are confounded because domestic sheep droppings were found on plots in the upper reaches of Pete's Bowl. Domestic sheep droppings are easily confused with deer droppings. Domestic sheep are not supposed to be using this area and we anticipate that in the future they will not be allowed to graze here. The pellet plot study offers good potential for drawing inferences regarding elk and deer use. If our results are as good as predictive calculations indicate, we should be able use this index in future work. The main advantage to this approach is that it is less expensive than intensive telemetry work. The disadvantage is that inferences are made indirectly from indices of use and without large sample sizes, the validity of conclusions is suspect. We are optimistic about the pellet plot approach.

Summer 1992 - Data Collection Approach

During summer 1992, elk use of the Back Bowls at Vail will be monitored 6 times each week for the period 25 May through 1 July. After 1 July monitoring will be conducted once every 10 days. We will evaluate pellet plots in Pete's Bowl in early August, and continue monitoring elk numbers in the McCoy Park\Mud Springs area, making observations at least once every week from 20 May through 1 July. After 1 July monitoring will be reduced to approximately every 10 days. Ground observations for both the Back Bowls and the

McCoy Park\Mud Springs area will be supplemented with aerial observations conducted by the Colorado Division of Wildlife. In early July, a preliminary report of observations will be provided to all cooperators, and during September 1992 a report summarizing all summer 1991 data collection will be provided.

Conclusions

We believe that it is important to continue collection of these data to elucidate patterns in elk response to disturbances. We will continue to use telemetry to evaluate gross movements of elk at Vail. The observational data we collect in the Back Bowls and at McCoy Park/Mud Springs will be compared to pre-disturbance data to evaluate the potential for elk to acclimate to disturbance. Data we collect from the plots in Pete's Bowl will be a "first ever" experiment that will allow us to develop a good pre-treatment data base that can be compared to post-development data. Although these data are an indirect measure of elk (and deer) use, they will provide a good index of use.

As recreational activities expand into areas that were once almost exclusively used for wildlife, the effects of these activities must be evaluated. Currently, these effects are perceived as either good or bad; but this perception is rarely based on scientifically credible data. The data we collect will continue the progression of steps we have begun to obtain credible input into the decision making process.

APPENDIX 1

Morrison, James R. 1992. The effects of ski area expansion on elk and accuracy of 2 telemetry systems in mountainous terrain. Master of Science Thesis. Colorado State University, Ft. Collins, CO. 98pp.

THESIS

THE EFFECTS OF SKI AREA EXPANSION ON ELK, AND ACCURACY OF 2 TELEMETRY SYSTEMS IN MOUNTAINOUS TERRAIN

Submitted by

James R. Morrison

Department of Fishery and Wildlife Biology

In Partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 1992

COLORADO STATE UNIVERSITY

May 25, 1992

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY JAMES R. MORRISON ENTITLED THE EFFECTS OF SKI AREA EXPANSION ON ELK, AND ACCURACY OF 2 TELEMETRY SYSTEMS IN MOUNTAINOUS TERRAIN BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

Gary C. White

Bruce A. Wunder

Adviser - A. William Alldredge

Department Head - Robert S. Cook

ABSTRACT OF THESIS

THE EFFECTS OF SKI AREA EXPANSION ON ELK, AND ACCURACY OF 2 TELEMETRY SYSTEMS IN MOUNTAINOUS TERRAIN

CHAPTER 1. ACCURACY OF A 2-ELEMENT, HAND-HELD ANTENNA AND AN AERIAL TELEMETRY ANTENNA IN MOUNTAINOUS TERRAIN

Few telemetry studies have reported the accuracy of hand-held or airplane antenna systems, and none has reported on accuracy in mountainous terrain. I measured the accuracy of a 2-element, hand-held antenna and a belly-mounted, airplane antenna on 2 study sites in mountainous terrain.

Precision of the hand-held antenna (s = 5.43°, n = 321) was better than that previously reported for this system in similar terrain and was closer to that reported in flat, non-timbered terrain. Contrary to the findings of Pace (1988, 1990), precision was constant, regardless of distance between transmitters and receiving stations. Significant bias of the antenna from 4 of 8 receiving stations (pooled bias = -3.21°, n = 321) indicated that bounced signals were common in mountainous terrain.

I used program TRIANG to triangulate the location of each transmitter, and afterwards, censored inaccurate locations by using the size of error ellipses as an index to poor locations. Using this method, I found that the Andrews Estimator had smaller errors associated with it than the Huber or Maximum Likelihood Estimator (**MLE**). The mean and 90% quantile of the distance between the true and estimated locations produced by the Andrews Estimator were 609 m and 1,105 m for Vail (n = 49); and 940 m and 1,531 m for Homestake (n = 50), respectively. Coverage of the Andrews error ellipses

was as good or better (coverage range = 8-39%) than error ellipses from other location estimators, but was still considerably less than the expected 95%.

When I utilized the airplane antenna system, I found that the mean and 90% quantile [490 m and 1,081 m, respectively (*n* = 50)] of the distance between true and estimated location for aerial locations was less than that of the hand-held system.

Key words: aerial and ground locations, errors, mountainous terrain, telemetry, TRIANG, Yagi antenna

CHAPTER 2. THE EFFECTS OF SKI AREA EXPANSION ON GEOGRAPHIC USE PATTERNS OF ELK

I documented the effects of physical disturbances in sub-alpine bowls at Vail Ski Area on the geographic use patterns of elk (*Cervus elaphus*). I used radio-telemetered elk and visual observations of elk in measuring the response to this type of development. Temporal control was achieved by comparing elk use patterns which were recorded 1 year before development to those of the following 2 years. Spatial control (incorporated by comparing use patterns of elk at the ski area to use patterns of an undisturbed elk population) allowed me to factor out the effects of weather (e.g., snow melt, plant phenologies) on use patterns.

Results from my telemetry data indicate no change in elk use patterns after development. However, the frequent radio-signal bounce that is associated with mountainous terrain may have inflated location errors and decreased my ability to detect changes in use patterns had they existed.

Observational data, having a much smaller associated error, allowed detection of more subtle changes in use patterns. Results from my observations indicate elk use in the entire treatment study area decreased threefold after development. My analysis of each bowl suggests that this decrease was primarily influenced by an 11-fold decrease in elk use of the most developed bowl, China Bowl. I detected no changes for the remaining, less developed bowls, Tea Cup and Siberia-Mongolia Bowls. Post development results suggest that elk may have partially acclimated, behaviorally, to these disturbances and/or revegetation in developed bowls may have attracted elk to these areas. Although I detected changes in geographic use patterns, elk did not completely abandon developed areas. The effects of these disturbances likely were minimized by excluding human activity from developed areas during periods of concentrated elk use.

Key words: behavior, *Cervus elaphus*, elk, development, physical disturbances, ski areas

CHAPTER 3. CHANGES IN THE NUMBER OF ELK OBSERVED AFTER DEVELOPMENT OF 2 COLORADO SKI AREAS

I documented the response of elk to both physical and human disturbances by measuring the changes in the number of elk observed in McCoy Park and Mud Springs drainages after development. Development occurred close to the drainages after 1987 and consisted of the construction and operation of Trapper's Cabin (a guest lodge built by Beaver Creek Ski Area) and Arrowhead Ski Area.

Elk were observed in McCoy Park and Mud Springs for 2 summers before development (1985 and 1987), and I compared these observations to those made during the 3 summers after development (1988-1990).

Using negative binomial statistics, I was unable to detect a statistical difference in the number of elk observed in McCoy Park, although the first summer after development the number of elk observed was nearly half that of the other 4 summers. There was a dramatic decrease in the number of elk observed in Mud Springs; a 46-fold decrease in elk use occurred during the first 2 summers after development. During the third year after development, the number of elk observed increased; however, the average number of elk observed was still fourfold less than before development.

I made comparisons between time of year elk were observed in both McCoy Park and Mud Springs and the time of year Trapper's Cabin was used. My results indicate that after development, elk altered their use patterns and occupied these drainages earlier in the summer, before Trapper's Cabin opened for use.

In 1988, changes in the number of elk observed were likely due to activities associated with the construction of Arrowhead Ski Area, and/or the presence and operation of Trapper's Cabin. Increases in elk use of both drainages in 1989 and 1990 were likely caused by the cessation of construction at Arrowhead Ski Area, and/or the behavioral acclimation of elk to disturbances.

Key words: behavior, *Cervus elaphus*, development, elk, human activity, physical disturbance

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For their interest and financial support I thank the following 11 agencies: Colorado Division of Wildlife, Vail Associates, Rocky Mountain Elk Foundation, National Wildlife Federation, Colorado State University, Eagle County, Colorado Ski Country - USA, U.S. Forest Service, Copper Mountain Ski Area, Homestake Water Board, and Arrowhead Ski Area.

Many people helped make the completion of this thesis successful. First, I am grateful to my major professor, Bill Alldredge and committee members Gary White and Bruce Wunder. All 3 provided valuable guidance, both professionally and personally.

Bill de Vergie shared the results of his past work and provided invaluable advice on study design and logistics. Bill was always willing to answer my endless list of questions.

Special thanks go to the following Colorado Division of Wildlife employees for showing a keen interest in this research and providing essential logistical support: Area Biologist, Gene Byrne; District Wildlife Managers, Bill Andree, Bill Heicher, and Craig Wescoatt; and pilot, Joe Frothingham. Without the help of these people, this study would not have been possible. Larry Lichliter of Vail Associates deserves special recognition for his interest and cooperation in this work. Numerous volunteers, far too many to mention, also provided essential logistical support each winter trapping elk and each summer collecting data.

I thank Jan Alldredge for spending many long hours editing my thesis. Bruce Hawkins, Alice Kelley, and Dave Schoep also reviewed my thesis and made helpful criticisms. In addition, I am grateful to the many graduate

students who provided valuable advice and comradeship throughout my masters.

Finally, I am indebted to my Mom, Dad, 3 sisters and my friends for their endless support.

PREFACE

My thesis is written in 4 chapters. In Chapter 1, I report on telemetry errors associated with a 2-element, hand-held antenna and a 2-element antenna mounted to the belly of an airplane. This chapter is important because assessment of telemetry error was critical in determining the resolution of changes in use patterns that report in the second chapter. In Chapter 2, I discuss the effects of the physical development associated with ski area expansion on early summer geographic use patterns of elk. In Chapter 3, I report the effects of both physical and human disturbances on elk use patterns at 2 other Colorado ski areas, and in Chapter 4 I summarize conclusions from my first 3 chapters. Finally, in an appendix I include a bibliography of articles addressing the effects of ski areas on the environment.

Much of the work in this thesis was completed by former graduate student, Bill de Vergie and myself. Both Bill and I are thankful for the opportunity and responsibility given to us to complete this study. We believe graduate students are logical investigators for studies like this because: (1) being students we can complete studies in a cost effective manner; (2) being at the university we have access to some of the newest technology and techniques used in wildlife studies; (3) because we do not have a vested interest in the outcome of results we are more likely to complete objective, third party studies; and (4) studies like this give us an excellent opportunity to become trained as professional biologists.

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CHAPTER 1

ACCURACY OF A 2-ELEMENT, HAND-HELD ANTENNA AND AN AERIAL TELEMETRY ANTENNA IN MOUNTAINOUS TERRAIN

Several studies have measured the accuracy of null-peak and/or twin, multi-element antenna telemetry systems (Springer 1979, Hupp and Ratti 1983, Lee et al. 1985, Garrott et al. 1986, Kufeld et al. 1987, Pace 1988, Mills and Knowlton 1989). However, use of these cumbersome antenna systems is limited because they must be fixed either at permanent towers or on vehicles. If highly mobile wildlife species, such as elk, do not remain in the vicinity of towers or roads accessible to vehicles, then these antenna systems have little utility. Consequently, to follow mobile animals, biologists have used either the 2-element, hand-held Yagi antenna, which is collapsible and easily transported, or airplanes with fixed antennas. Unfortunately, little is known about the accuracy of these telemetry systems, especially in mountainous terrain where radio signal bounce is frequent. Because of the nature of high frequency radio signals, these signals can bounce off rocks, cliffs, and even trees, which may make locating transmitters difficult (Hupp and Ratti 1983, White and Garrott 1990).

Three studies have measured the accuracy of the hand-held antenna (Garrott et al. 1987, Hupp and Ratti 1983, Pace 1988). Hupp and Ratti (1983) found the 2-element antenna (n = 3) was 2-3 times less precise and 8-10 times more biased than the null-peak antenna, when it was used in areas that were relatively flat and non-timbered. Areas with more relief and timber created errors for both systems which were too large to accurately estimate locations of radio transmitters. Pace (1988) reported errors for a 4-element, hand-held antenna on flat farmland and had similar findings to those of Hupp and Ratti; however, bias and sample size were not reported. Garrott et al. (1987) did not measure the precision or bias of their 2-element antenna system, but instead measured the distance between true and estimated locations. With distances between the tracker and transmitter ranging from 0.3-1.0 km, they reported a mean error of 267 m (range, 74-1,025 m) for moderately rolling terrain.

Several biologists have described methodology for obtaining accurate telemetry locations from aircraft (Kolenosky and Johnston 1967, Seidensticker et al. 1970, Mech et al. 1971, Whitehouse and Steven 1977, Gilmer et al. 1981); but again, few have measured the error associated with such methods. Hoskinson (1976) and Whitehouse and Steven (1977) reported errors associated with their locations from strut-mounted antennas ranging from 7-75 m (n = 20) and 15-400 m (n = 45), respectively. In both studies, airplanes flew at low altitudes [Hoskinson (1976) flew 15-30 m above ground level] over flat terrain and made several passes over each transmitter while biologists made location estimates. Garrott et al. (1987) made locations in moderately rolling terrain (they flew 100-400 m above ground level) and reported errors associated with their strut-mounted antenna ranging from 25-750 m (mean = 275 m, n = 15).

Unfortunately, inferences may be limited from the above studies when one or more of the following conditions are not met: (1) Belly-mounted antennas are used to locate transmitters rather then strut-mounted antennas. (2) In studies where many transmitters are used, locations must be determined quickly and several passes over each transmitter may not be possible. (3) Finally, mountainous terrain precludes flying at low altitudes. (for safety reasons pilots must fly at least 200-600 m above ground level).

If biologists continue to use hand-held and airplane-mounted antennas to locate telemetered animals, further assessment of the error associated with locations needs to be made, especially in mountainous terrain where radio signal bounce can frequently occur. During my telemetry work with radio-collared elk, I measured the accuracy in mountainous terrain of both a 2-element, hand-held Yagi antenna and a 2-element Yagi antenna mounted under an airplane.

STUDY AREA

My 2 study sites were in central Colorado near the city of Vail (39°30' N, 106°25' W). The Vail study site covers most of Two Elk Creek, a secondary drainage that includes 12 primary drainages. These drainages are V-shaped, indicating little past glacial activity. Elevation ranges from 2,740-3,480 m (9,000-11,400 ft). South facing slopes are approximately 20% timbered, primarily at lower elevations, and north facing slopes are 80% timbered. The Homestake study site encompasses the lower extent of Homestake Creek. Homestake Creek is U-shaped, and contains numerous rock micro-ridges (10-50 m high), suggesting past glacial activity. Elevation ranges from 2,740-3,800 m (9,000-12,450 ft), and both south and north facing slopes are 90% timbered.

METHODS

Ground Locations

During the summers of 1989 and 1990, 9 and 8 Telonics[1] transmitters (150-151 Mhz) were placed in the Vail and Homestake study sites, respectively. Transmitters with antenna sewn into radio collars were situated in locations unknown to me and were fastened to trees 1-1.5 m above the ground (approximately the height of transmitters on standing elk).

I used a Telonics 2-element, hand-held Yagi antenna and a Telonics scanning receiver from 3 or 4 (of 5 potential) receiving stations at Vail and 3 stations at Homestake (Fig. 1.1) to estimate the location of each transmitter. I chose each of the 8 receiving stations from 31 potential stations based on the following criteria:

1. The station was topographically prominent and provided good radio signal reception with line-of-sight across the study site, thus reducing the probability of receiving a bounced signal.
2. I positioned each station to facilitate location of 20-25 transmitters in 2-4 hours. Because I was solely responsible for determining the locations of telemetered elk while estimating the location of the above transmitters, I had to visit all stations as quickly as possible to reduce

[1]Use of commercial name does not imply endorsement by Colorado State University.

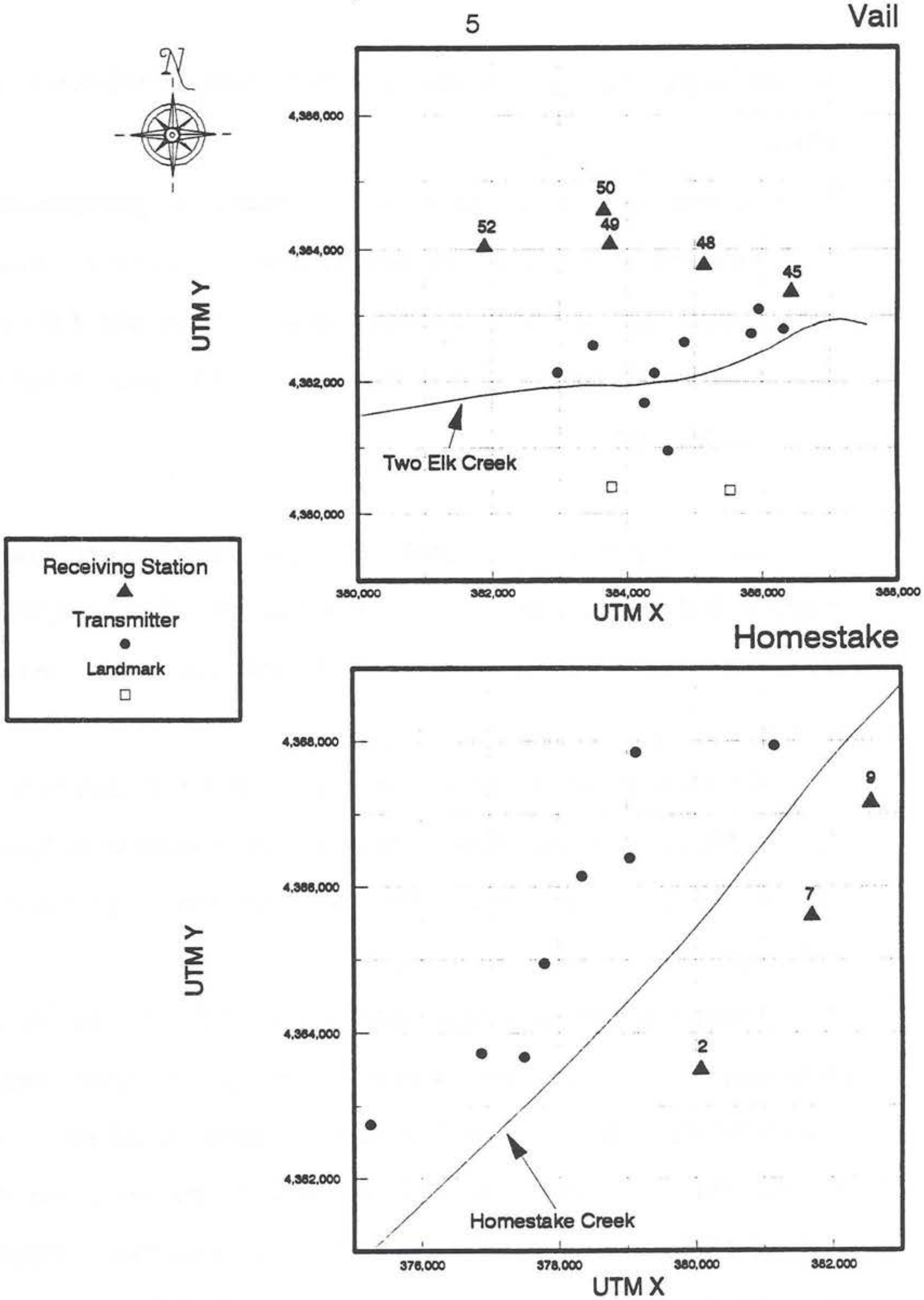

Fig. 1.1. Maps of receiving stations, transmitters, and landmarks on Vail and Homestake study sites. Number for each receiving station is listed. Mean distances between stations and transmitters were 2.5 km (range, 0.5-4.6 km) and 4.2 km (range, 1.6-8.5 km) respectively for Vail and Homestake sites. Mean distance between stations and landmarks was 4.0 km (range, 3.3-5.2 km). Axes are scaled by Universe Transverse Mercator (UTM) coordinates, and each block is 1 km² or 100 ha.

location errors which might be due to animal movements (Schmutz and White 1990).

3. I located each station as close as possible to geometrically optimal locations (White 1985). In general, to minimize errors in triangulation, stations should not be too close to each other, and if the study site includes an entire drainage, they should be located on both sides of the drainage.

Because of criterion 2, I could not situate stations on both sides of the drainage and still complete locations in 2-4 hours. Consequently, I placed stations only on 1 side of the drainage for both Vail and Homestake study sites.

Elevation of receiving stations averaged 3,350 m (11,000 ft) for Vail and 3,230 m (10,600 ft) for Homestake. Mean distances between transmitters and receiving stations were 2.5 km (range, 0.5-4.6 km) and 4.2 km (range, 1.6-8.5 km), respectively, for Vail and Homestake.

I measured the bearing at each station, within 1°, to the strongest radio signal for each transmitter with a Silva Ranger[2] mirrored compass, and I estimated 4-5 locations for each of the 17 transmitters, (49 and 50 locations for the Vail and Homestake sites, respectively) by using the computer program TRIANG (White and Garrott 1984, 1990). I maximized independence of the 4-5 locations on each transmitter by taking the following precautions to prevent past locations from influencing future locations: (1) While I located

[2]Use of commercial name does not imply endorsement by Colorado State University.

transmitters fixed to trees, I also located transmitters on 20-25 moving elk. (2) I made locations at least 1 week apart. (3) I did not use program TRIANG to estimate transmitter locations until I retrieved transmitters. The true location of each transmitter was determined with topographic maps, using triangulation on known landmarks and careful inspection of proximate topography and vegetation. I did not measure the error associated with ascertaining these true locations, but because I used the above methods to determine these locations, the error of the true location of each transmitter is likely within 30-50 m.

I measured the error associated with this telemetry system using the following methods:

1. I measured the precision of all 8 receiving stations. This was measured for each station by standardizing the median of bearings for each transmitter to zero and then pooling the data for all transmitters. In addition, data for all 8 stations were pooled to get an overall precision. Because TRIANG requires that standard deviation of all towers be equal, I tested to see if standard deviations differed between the 8 stations by using Levene's test (LEV1:Median variation) for homogeneous variance (Conover et al. 1981). This variation used the absolute difference between each datum and the median. In addition to testing for equal precision between receiving stations, I tested for equal precision as distance between transmitters and receiving stations increases. The Andrews, Huber and Maximum Likelihood Estimator assume that precision is equal as distance increases; however, Pace (1988, 1990) found that precision for his telemetry system was not

constant as distance increased, but rather the relationship was more bath-tub shaped [i.e., precision remained constant over most of the spectrum of distances and increased only at close (< 5 m) and far distances (> 950 m)] (Fig. 1.2). Using Levene's test, I tested for changes in precision as related to distance by using distance criteria to block data for bearings standardized to zero. Distances between transmitters and receiving stations ranged from 0.56 km to 8.5 km. Consequently, I blocked data into 5 groups; 0-1, 1-3, 3-5, 5-7, and 7-9 km.

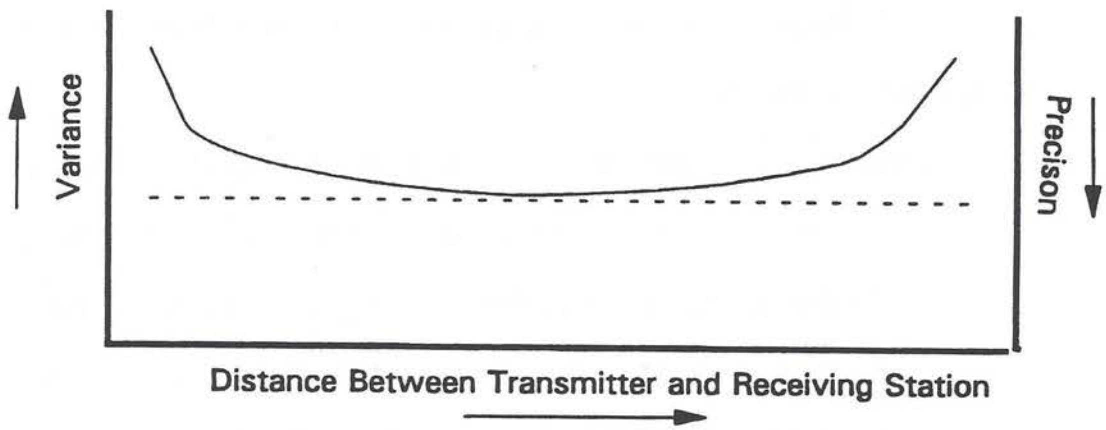

Fig. 1.2. Theoretical behavior of variance and precision as related to the distance between transmitter and receiving station. Solid line illustrates Pace's theory where precision increases at close and far distances. Dashed line illustrates the theory of constant precision.

2. I measured the bias of bearings by averaging the differences between the true bearing for each transmitter and each estimated telemetry bearing. Biases of transmitters were pooled for each station. Using Student's t-test, I tested whether the bias was different from zero for each station and all stations pooled.

3. I measured the distance between true and estimated locations for all 3 estimators available through TRIANG, the Andrews, Huber and MLE (Lenth 1981). Without radio signal bounce, these 3 estimators produce the same location estimate (White and Garrott 1990). However, with signal bounce, the Andrews and Huber Estimators attempt to detect this bounced signal by weighing signals less where the distance between the receiving station and estimated location is greatest and weighing signals more where intersection with other bearings is closest to the optimal angle of 90° (White and Garrott 1990). Neither of these estimators are designed to estimate locations with more than 1 bounced signal when only 3-4 receiving stations are used.
4. Finally, I measured the coverage of error ellipses, which is the percentage of error ellipses that covered true locations, for all 3 estimators.

Because bearings from 2-element antennas are not as precise as those from null-peak antennas (Hupp and Ratti 1983), TRIANG is not as sensitive in detecting bounced signals. As a result, TRIANG uses bounced signals to estimate locations when it should not. To decrease the probability of using less accurate locations, I used a censoring method identical to that used by Garrott et al. (1986). I completed censoring by plotting Andrew's error ellipse versus distance between true and estimated location for each study site. In theory, the relationship between error ellipse size and the distance between true and estimated locations should be positive and curvilinear; i.e., the area of error ellipses increases to the squared power while the distance between the true and estimated locations increases to the first power. If a positive relationship exists between these 2 variables, one can then delete locations with error ellipses above a certain size to decrease the probability of using locations with the greatest error.

After inspection of the positions of Homestake receiving stations in relation to the transmitters, I realized my receiving stations were not positioned adequately to allow estimation of locations for the southern section of the study site (Fig. 1.1) (White 1985). Consequently, to decrease the probability of using poor locations, I deleted all locations that had a Universe Transverse Mercator (**UTM**) Y coordinate south of 4364000 N.

I also tested for triangulation errors associated with reading a hand-held compass by making 10 visual locations of 2 landmarks (5 each) in Super Bowl on the Vail study site. I used stations 48, 49, and 52 to make these locations. For analysis, I pooled data from all 3 stations and named this station 99. To allow for comparison, I used the same 4 methods for measuring error on both visual locations and telemetry locations (except, precision was not tested as related to distance between landmark and receiving station). Mean distance between landmarks and receiving stations was 4.0 km (range, 3.3-5.2 km).

Aerial Locations

Fifty locations were completed from an airplane on 17 transmitters fixed to trees, and 10 additional transmitters that had fallen from radio-collared elk (these were on collars that were designed to drop off elk after a 2 year period or were transmitters from elk mortalities). Aerial locations were determined 200-600 m above ground from a Cessna 185 airplane with a rotating, belly-mounted antenna. Locations of these transmitters were made while concurrently locating 50-60 radio-collared elk during flights lasting from 4-6 hours. Because of the large number of transmitters being located, locations were made as quickly as possible (mean location time = 4-6 min/location). Generally, each transmitter signal was tracked to the strongest signal source and the pilot circled this source once. Locations were plotted on 7.5 minute topographic maps and were later converted to UTM coordinates. I report error as distances between true and estimated locations. This error includes the error associated with locating transmitters and that associated with plotting locations on topographic maps.

RESULTS

Ground Locations

Using Levene's test for homogeneous variance, I rejected my null hypothesis that precision was equal between all receiving stations (P = 0.0001) (Fig. 1.3). After further analysis, I found that when I deleted the least precise station (Station 45) I was unable to reject (P = 0.42). Although the standard deviation of Station 45 was larger than the rest, I included this station in the pooled standard deviations used for TRIANG. TRIANG uses this standard deviation to calculate the size of error ellipses (e.g., a larger standard deviation will cause TRIANG to produce larger error ellipses) and I chose to include station 45 so that error ellipses would reflect the maximum error of locations and provide the highest coverage of true locations. The pooled standard deviation for the 8 receiving stations was 5.43°. The standard deviation for the visually located landmarks was 1.2°.

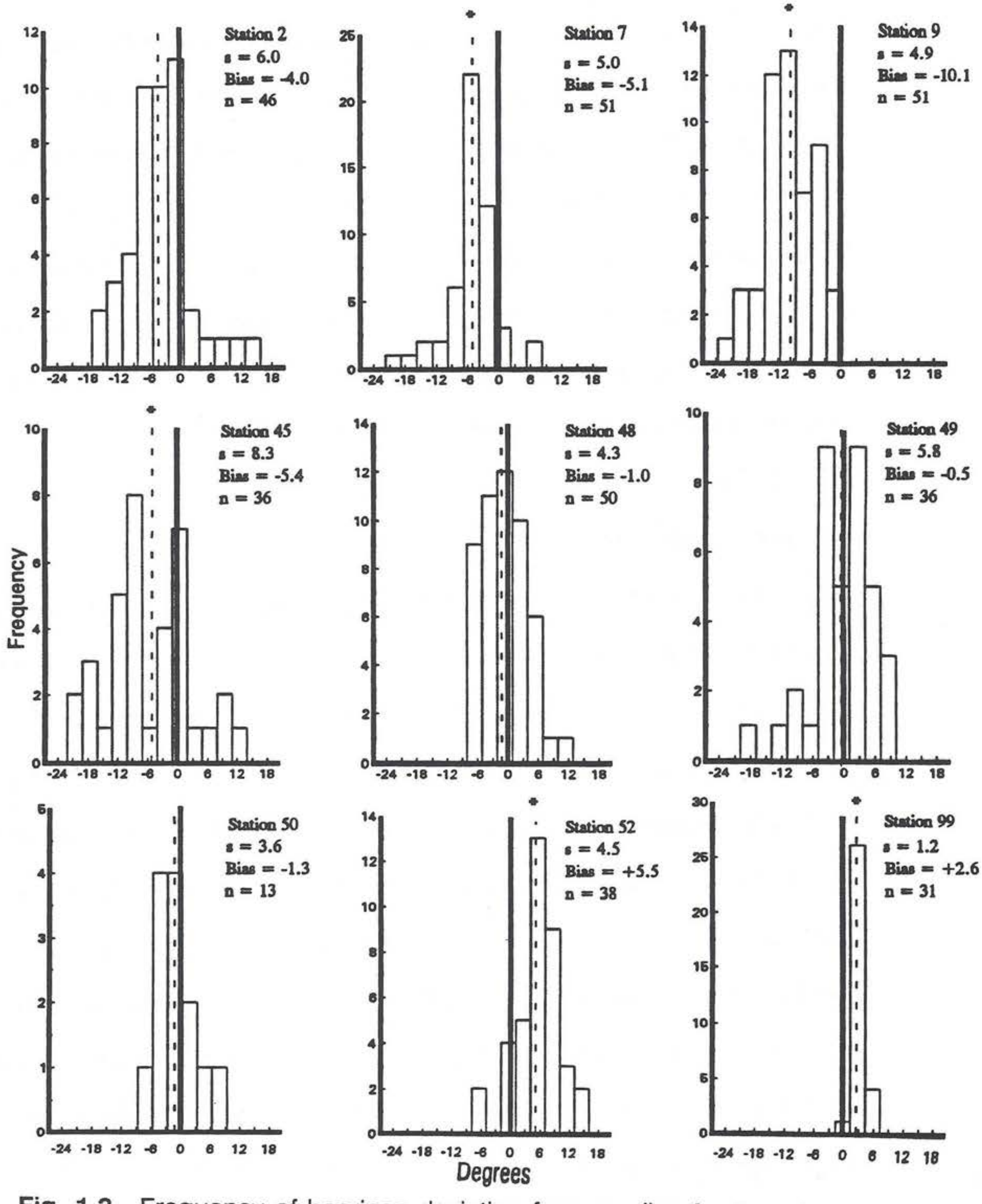

Fig. 1.3. Frequency of bearings deviating from median for 8 stations used to make telemetry locations. Bias is indicated for each station by shifting distributions from 0. Stations 2, 7 and 9 are in the Homestake study site and stations 45, 48, 50 and 52 are in the Vail study site. The 9th station, 99, is for landmarks in Super Bowl that were visually located and sighted in with compass. Dotted vertical line marks bias for each station and vertical solid line marks no bias. Asterisks mark stations that had a bias significantly different from zero ($\alpha = 0.05$). For **all** stations, except Station 99, $n = 321$.

Overall, precision of bearings did not change as a function of distance between transmitters and receiving stations (P = 0.13) (Fig. 1.4). However, a general trend of greater precision as the distance between transmitter and station increased was present. When I grouped data for the transmitters that were between 0.5 km and 5 km from receiving stations and compared them with data for transmitters greater than 5 km, I found the bearings on the distant transmitters to be more precise (P = 0.02).

Fifty percent of 8 stations (40% at Vail, 67% at Homestake) had a mean bias significantly different from zero (α = 0.05) (Fig. 1.3). Mean bias for all 8 stations pooled was -3.21°, which was significantly different from zero (P = 0.0001). Bias for visually located landmarks was +2.6°, which was also significantly different from zero (P = 0.001).

A positive correlation existed between error ellipse size and distance between true and estimated locations (r^2 = 0.76) (Fig. 1.5) for Vail data. I deleted all locations with error ellipses greater than 150 ha. I did not delete ellipses less than 150 ha because errors did not decrease significantly after those deletions. No correlation (r^2 = 0.001) was observed between error ellipse size and the distance between true and estimated location for stations at Homestake. However, to delete obviously poor locations at Homestake, I censored only those locations with error ellipses greater than 300 ha.

The MLE had a lower associated error than Andrews or Huber Estimators before deleting poor locations (Fig. 1.6, Table 1.1) at Vail. The MLE performed as well (within 5-10 m) as the Andrews and Huber for all locations except for a few with large errors (errors > 2,000 m). For locations associated with larger errors, the MLE was substantially better, with

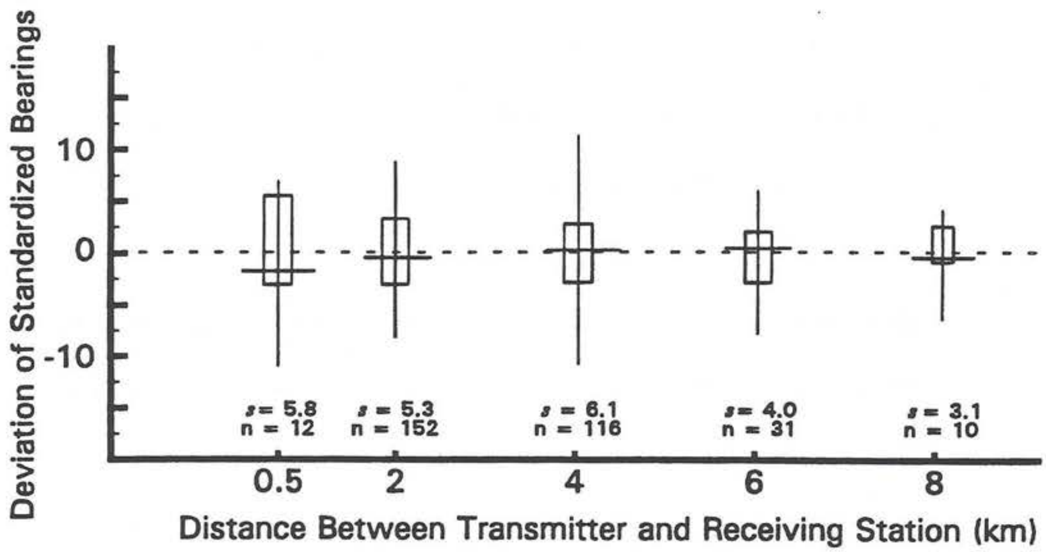

Fig. 1.4. Precision of standardized telemetry bearings as related to distance between transmitter and receiving station. Horizontal line marks median, upper and lower box lines mark 75% and 25% quantile, respectively, and upper and lower points of each vertical line mark 95% and 5% quantile, respectively. I detected no difference overall (P = 0.13), but a difference was detected when bearings were pooled for the first 3 groups and compared to the later 2 groups (P = 0.02).

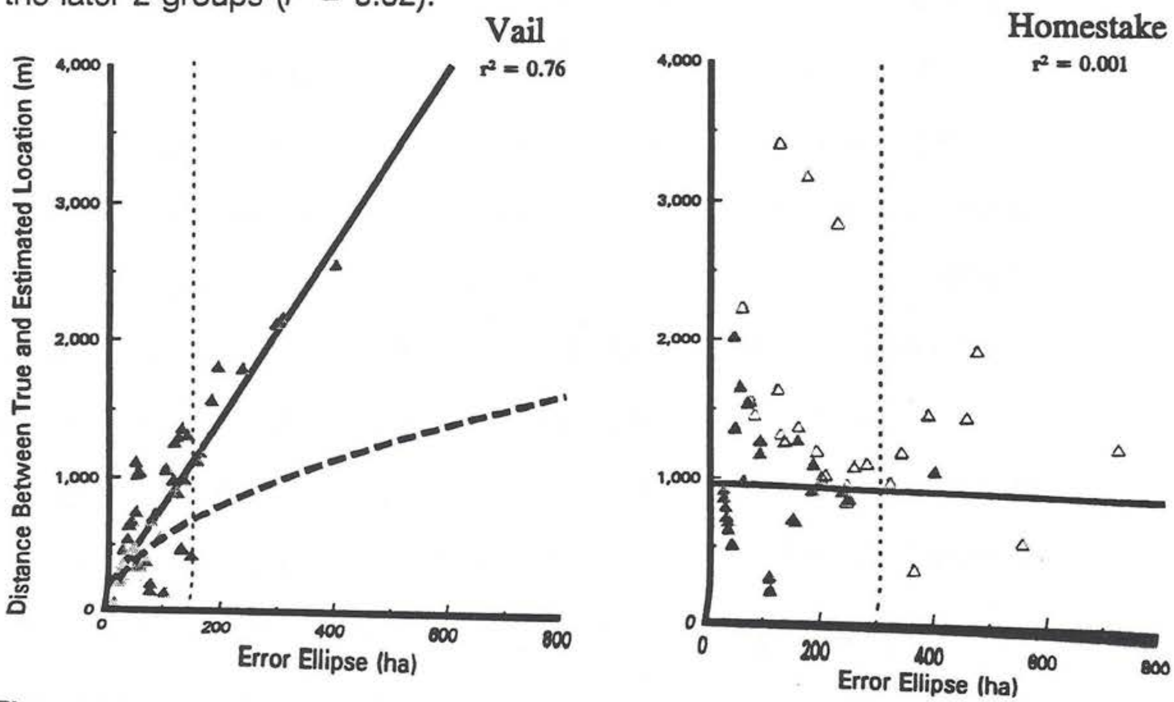

Fig. 1.5. Distances between true and estimated locations as a function of Andrew's error ellipses from program TRIANG. Dashed line for Vail shows expected curvilinear relationship, assuming circular ellipses. Vertical dotted lines show cut-off point for censoring, and locations with error ellipses greater than lines were deleted. Unshaded triangles for Homestake are those locations that were not adequately covered by receiving stations. For Vail, n = 49 and for Homestake n = 50.

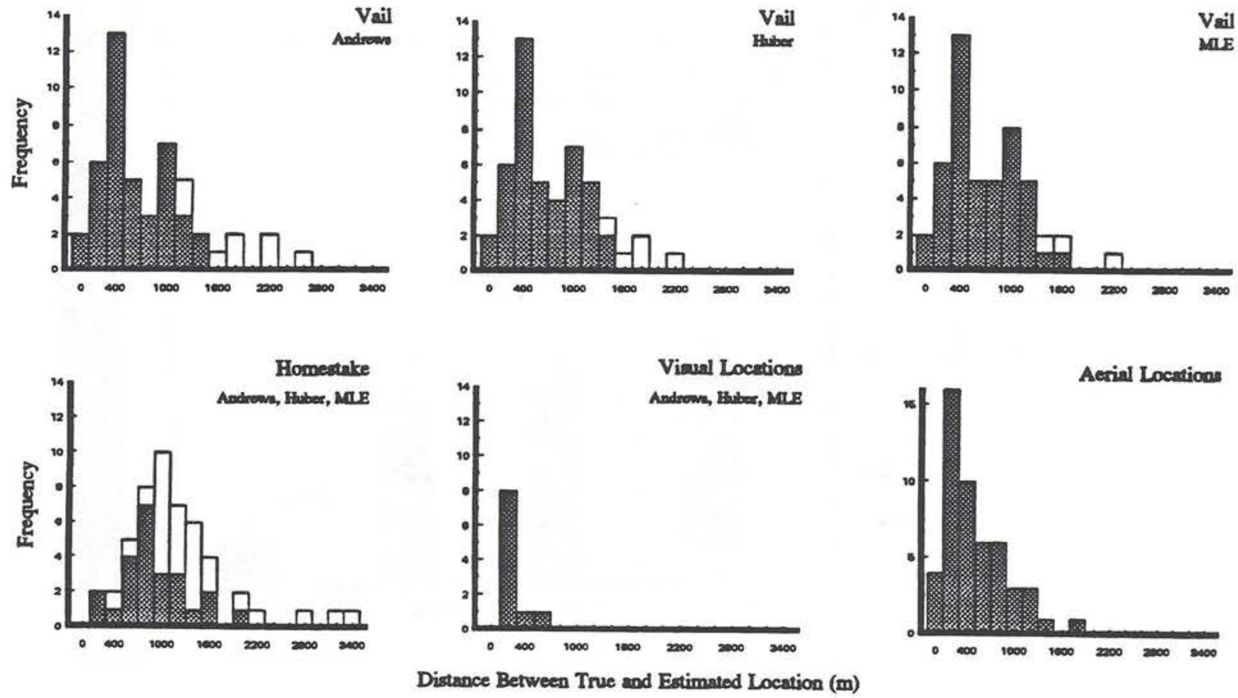

Fig. 1.6. Histograms of distance between true and estimated locations for ground, visual and aerial locations. Ground and visual location histograms show the performance of the Andrews Estimator, Huber Estimator and MLE. Unshaded bars are locations deleted and shaded bars are locations remaining after censoring. All 3 estimators produced the same histograms for Homestake and the visual locations. Unshaded bars are locations deleted after censoring.

Table 1.1. Mean and 90% quantile before and after censoring for Andrews, Huber and MLE for Vail, Homestake and Super Bowl locations. Mean and 90% quantile are also listed for aerial locations.

		Before censoring (m)		After censoring (m)	
		Mean	90%	Mean	90%
Vail	Andrews	800	1,781	609	1,105
	Huber	755	1,420	643	1,239
	MLE	670	1,322	657	1,216
Homestake		1,196	1,954	940	1,531
	Huber	1,194	1,952	937	1,531
	MLE	1,194	1,952	938	1,531
Super[a]	Andrews	286	462	-	-
	Huber	286	461	-	-
	MLE	286	461	-	-
Aerial[a]	-	490	1,081	-	-

[a] Locations not censored.

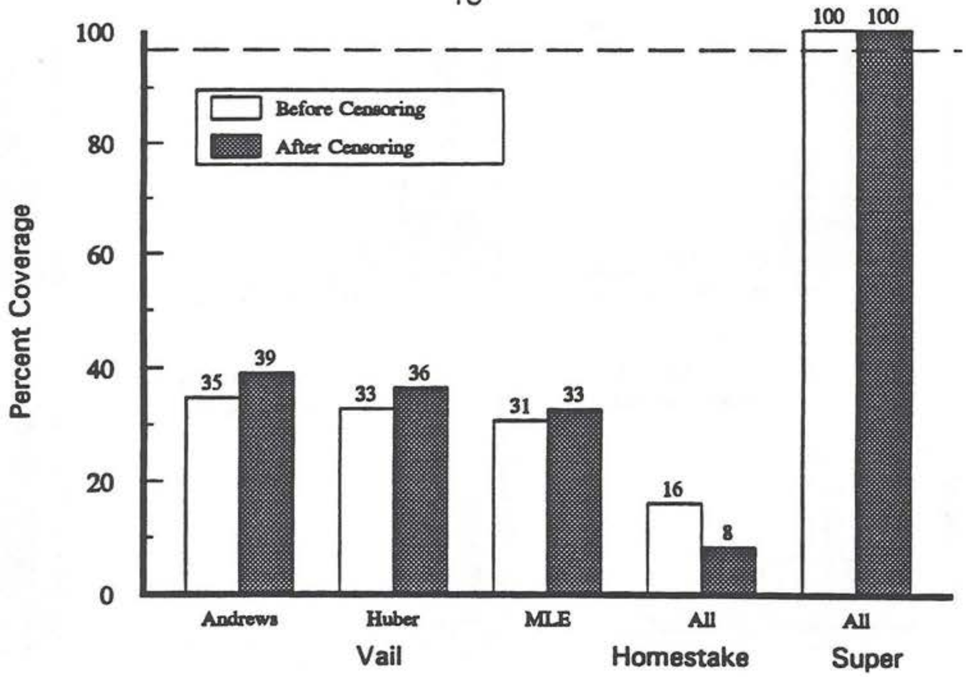

Fig. 1.7. Percent of error ellipses, before and after censoring, that covered true location. Percent coverage is shown for all 3 estimators at Vail. Coverage for all estimators at Homestake and Super Bowl were identical. Coverage for landmarks in Super Bowl was calculated with $s = 5.43°$. Coverage with $s = 1.2°$ was 10%. Dashed line is expected coverage of estimators. For; Vail $n = 49$, Homestake $n = 50$, and Super Bowl $n = 10$.

errors 200-1,700 m less than Andrews and Huber; however, after censoring these inaccurate locations, the Andrews Estimator performed better. Telemetry locations in Homestake and visual locations in Super Bowl produced location estimates with similar errors (within 5-10 m of each other) for all 3 estimators.

Coverage, the percentage of error ellipses that include the true location, for all 3 estimators (for both Vail and Homestake) was substantially lower than the expected 95% (Fig. 1.7). Coverage increased slightly after censoring locations in Vail, but, surprisingly, decreased for Homestake. Coverage for visually located landmarks in Super Bowl, when using error ellipses created with the bearing standard deviation from telemetry data of

5.43° was 100%; however, when the standard deviation for visual locations (1.2°) was used, TRIANG produced much smaller error ellipses and coverage dropped to 10%.

Aerial Locations

The mean distance between true and estimated aerial locations with the belly-mounted antenna was 490 m with a 90% quantile of 1081 m (Fig. 1.6, Table 1.1).

DISCUSSION

Ground Locations

The precision and bias of my 2-element antenna system in timbered, mountainous terrain (precision, s = 5.43°, bias = -3.21°, n = 321) was better than that reported by Hupp and Ratti (1983) (precision, s = 83.8°, bias = 17.2°, n = 3) for similar terrain. In fact, my precision and bias were most similar to Hupp and Ratti's best study site, which was non-timbered, flat terrain (precision, s = 5.00°, bias = -3.24°, n = 3). My precision was also close to that reported by Pace (1988) (precision, s = 5.74°, n and bias = unknown) on flat farmland. Although the mean distance between my true and estimated locations was 3-4 times more than that reported by Garrott et al. (1987), the distance between my transmitters and receiving stations was also 3-4 times greater.

Although bearings tended to be more precise as distance between transmitter and receiving station increased, I did not detect a distinct decrease in precision at close and far distances, as Pace (1988, 1990) did. My inability to show a change in precision as distance increased may be due to the following differences between my study and Pace's: (1) Pace used a

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CHAPTER 2

THE EFFECTS OF SKI AREA EXPANSION ON GEOGRAPHIC USE PATTERNS OF ELK

Skiing has become a major industry in North America. Currently, 684 ski areas exist in North America (Enzel 1988), and the industry continues to grow. In just 12 years (1976-77 to 1988-89), estimated skier days nearly doubled (from 28 to 53 million) and gross revenues increased fivefold (from 349 million to 1.83 billion) (Goeldner and Farwell 1977, Goeldner et al. 1990). As a result of this growth, proposals for new ski areas and expansion of existing ski areas has become common. For example, in Colorado 3 new ski areas have been proposed and expansion has been planned for many of the existing 30 ski areas. Tragically, the effects of this billion dollar industry on the environment have rarely been documented (Alldredge 1988, Rosenstock 1988) (see Appendix A for a list of studies on ski areas and their effects on the environment). Since the National Environmental Policy Act (NEPA) was passed in 1969, every ski area on federal land has been required to complete an Environmental Assessment (EA) or Environmental Impact Statement (EIS) before development. However, these documents only speculate on the effects ski areas may have on the environment; private or public agencies rarely measure the effects after development. In my study, I measured the response of Rocky Mountain elk (*Cervus elaphus nelsoni*) to physical disturbances resulting from ski area expansion, as reflected in changes of early summer geographic use patterns.

Prior to this study, no one had quantified the effects of ski areas on elk; however, biologists have completed research measuring impacts from similar disturbances, such as logging and/or roads. Disturbances associated with these activities consists of 2 components, physical and human. The effects of physical disturbances (e.g., clear-cuts) on elk are uncertain. Ward (1976) and Lyon and Jensen (1980) suggest that elk prefer clear-cuts; however, Hershey and Leege (1976) found the opposite, in fact, that elk may even avoid clear-cuts. The effects of human disturbances on elk are more consistent. Ward (1976) and Lyon (1979b) suggest that elk avoid active logging. Hershey and Leege (1976), Perry and Overly (1976), Lyon (1979a), and Morgantini and Hudson (1980) suggest that elk avoid roads open to human use. Generally, studies measuring the effects of logging and roads on hunted elk populations indicate that elk avoid areas where habitat alterations have occurred, especially if levels of human activity are high. Unhunted elk (e.g., in national parks) tend to be more tolerant of human activities (Lyon and Ward 1982).

These studies provide biologists only a start from which to predict the effects of ski area development on elk. Ski area development differs from logging and roads, in that, development is predominately at a larger scale; the average ski area is 733 hectares with 260 skiable hectares (range, 15-5,700 hectares) (Goeldner et al. 1990), whereas clear-cut logging in the above studies encompassed only 2-138 ha. Also, human activity associated with ski areas during winter and summer months may be much more intense than that found during and after logging, or along roads.

Data collection for this study began in 1985, when the Colorado Division of Wildlife became interested in documenting movements of elk near Vail. From 1987 to 1988, de Vergie (1989) further quantified the movement of the 2 migratory and hunted elk populations used in this study, 1 population located south of the city of Vail and the other population residing in Homestake drainage. After de Vergie's last field season in 1988, Vail Associates expanded Vail Ski Area into the Back Bowls, adding 770 hectares of skiable terrain, and completed the single largest ski area expansion ever undertaken in the United States (Beasly 1989). For 2 years after this expansion, I measured the response of elk to these physical disturbances.

STUDY AREA

I worked with 2 migratory elk populations, each of approximately 200-300 animals (B. Andree, Colo. Div. Wildl., pers. commun.) on 2 study sites, 15 km apart, located in central Colorado near the city of Vail (39°30' N, 106°25' W). The Vail study site encompassed most of Two Elk Creek. Elk in this area winter northwest of Two Elk Creek and use Two Elk Creek primarily in early summer during calving season. Elevation of Two Elk Creek ranges from 2,740-3,475 m (9,000-11,400 ft). South facing slopes, hereafter referred to as the Back Bowls, are 20% timbered with quaking aspen (*Populus tremuloides*) and lodgepole pine (*Pinus contorta*) occurs predominantly at lower elevations (< 3,200 m). The remaining non-forested areas are comprised of sub-alpine meadows. North facing slopes are 80% timbered with lodgepole pine at lower elevations and subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) at upper elevations. Human activity on this site was concentrated on a trail besides Two Elk Creek. Most human activity consisted of hiking, mountain biking, and occasional motor cycling.

The Homestake study site encompassed the middle and lower extent of Homestake Creek. The Homestake elk population differs from the Vail elk population in that elk in the Homestake area use the same drainage during both winter and early summer. Elevation of the Homestake study site ranges from 2,740-3,795 m (9,000-12,450 ft). The lower elevations of southeast facing slopes are 60% timbered and are predominantly quaking aspen with mixed subalpine fir and Engelmann spruce. Upper elevations of southeast facing slopes and all of the northwest facing slopes are 90% timbered and are predominantly lodgepole pine. Human activity at Homestake was concentrated besides the drainage bottom, as it appeared to be in the Vail site. However, because a gravel road instead of a trail lies along the drainage bottom, this area was much more accessible to humans and consequently, levels of human activity were higher. Because I saw no indications of changes in human activity levels, I assumed human activity levels were constant throughout this study in both Vail and Homestake sites.

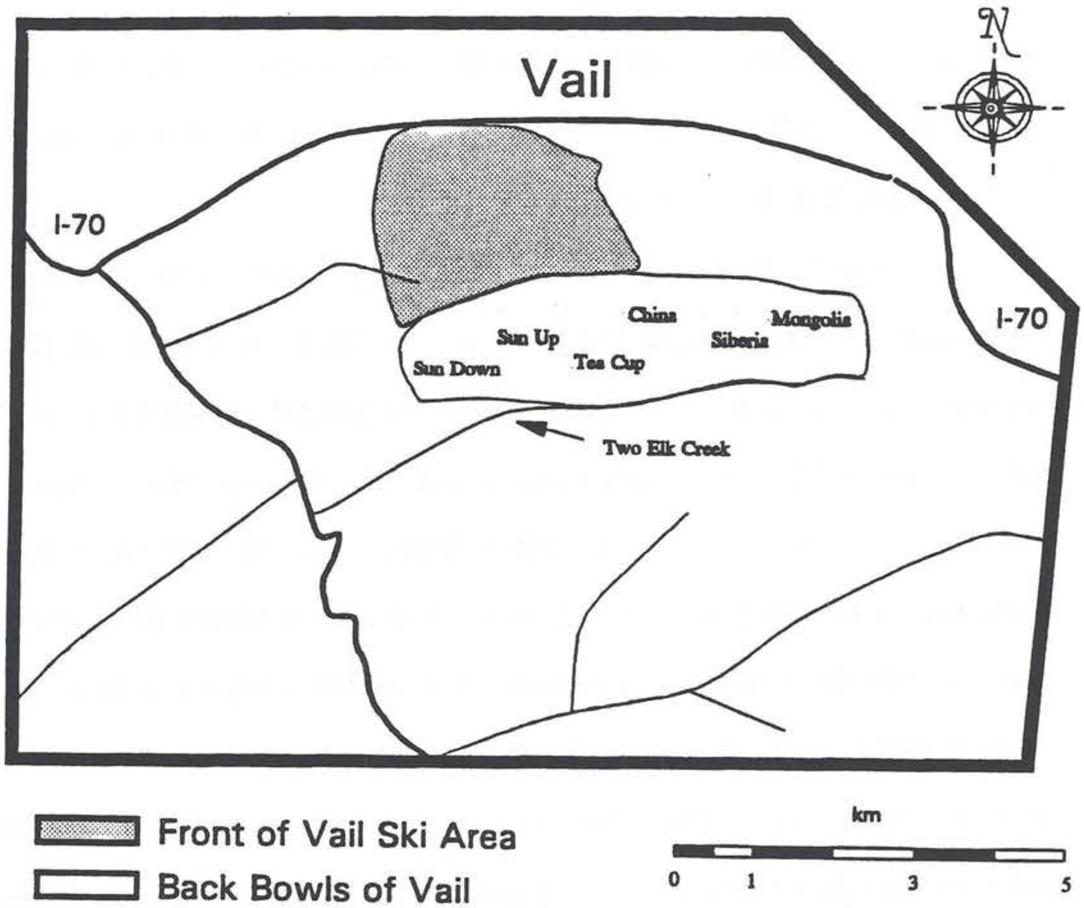


Fig. 2.1. Map of the Back Bowls and front side of Vail Ski Area.

METHODS

Treatments 1, 2 and 3

Vail Associates began development of Sun Up, Tea Cup, China and Siberia Bowls in the Back Bowls in Fall 1988 (Fig. 2.1). Approximately 90% of the development was completed that year with the remaining development completed in Fall 1989. Development consisted of typical disturbances associated with ski area development, such as service roads, timber removal, chair lift installation, and revegetation. Because all these disturbances occurred in either 1988 or 1989, or both years, I was unable to determine whether elk responded more to one disturbance (e.g., timber removal) than another. However, because more development occurred in 1988 (approximately 90% of total development), I was able to measure how elk responded to 2 levels of development.

I divided development in the Back Bowls into 3 treatments. Treatment 1, completed during the fall of 1988, consisted of: (1) timber removal in Tea Cup and China Bowl, (2) ground disturbance and road construction in Sun Up, Tea Cup, China and Siberia Bowls, and (3) the installation of chair lift #21 in China Bowl. For each bowl, I quantified Treatment 1 by using a surveying wheel and tape measure to determine the area of service roads, revegetation, and timber removal (estimated from ground disturbance in timber stands), and I also measured the length of service roads. I compared the area of these disturbances to the relative areas of each bowl and the relative area of bowls below 3,230 m (10,600 ft). Prior to Treatment 1, elk were not observed above 3,230 m (de Vergie, pers. commun.). I also obtained data on the volume of timber removed associated with the development (W. Bailey, U.S. For. Serv., pers. commun.). To measure the effects of Treatment 1, I compared elk use patterns from 1988 to those of 1989.

Treatment 2 was completed during the fall of 1989 and consisted of: (1) thinning China Bowl timber stand, (2) revegetation of disturbed ground in Sun Up, Tea Cup, China and Siberia Bowls, and (3) time. I used time to test whether or not elk acclimated, behaviorally, to physical disturbances. I quantified Treatment 2 using ground measurements from Treatment 1 to estimate revegetation and the volume of timber removed (W. Bailey, U.S. For.

Serv., pers. commun.). To measure the effects of Treatment 2, I compared elk use patterns from 1989 to those of 1990.

Treatment 3 resulted from the combined development of Treatment 1 and Treatment 2 which consisted of: (1) timber removal in Tea Cup and China Bowl, (2) ground disturbance and road construction in Sun Up, Tea Cup, China and Siberia Bowls, (3) the installation of chair lift #21 in China Bowl, (4) revegetation of disturbed ground in Sun Up, Tea Cup, China and Siberia Bowls, and (5) time. To measure the effects of Treatment 3, I compared elk use patterns from 1988 to those of 1990.

All 3 treatments, with the exception of time, involve only physical disturbances and do not include any forms of human activity. With cooperation from study contributors, it was possible to close the Back Bowls to human activity and prevent an increase in human use during periods of concentrated elk use (May 15 to July 1). Thus, my results reflect the effects of the physical development associated with ski areas, and they were not confounded with increased human activity, commonly found after such developments.

Temporal and Spatial Control

My study included both temporal and spatial controls. Temporal control was achieved by collecting data on elk use patterns prior to treatment (I had 1 and 3 years of pre-development data for my telemetry data and observational data, respectively) and comparing these to data on elk use patterns for 2 years after treatment. Spatial control was incorporated by monitoring both treatment and control elk populations. The treatment population, Vail elk, experienced treatment from Vail's expansion. The

Homestake population, which was the control group, experienced no development or increase in human activities. I used this spatial control to factor out changes in use patterns due to weather (i.e., snow melt, plant phenologies).

Sample Units

Only cow elk were used for the telemetry data in this study. Adult female elk were trapped and fitted with 150-151 Mhz radio-collars at both Vail and Homestake sites from the winter of 1986-1987 to the winter of 1989-1990. Elk from the Vail population were trapped with portable corral traps (Taber and Cowan 1969) in 1986-1987 and 1988-1989 and with Clover traps (Clover 1956) in 1987-1988 and 1989-1990. Elk from the Homestake population were trapped with corral traps in 1986-1987 and Clover traps the remaining winters. Although certain elk may be more likely to be trapped than others (e.g., young "naive" elk may be more likely to enter a trap than older "wise" elk), I did not observe any tendency to trap one age class over another. Consequently, I have assumed that the populations of cow elk were randomly sampled.

I analyzed each treatment using only data on those elk for which I had both pre- and post-treatment data (Table 2.1). An alternative was to use data from all collared elk for each year. Because elk were trapped each winter, this design would have resulted in larger sample sizes for post-treatment years. This approach was not used because I feared newly collared elk would have caused me to falsely conclude that there were changes in elk use patterns. Some of the newly radio-collared elk had distinctively different use patterns than previously collared elk. In 1987, locations were made of elk that were trapped in 1986-1987; however, I did not use data from this year for analysis because no collared elk from the Vail population used the Back Bowls.

Table 2.1. Number of radio-collared elk available for each treatment for Vail and Homestake elk populations. Treatment 1 compares 1988 to 1989; Treatment 2 compares 1989 to 1990; and Treatment 3 compares 1988 to 1990.

	Treatment 1	Treatment 2	Treatment 3
Vail	8	17	7
Homestake	7	14	4[a]

[a] For 2 of the 3 analyses, radio-collar failure reduced the number of telemetered elk to 2.

In addition to telemetry data, I used changes in the number of elk visually observed in the Back Bowls to detect changes in use patterns. I used all sex and age class data for subsequent analysis.

Location Methods

Radio-collared elk were located using a Cessna 185 airplane with a belly-mounted antenna every 7-10 days from May 15 - July 1 (locations for each elk per year = 5), and every 2-3 weeks from July 1 to September 1 for each year. In addition, from May 15 - July 1, elk were located on the ground every 1-3 weeks in 1988, and every 2-3 days in 1989 and 1990. In 1988, animals were located on the ground by tracking the radio signal to its strongest source, and then attempting to make a visual observation (27% of locations were visuals) (de Vergie 1989). In 1989 and 1990, because of increased sample size and the increased frequency of locations, elk locations were estimated by triangulation using program TRIANG (White and Garrott 1984, 1990) (0.6% of locations were visuals). See Chapter 1 for details on methods used to make locations and associated errors with these locations.

Accuracy of telemetry locations made in 1988 was not measured; however, error associated with these locations was likely equal to or less than that of locations in later years. In 1988, fewer elk were radio-collared and more time was spent locating animals.

Changes in Elk Geographic Use Patterns

Analysis of my data was difficult because it consisted of 3 response variables, X and Y location coordinates, and time. Previously, several biologists (Edge et al. 1985, Kuck et al. 1985, Knick 1990) have used changes in home range size to detect changes in geographic use patterns. This approach, however, has one serious fault. Animals may spatially shift actual home ranges without changing home range size, and analysis, in that case, would not detect a change. An alternative approach, parametric multivariate statistics, was not appropriate in this study because not all variables were normally distributed (e.g., times when locations were made were uniformly distributed). Because I could not find 1 ideal analysis that met all my needs, I employed 5 different methods to detect changes in elk use patterns between treatments. These multiple analyses were not intended to increase the probability of rejecting the null hypothesis (Type I Error), but instead were utilized to understand the data as fully as possible (each method evaluates data from a different perspective) and to insure that no changes in use patterns went undetected.

My first 3 methods use telemetry data for analysis. Method 1 works well in detecting changes in spatial distribution of elk locations; however, it fails to directly incorporate data from the Homestake elk population as a control. Method 2 uses the Homestake elk population as a control and concentrates more on the temporal aspect rather than spatial distributions. Method 3 also incorporates time, but it concentrates more on the developed area in the Back Bowls and does not assume the Homestake elk population as a control. Method 4 works with changes in visual observations of elk. Because the error associated with making visual locations was considerably less than the error associated with telemetry locations, Method 4 has greater statistical power to detect changes in use patterns. Finally, Method 5 was a survey looking for elk sign in developed bowls. I analyzed data for the first 4 methods statistically; the level of rejection for these tests was $\alpha = 0.05$. Because no quantifiable data were collected for Method 5, I did not perform any statistical analysis.

Method 1. Changes in spatial distribution of elk locations - I measured changes in the spatial distribution of elk locations between treatments using Multi-Response Permutation Procedures (**MRPP**) (Biondini et al. 1988). MRPP was used for analysis because, unlike other statistical procedures, MRPP can handle 2 dimensional data such as Universe Transverse Mercator (**UTM**) coordinates. The third response variable, time, was not included in this analysis because the time of these locations was equally spaced for each year. If I included time in my MRPP analysis, consistent sampling would make the analysis less sensitive to changes in the spatial distribution of locations. In order to keep sampling schedules and sample sizes consistent and reduce the probability of using poor telemetry locations, I used only aerial locations in this analysis. Elk were located approximately 5 times during the season of concentrated elk use, May 15 - July 1. As discussed above, because of the inherent limitations of MRPP, I was unable to use the

Homestake elk population as a control to factor out the effects of changes in snow melt rates on the use patterns of the Vail elk population. Consequently, I completed separate analyses for Vail and Homestake elk populations, and changes in use patterns between the 2 populations were explained descriptively. The null hypothesis for method 1 was the following: H_0: There was no difference in the spatial distribution of elk locations.

Method 2. Changes in the time of year elk left Vail and Homestake Regions - From location data collected from 1987-1990, I created a region for both Vail and Homestake elk populations that represented winter (December 1 - May 15) and early summer ranges (May 15 - July 1) (Fig. 2.2). I then used the dates that elk left their respective regions to detect changes in use patterns. Changes in use patterns between treatments for the Homestake elk population were assumed to be weather-related (i.e., snow melt, plant green-up) and were used to factor out the same weather-related changes in use patterns from the Vail elk population. I estimated the date each elk left these regions using the mean date of the last location in each region and the date of the first location outside the region. Both aerial and ground locations were used in estimating the date that elk left the Vail and Homestake Regions. Although some ground locations had higher degrees of error associated with them than others (see Chapter 1), I incorporated all ground locations in my analysis. When elk moved outside either the Vail or Homestake Region, ridges obscured line-of-sight between transmitter and receiving station; thus decreasing signal quality (signals were not as loud and were distorted). High quality signals that originated in these regions were easily distinguished from signals that originated outside these regions. For example, none of the 99 transmitter locations used in Chapter 1, known to be within either the Vail or Homestake Regions (49 locations at Vail and 50 locations at Homestake), was incorrectly estimated outside of its respective region. During 1990, the Homestake sample size was reduced from 4 to 2 because of radio failures which occurred before elk had migrated to late summer ranges.

My response variable was the difference between the dates (later year - earlier year) elk left their respective regions (e.g., June 24, 1990 - June 18, 1989 = 6 days). I ran analyses separately for each treatment employing Student's two-sample t-tests. Each t-test was tested for homogeneous variances using Levene's (LEV1:Median Variation) (Conover et al. 1981). I also used MRPP, a comparable non-parametric test, for analysis. MRPP and Permutation Tests for Matched Pairs (**PTMP**, a version of MRPP for matched pairs) (Biondini 1988) were used for Method 2 and 3, respectively. These non-parametric tests provided an additional method of detecting changes in use patterns. Although these analyses are not as statistically efficient as parametric tests, they do not require the assumption of normality. My null hypothesis for method 2 was the following: H_0: Vail elk did not leave their region earlier or later when compared to the Homestake elk.

*Method 3. Changes in the length of time elk used the Greater Teacup, China and Siberia Region (**GTCSR**)* - This method concentrates more on changes in use of the developed bowls and is analogous to Method 2, but differs in that I did not use the Homestake elk as a control, and I determined the number of days that elk used this region, rather than the date that they left. The GTCSR contains the 3 bowls listed plus a buffer zone around the edge, which was 1,100 m wide (Fig. 2.2). I added this buffer zone to increase the probability of including locations of elk that were actually located in the above bowls (these elk were most likely located along the southern boundaries of these bowls), but because of telemetry errors their locations were estimated south of these bowls. I chose 1,100 m because this was the 90% quantile of ground telemetry errors (see Chapter 1 for more details). Theoretically, with this buffer I have included 90% of the elk locations that were along this southern edge. I used aerial and ground locations for this analysis; however, to reduce the probability of using poor locations, I censored ground locations and used only those locations that had an error ellipse of less than 150 ha. (See Chapter 1, for more information on why I chose 150 ha for censoring locations.) I estimated the number of days that elk used the GTCSR by subtracting the mean date of the last elk location before they moved into the region and first location in the region from the mean date of the last elk location in the region and the date of the first location outside the region, or:

$$\text{Days in GTCSR} = \frac{\text{Last Location in} + \text{1st Location out}}{2} - \frac{\text{Last Location out} + \text{1st Location in}}{2}$$

I did not use a control at Homestake to factor out the effects of changes in snow melt rates between years, because changes in snow melt rates may shift when elk use this region, but these changes should not affect how long elk use the area. Topography surrounding GTCSR is such that elk

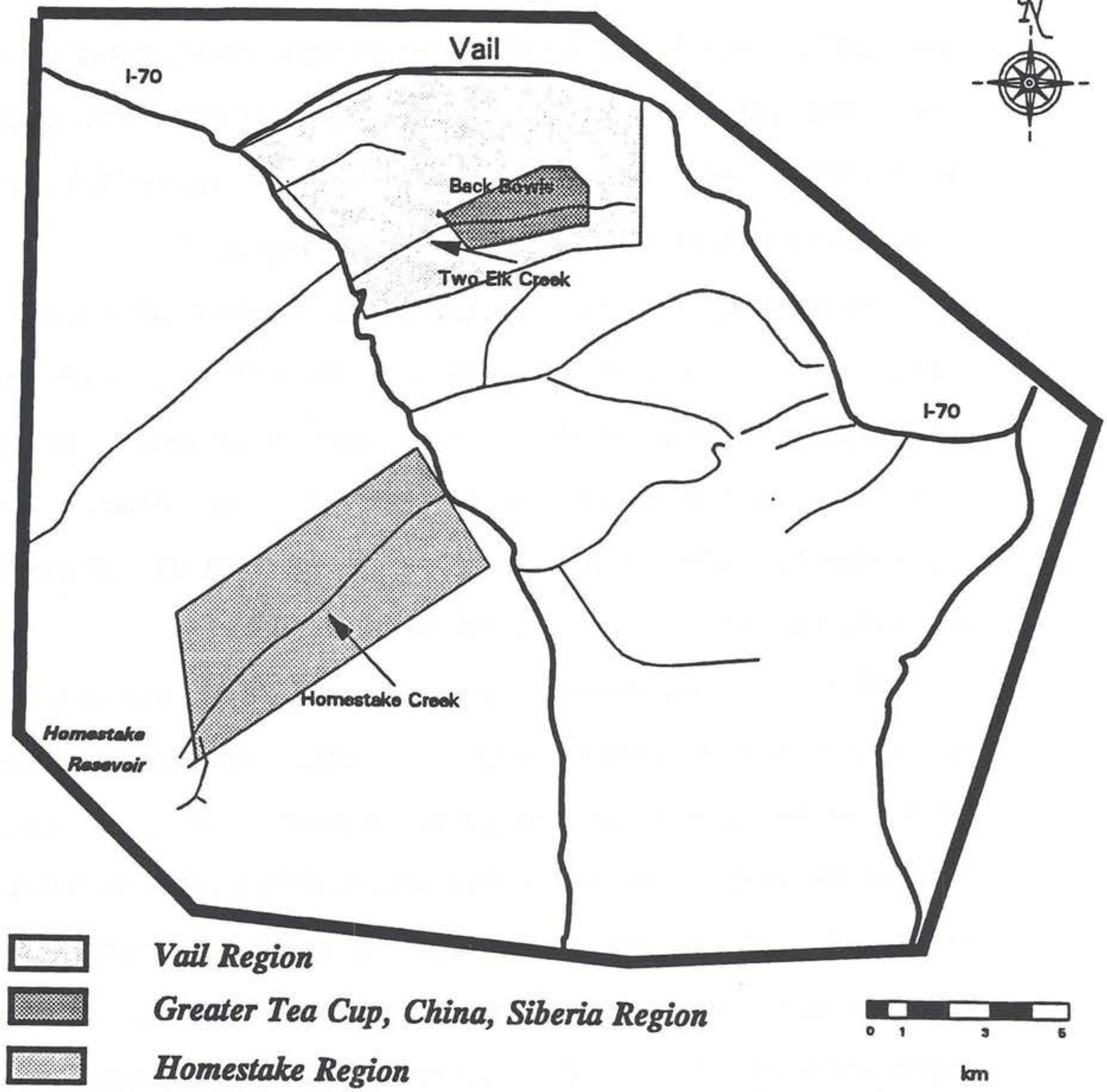


Fig. 2.2. Map of Vail Region, Homestake Region and, the Greater Tea Cup, China and Siberia Region (**GTCSR**) used for second and third analysis to detect changes in elk use patterns.

must cross one ridge to enter this region and another to exit. The first ridge is at lower elevations and snow melts earlier there than on the second, higher ridge. It appears that snow melt on these ridges influences when elk can move in and out of the GTCSR. For example, during years when snow on these ridges melts later, elk likely move into the GTCSR at a later date, but snow on the second ridge will also keep elk from moving out of the GTCSR until a later date. In theory, without the effects of treatments, changes in snow melt between years may shift when elk use the GTCSR, but these changes should not affect how long elk use this region.

In analyzing my data, I compared the difference (later year - earlier year) in the number of days that elk used the GTCSR for each treatment using a paired t-test to test whether or not that number differed from zero. In addition, I used a comparable non-parametric test, PTMP. The null hypothesis for method 3 was the following: H_0: Elk did not increase or decrease the length of time they used the GTCSR.

For both of the previous methods, I computed the statistical power of analyses if the null hypothesis was not rejected. An analogy of statistical power can be made by comparing it to the power of an optical instrument. With the naked eye a person may be unable to detect a difference between 2 species of grass, but with a more powerful optical instrument, such as a dissecting scope, a person may notice that one grass species is more heavily pubescent (hairy) than the other. As power increases, a person's ability to detect differences between 2 groups also increases. A technical definition of statistical power is the probability of rejecting the null hypothesis at a specified difference between treatment and control populations and sample size. Power increases as the effects of a treatment and sample size are increased. I computed power for the 2-sample t-test used in Method 2, and the paired t-test used in Method 3.

Method 4. Changes in the number of elk observed in the Back Bowls - In addition to telemetry locations, I used changes in the number of elk visually observed in the Back Bowls to detect changes in use patterns. In timbered areas, changes in the number of elk seen may not adequately measure changes in use patterns. Elk may change their use patterns in timbered areas, and because they are not easily observed in timber, those changes will not be detected. (Telemetered animals are useful when timber obstructs observation of elk, as habitat type does not impede location of animals.) However, because the Back Bowls are approximately 80% non-timbered and I was able to visit high, unobstructed vantage points were I could view elk without disturbing them, changes in the number of elk observed is likely an effective method to measure changes in use patterns. Unfortunately, because the control elk population used a more heavily timbered habitat (i.e., 60-90% timbered), I was unable to use changes in elk use patterns of the Homestake elk population to factor out the effects of weather from the Vail elk population. To evaluate whether or not changes in weather influenced the number of elk that were seen, I inspected weather data to see if any changes between 1988-1990 (in precipitation or temperatures) could be used to explain differences in elk abundance.

Visual observations were made in each of the Back Bowls, Sun Down, Sun Up, Tea Cup, China, and Siberia-Mongolia during aerial flights and ground locations between May 15 and July 1, 1986-1990. Aerial flights comprised 27%, 42%, 50%, 18% and 16% of all observations for 1986, 1987, 1988, 1989 and 1990, respectively. Sampling schedules were approximately uniform throughout this time period and observations in each bowl were assumed to be independent. I grouped observations in Siberia and Mongolia bowls because observers were not always successful in distinguishing elk in Siberia Bowl from those in Mongolia Bowl.

Because data on the number of elk seen had a negative binomial distribution (i.e., smaller groups were observed more frequently than large groups), I chose analysis based on this distribution, and used program SURVIV (White 1983). Within SURVIV, I arbitrarily chose to use 14 cells to model the negative binomial distribution for each year. A cell consisted of a single group size and the frequency of observations for that group size. For example, if group size was 2 and frequency was 4, then 4 groups of 2 elk were seen in that year. If 14 different group sizes were not observed, I added cells where zero occurrences were noted from a group size of 1 until 14 cells were filled. I created 9 models for all possible changes in elk use patterns (Table 2.2). The best fitting model was selected using Akaike Information Criteria (Akaike 1973, Sakamto et al. 1986) and, ultimately, likelihood ratio tests ($\alpha = 0.05$). In negative binomial statistics, m = mean, and k is a measure of dispersion. As data become clumped, $k \rightarrow 0$; as data approach a random distribution, $k \rightarrow \infty$. The mean number of elk seen, m, was the primary parameter of interest. Estimates of k are not discussed unless dramatic changes were measured. Separate analyses were completed for pooled data from all the Back Bowls and for data from each individual bowl. The null hypothesis (or null model) for method 4 was the following: H_0: There was no change in the mean number of elk observed per visit, m, after 1988.

Goodness-of-fit for all models was acceptable ($P > 0.10$) for all analyses except for the Back Bowls and China Bowl. Goodness-of-fit for

Table 2.2. Nine negative binomial models used to test differences in the number of elk seen in the Back Bowls between years. With negative binomial statistics, m = mean, and k is a measure of dispersion. As data become clumped, $k \rightarrow 0$; as data approach a random distribution, $k \rightarrow \infty$.

Model	Model Description
M__K__	*m* and *k* were same for all years
M__	*m* was same for all years, *k* was different for all years
K__	*m* was different for all years, *k* was same for all years
M_T_K_T_	*m* was same for all years before treatment, *m* was same for both years after treatment *k* was same for all years before treatment, *k* was same for both years after treatment
M_T_	*m* was same for all years before treatment, *m* was same for both years after treatment *k* was different for all years
K_T_	*m* was different for all years *k* was same for all years before treatment, *k* was same for both years after treatment
M_T2K__	*m* was same for all years before treatment, but different for both years after treatment *k* was same for all years
M_T2K_T_	*m* was same for all years before treatment, but different for both years after treatment *k* was same for all years before treatment, *k* was same for both years after treatment
ALL_DIFF	*m* and *k* were different for all years

these analyses were poor because large group sizes created excessively large chi-square values. Without these few large groups, goodness-of-fit was acceptable. Because goodness-of-fit improved without data for large groups, fit was likely not low because my data were not appropriate for the negative binomial distribution, but instead because the test for goodness-of-fit did not handle these large values adequately. I prefer negative binomial analysis over alternative statistical analyses, Analysis of Variance and MRPP, for the following reasons: (1) My data do not meet the assumption of normality and homogenous variance as required for Analysis of Variance. (2) MRPP, like negative binomial statistics, tests for changes in means and dispersion, but unlike negative binomial statistics, it can not determine whether rejection was caused by a change in the mean or in dispersion.

Method 5. Changes in elk sign in Tea Cup and China Bowl - This survey was completed on foot for Treatment 1 only. In early July, 1988 and 1989, 3-4 biologists (2 of these 3-4 biologists completed this both years) traversed Tea Cup and China Bowl and made notes on tracks and pellet groups. Because comparison between years was somewhat subjective and this method was not easily quantified, this survey was not completed in 1990. Consequently, no comparison was made for Treatment 2 or 3.

Weather

It is possible that changes in weather between years may influence elk use patterns. For example, changes in snow melt between years may delay plant phenologies (Holoway 1962, Bock 1976) and thus, may affect elk use patterns (Sweeny 1975). In addition, I speculate that more snow in May and early June may inhibit elk movements and consequently affect elk use patterns. To evaluate the relationship between changes in weather and elk use patterns, I used data from the following 3 sources:

1. I used data from Eagle weather station (via Colorado Climate Center, Fort Collins). I used Eagle's data, after considering several weather stations, because Eagle's weather data were complete, reliable, and covered the last 45 years. Although the climate at Eagle is generally dryer and warmer than that experienced by Vail and Homestake elk

populations, it functions as an index of fluctuations in temperature and precipitation.

2. I used peak run-offs from the Gore Creek-Minturn stream monitoring station to indicate peaks in snow melt. This station is located 15 km east of Vail; no water diversions exist above this monitoring station.
3. Finally, I used photo-points (fixed points where photos are taken) that I established in 1989 in the Back Bowls to indicate changes between years in snow melt and plant green-up. I took photos for 5 photo-points every 3-5 days between May 20 and June 15 and approximately once every 2 weeks afterwards for 1989 and 1990. Photos between years were matched for similar snow melt patterns (i.e., bare ground showing) and dates for matching photos were compared.

I limited my discussion to changes in weather that most likely affected snow melt and plant green-up, since those are the factors that are most likely to have the greatest effect on elk use patterns (Sweeny 1975).

Plant Phenologies

Initially, I postulated that snow compaction caused by skier activities might have affected snow melt rates and plant phenologies, thus, influencing elk habitat selection (Sweeny 1975), and I attempted to quantify the effects of snow compaction. After realizing that the interaction of slope, aspect, extent of compaction, wind and micro-topography on snow melt rates was complex and required extensive measurements to adequately quantify the effects, I deleted a comprehensive investigation of this factor. However, I did complete a pilot study of the effects of snow compaction on plant phenologies using: (1) photo-points, and (2) vegetative measurements on 2 plots with different snow melt rates.

I used 3 of the above 5 photo-points to estimate the effects of snow compaction on snow melt rates. These 3 photo-points were situated along out-of-bounds boundaries (where one side experienced snow compaction from skiers and the other side did not) on wind-compacted, sub-alpine areas in the Back Bowls. Comparison of snow melt rates and plant green-up on skied and un-skied areas were made for all 3 photo-points.

To measure the effects of early and late snow melt on plant phenologies I set up 2 pilot study plots in upper China Bowl (elevation = 3,410 m). These plots, which measured 15 m by 15 m and were 50 m apart, had different snow melt rates because of micro-topographical differences. The early snow melt plot was free of snow approximately 1 week before the second. I sampled these plots systematically at 10 points, with 2 sub-samples per point, and I estimated phenological stages by measuring leaf length of 2 dominant species, *Senecio sp.* and *Achillia lanulosa*. I measured plots 3 times in 1989: June 24 (shortly after snow melt on the late snow melt plot), July 14, and August 24. I did not statistically analyze resulting data, except for means and standard errors, because plots were initiated as a pilot study and were not intended to supply definitive results.

RESULTS

Treatments 1, 2 and 3

Total ground disturbance (below 3,230 m) in all developed bowls was 5.5% (Table 2.3) in Treatment 1. Ground disturbance ranged from a low of

2.3% in Siberia Bowl to 11.2% in China Bowl. The volume of timber removed that was more than 8" diameter at breast height (DBH) was 67.3 thousand board feet (MBF). Two hundred eleven cords of aspen and other logs measuring 5-7.9" DBH were also removed.

The average percentage of ground revegetated (below 3,230 m) in all developed bowls was 4.6% in Treatment 2 (Table 2.3). Revegetation ranged from 1.9% in Siberia Bowl to 10.1% in China Bowl. During the thinning of timber in China Bowl, 7.4 MBF (trees > 8" DBH) and 0.8 cords (5" DBH < trees < 7.9" DBH) were removed. As discussed earlier, Treatment 3 consisted of all components of Treatments 1 and 2.

Table 2.3. Treatment 1 measurements of service roads, revegetation, timber removal and total ground disturbance in Tea Cup, China and west Siberia Bowls. Measurements of disturbances in Sun Up Bowl are included in total below 3410 m. 1 ha = 2.47 acres.

	Service Roads			Revegetation		Timber [a]		Total	
	km	ha	%	ha	%	ha	%	ha	%
Below 3,230 m									
Tea Cup	3.1	1.6	0.9	4.2	2.2	4.1	2.2	5.8	3.1
China	1.5	1.1	1.1	10.5	10.1	4.3	4.1	11.7	11.2
Siberia	0.6	0.2	0.4	0.8	1.9	0.0	0.0	1.0	2.3
Total	5.2	2.9	0.9	15.5	4.6	8.4	2.5	18.4	5.5
Below 3,410 m									
Total	8.8	5.1	0.6	23.9	3.0	8.4	1.1	29.0	3.7

[a] Timber removal estimated from ground disturbances

In general, disturbances in China Bowl were 2-5 times greater than those in Tea Cup and Siberia Bowls for all 3 treatments. These disturbances were typically at lower elevations and closer to Two Elk Creek than those in Tea Cup or Siberia Bowls.

Changes in Elk Geographic Use Patterns

Method 1. Changes in spatial distribution of elk locations - Using MRPP, I was unable to detect any changes in use patterns of elk for all treatments at Vail and Homestake except for Treatment 3 in the Homestake elk population (Fig. 2.3-2.8) (see Table 2.7 for *P* values).

Table 2.7. Summary of analyses for first 4 methods to detect changes in elk use patterns. Null hypothesis is stated for each analysis. For the 3 telemetry methods *P* values are given for each treatment. For the fourth method, the best fitting model is described.

	Treatment 1	Treatment 2	Treatment 3
1. MRPP	H_0: No difference in spatial distribution		
Vail	0.44	0.27	0.40
Homestake	0.07	0.55	0.01
2. Vail and Homestake Region	H_0: No difference when elk left region		
Two sample t-tests	0.13	0.78	0.71
MRPP	0.10	0.66	1.00
3. GTCSR	H_0: No difference how long elk used region		
t-tests	0.20	0.85	0.50
PTMP	0.28	0.86	0.56
4. Elk observations	H_0: No difference in m or k after 1988		
Model # 1	$m \downarrow$ for all Back Bowls, $m \downarrow$ for China Bowl, m = for Tea Cup and Siberia-Mongolia Bowls		

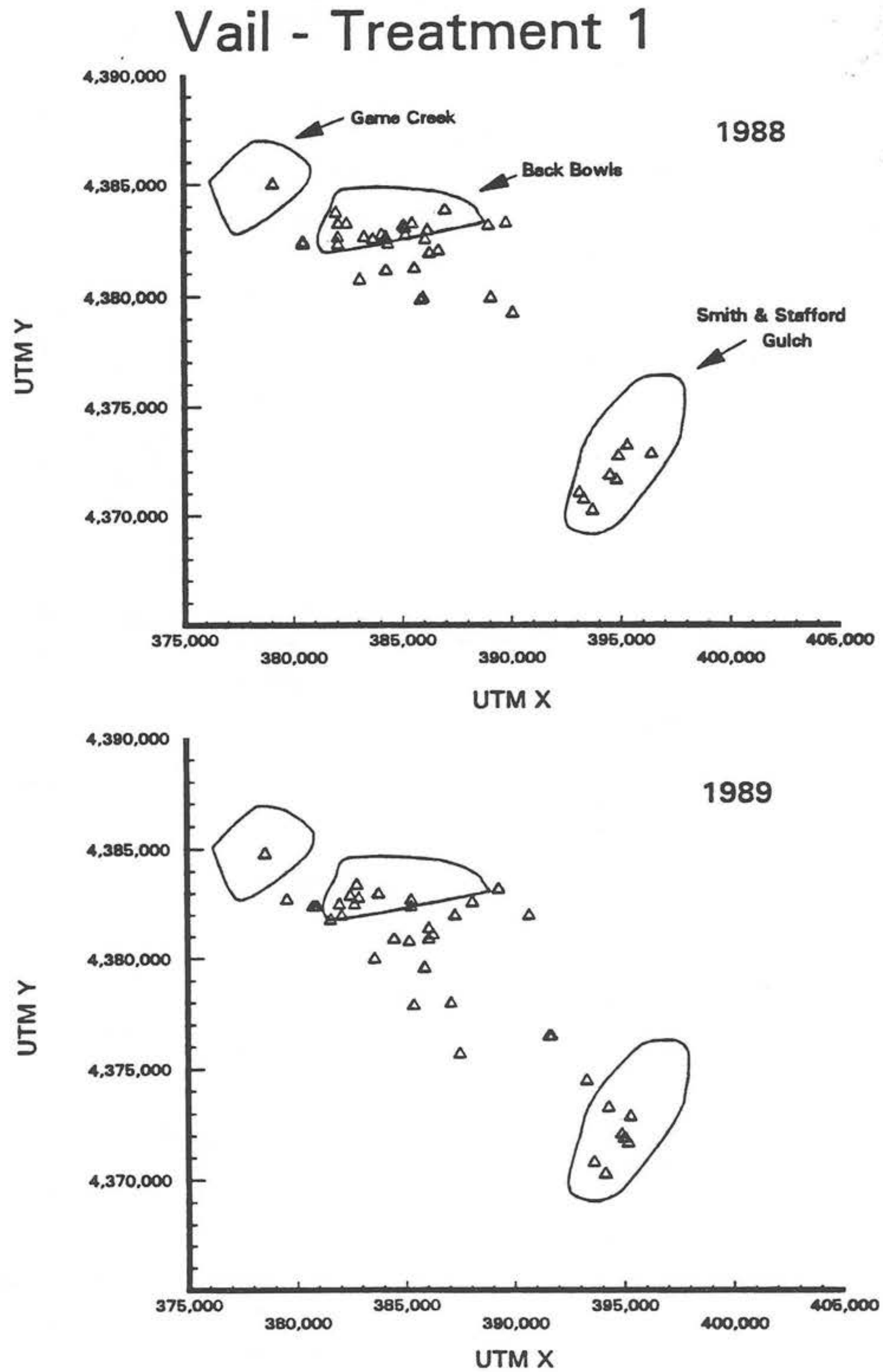


Fig. 2.3. Locations of elk at Vail between May 15 and July 1 for Treatment 1. Most of the elk from the Vail population migrate from their winter range near Game Creek to the Back Bowls and then to their late-summer range near Smith and Stafford Gulch. Using Multi-Response Permutation Procedures I was unable to reject the null hypothesis (P = 0.44). For elk n = 8; for locations in 1988 n = 40; and for locations in 1989 n = 40.

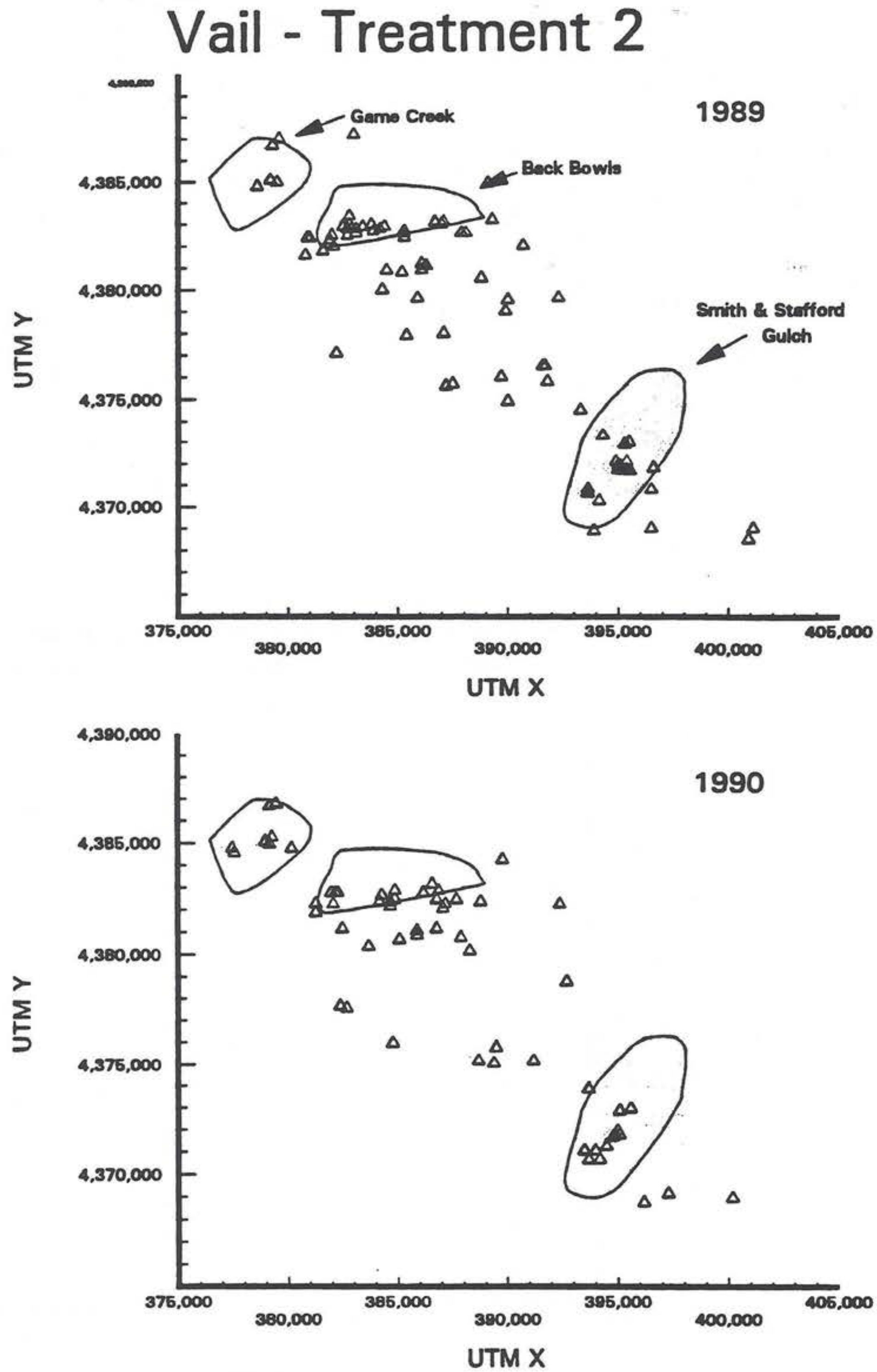


Fig. 2.4. Locations of elk at Vail between May 15 and July 1 for Treatment 2. Most of the elk from the Vail population migrate from their winter range near Game Creek to the Back Bowls and then to their late-summer range near Smith and Stafford Gulch. Using Multi-Response Permutation Procedures I was unable to reject the null hypothesis (P = 0.27). For elk n = 17; for locations in 1989 n = 85; and for locations in 1990 n = 83.

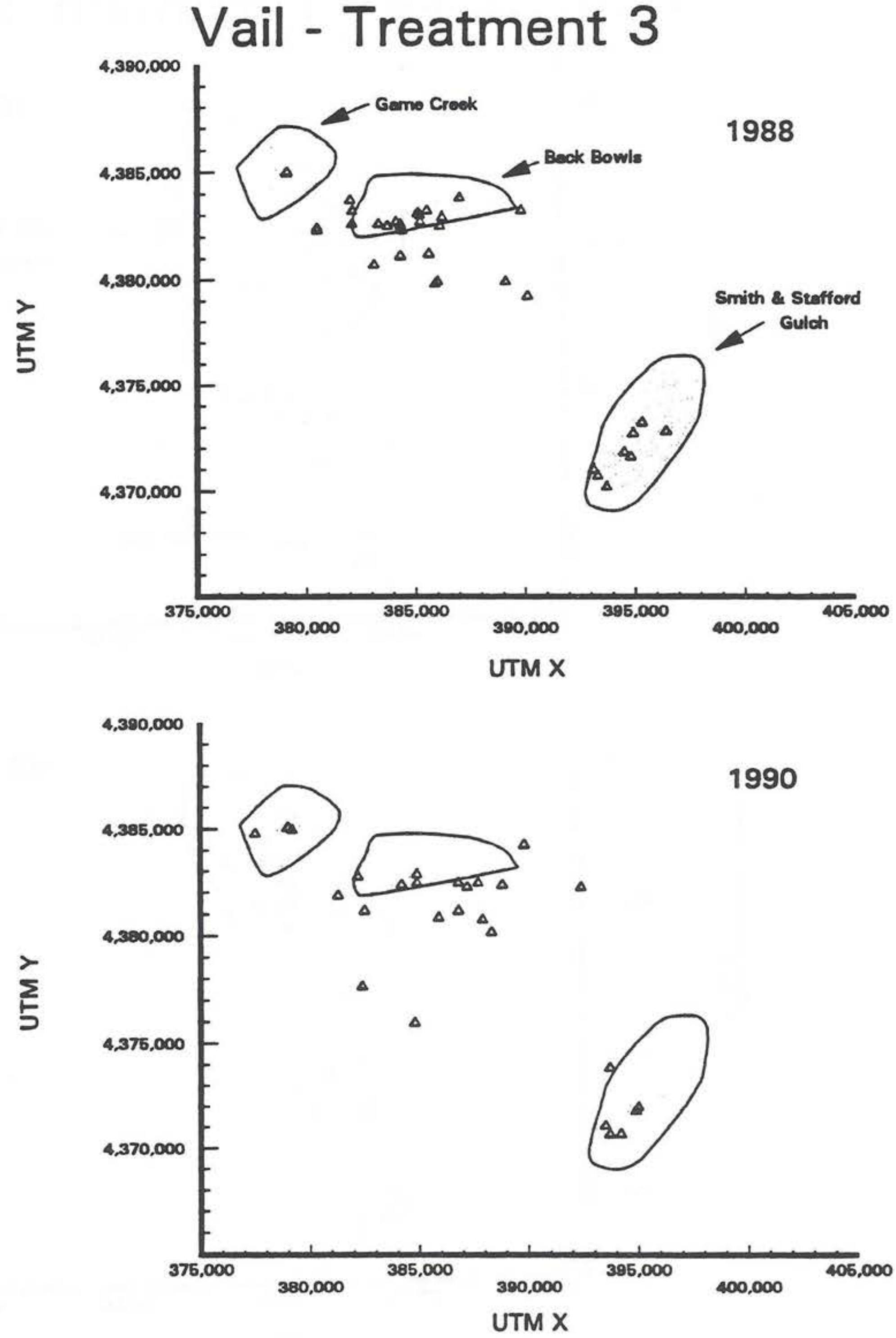


Fig. 2.5. Locations of elk at Vail between May 15 and July 1 for Treatment 3. Most of the elk from the Vail population migrate from their winter range near Game Creek to the Back Bowls and then to their late-summer range near Smith and Stafford Gulch. Using Multi-Response Permutation Procedures I was unable to reject the null hypothesis (P = 0.40). For elk n = 7; for locations in 1988 n = 35; and for locations in 1989 n = 35.

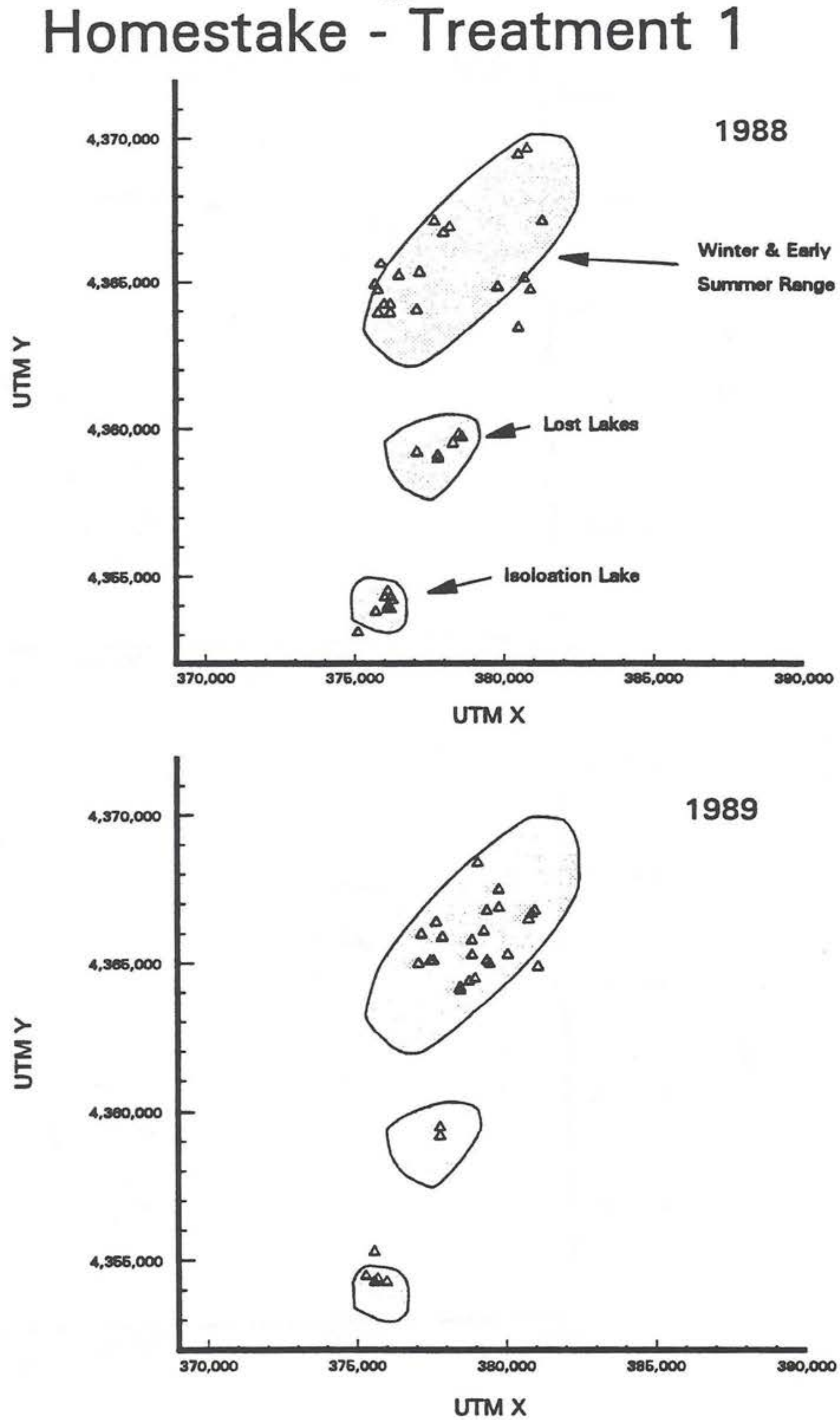
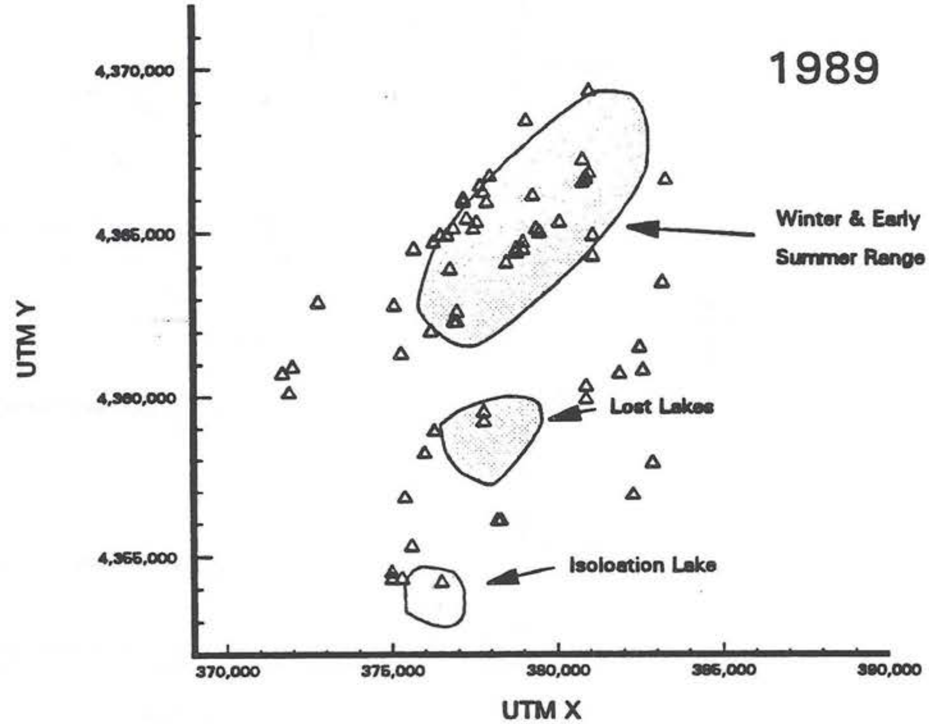


Fig. 2.6. Locations of elk at Homestake between May 15 and July 1 for Treatment 1. Most of the elk from the Homestake population migrate from winter-early summer range to late-summer ranges near Lost and Isolation Lakes. Using Multi-Response Permutation Procedures I was unable to reject the null hypothesis (P = 0.068). For elk n = 7; for locations in 1988 n = 35; and for locations in 1989 n = 34.

Homestake - Treatment 2



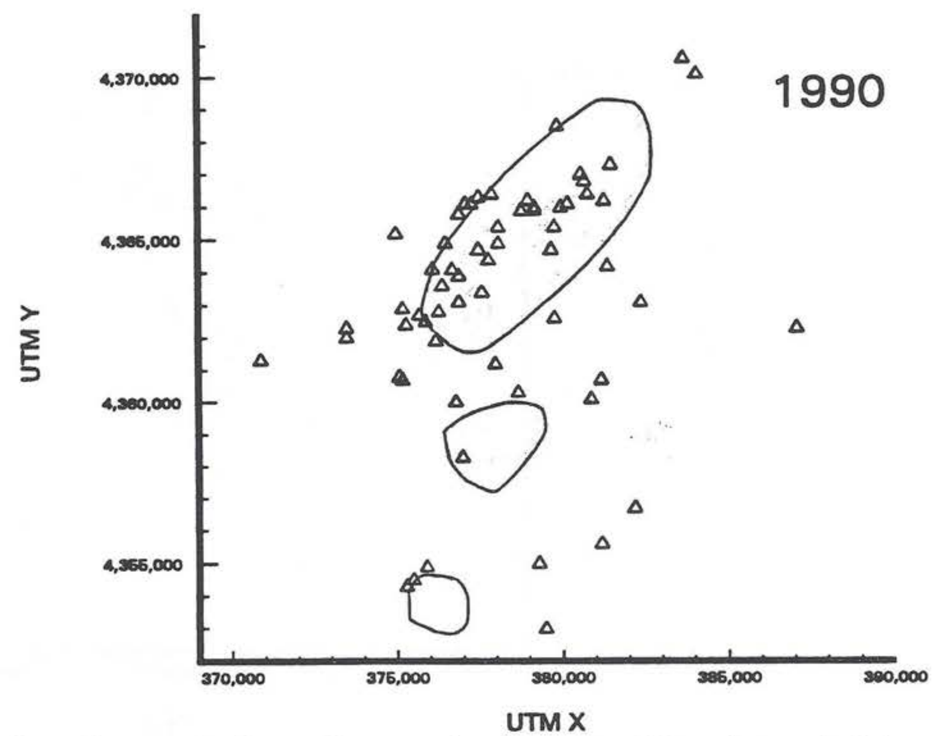


Fig. 2.7. Locations of elk at Homestake between May 15 and July 1 for Treatment 2. Most of the elk from the Homestake population migrate from winter-early summer range to late-summer ranges near Lost and Isolation Lakes. Using Multi-Response Permutation Procedures I was unable to reject the null hypothesis (P = 0.55). For elk n = 14; for locations in 1989 n = 69; and for locations in 1990 n = 63.

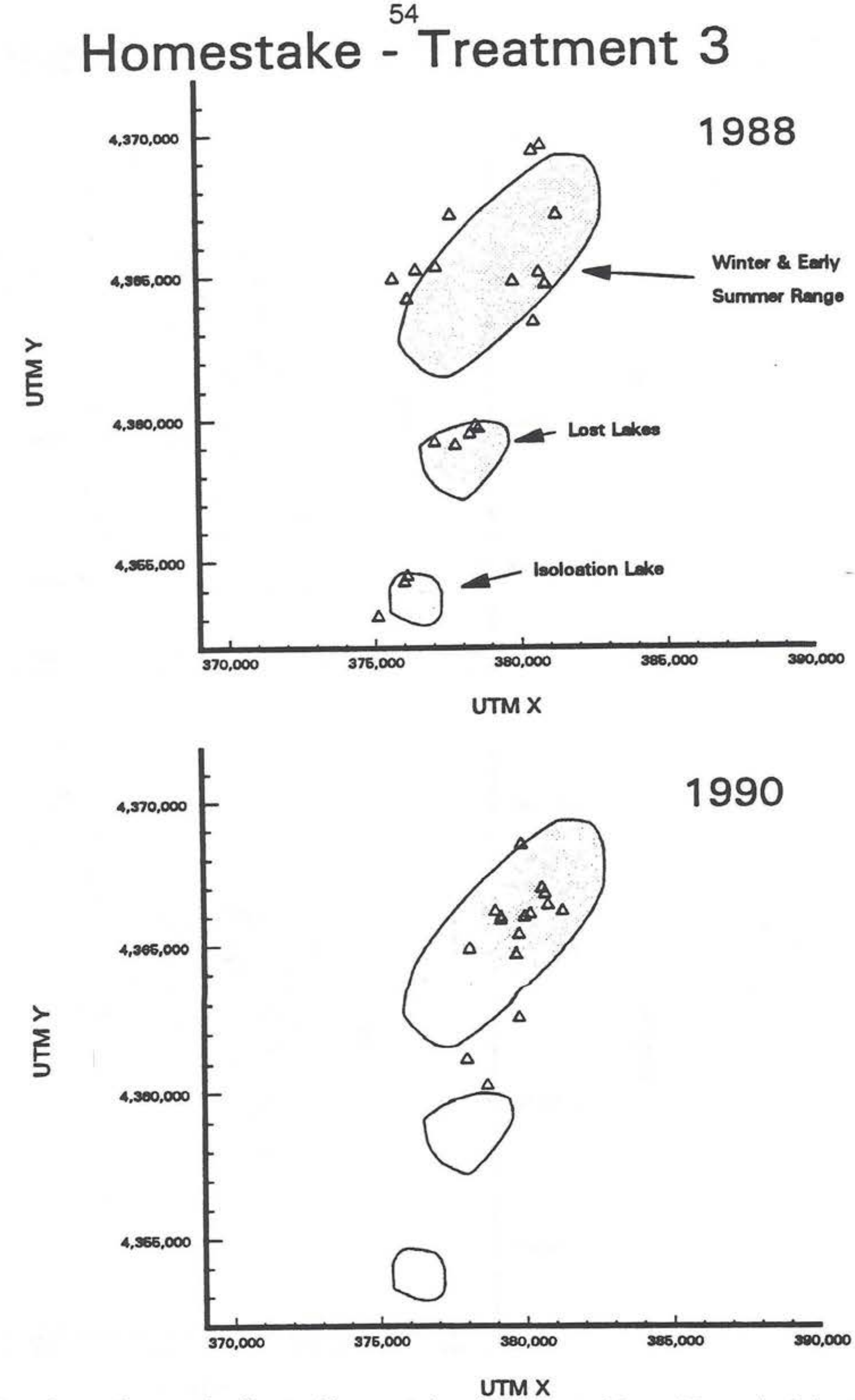


Fig. 2.8. Locations of elk at Homestake between May 15 and July 1 for Treatment 3. Most of the elk from the Homestake population migrate from winter-early summer range to late-summer ranges near Lost and Isolation Lakes. Using Multi-Response Permutation Procedures I was able to reject the null hypothesis (P = 0.009). For elk n = 4; for locations in 1988 n = 20; and for locations in 1990 n = 16.

Method 2. Changes in the time of year elk left the Vail and Homestake Regions - Vail elk did not appear to leave their region earlier or later (after treatments) when compared to changes of the Homestake elk. Variances of Vail and Homestake data were equal for all treatments ($P > 0.60$) except for Treatment 1 ($P = 0.051$). Using appropriate two-sample t-tests, I was unable to reject my null hypothesis for all treatments (Fig. 2.9) (See Table 2.7 for *P* values). My results were similar when I used MRPP. In general, for Method 2 and 3, *P* values of non-parametric tests did not differ from those of parametric tests.

Method 3. Changes in the length of time elk used the Greater Teacup, China and Siberia Region (GTCSR) - Elk used the GTCSR for the same number of days (before compared to after development) for all 3 treatments. Using paired t-tests and PTMP I was unable to reject my null hypothesis, that elk did not increase or decrease the length of time they used GTCSR, for all treatments (Fig 2.9) (See Table 2.7 for *P* values).

Statistical power for Vail and Homestake Region analysis (Method 2) was 38% for Treatment 1 and 5% for Treatments 2 and 3 (Table 2.4). For GTCSR analysis (Method 3), power was 23%, 4%, and 9% for Treatments 1, 2, and 3, respectively (Table 2.5). These analyses did not possess good power (i.e., power > 85%) until treatment effects were 2-5 times greater (i.e., the difference between changes in when elk left their region between Vail and Homestake was 15-25 days, or the changes in length elk used GTCSR was 7-10 days). Increasing sample size to 100 radio-collared elk (50 elk in control and 50 elk in treatment population) would not increase power as much as

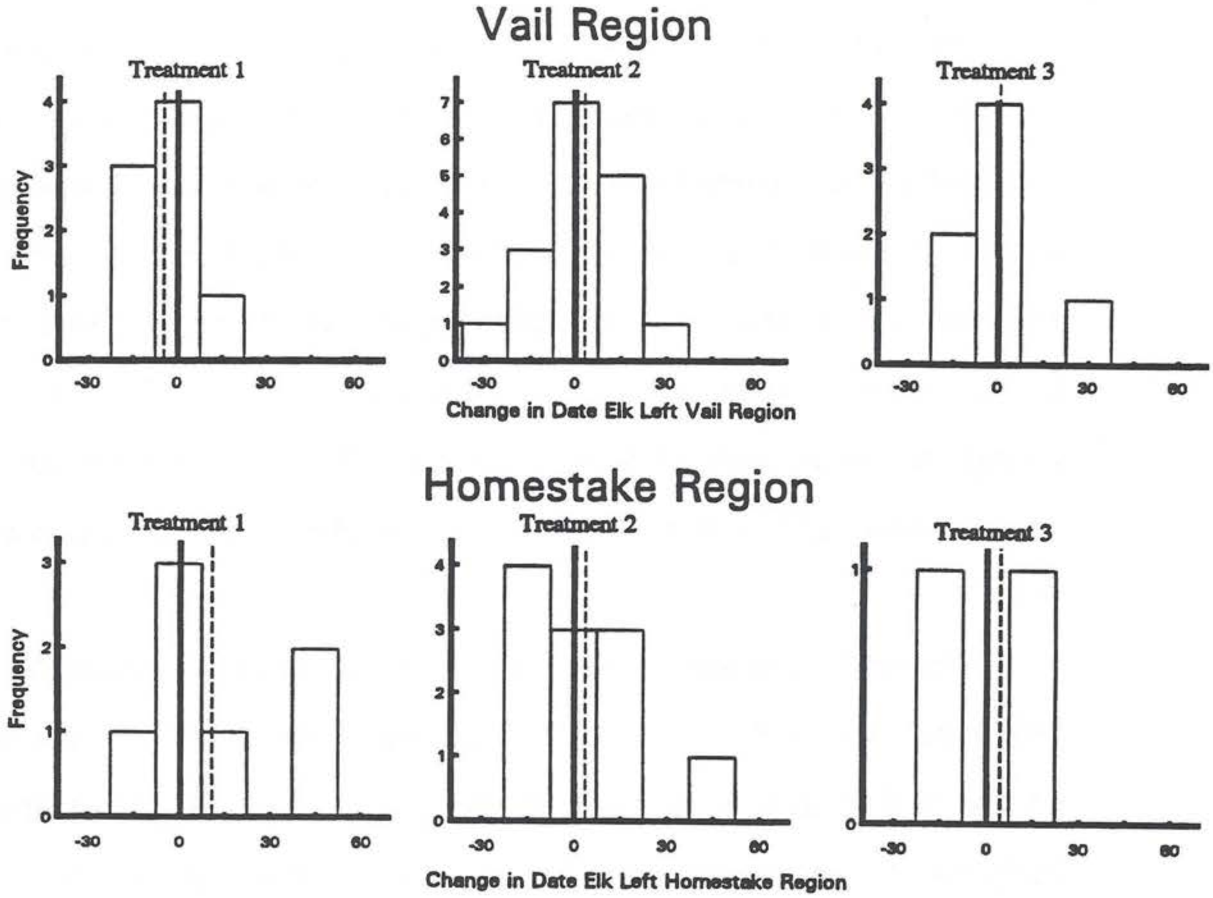


Fig. 2.9. Change in the date elk left Vail and Homestake Region over Treatments 1, 2 and 3. Solid vertical line marks no change and dashed line shows mean of all elk. For; Treatment 1, P = 0.13, Treatment 2, P = 0.78, and Treatment 3, P = 0.71. For Vail; Treatment 1, n = 8; for Treatment 2, n = 17; and for Treatment, 3 n = 7. For Homestake; Treatment 1, n = 7; for Treatment 2, n = 11; and for Treatment 3, n = 2.

Table 2.4. Statistical power calculations for 2-sample t-test used to measure the difference in date elk left Vail and Homestake Regions for Treatments 1, 2 and 3. Power for observed change in use for each treatment and my sample size is in bold print.

	Treatment 1				Treatment 2				Treatment 3		
mean	*n*			mean	*n*			mean	*n*		
(days)	15	40	100	(days)	28	40	100	(days)	9	40	100
16.3	**0.38**	0.42	0.43	7.2	**0.05**	0.05	0.05	5	**0.05**	0.06	0.06
19	0.79	0.83	0.84	14	0.82	0.83	0.84	23	0.73	0.83	0.84
23	0.90	0.93	0.93	16	0.92	0.93	0.93	26	0.85	0.93	0.93
26	0.93	0.97	0.98	18	0.97	0.97	0.98	30	0.93	0.97	0.98

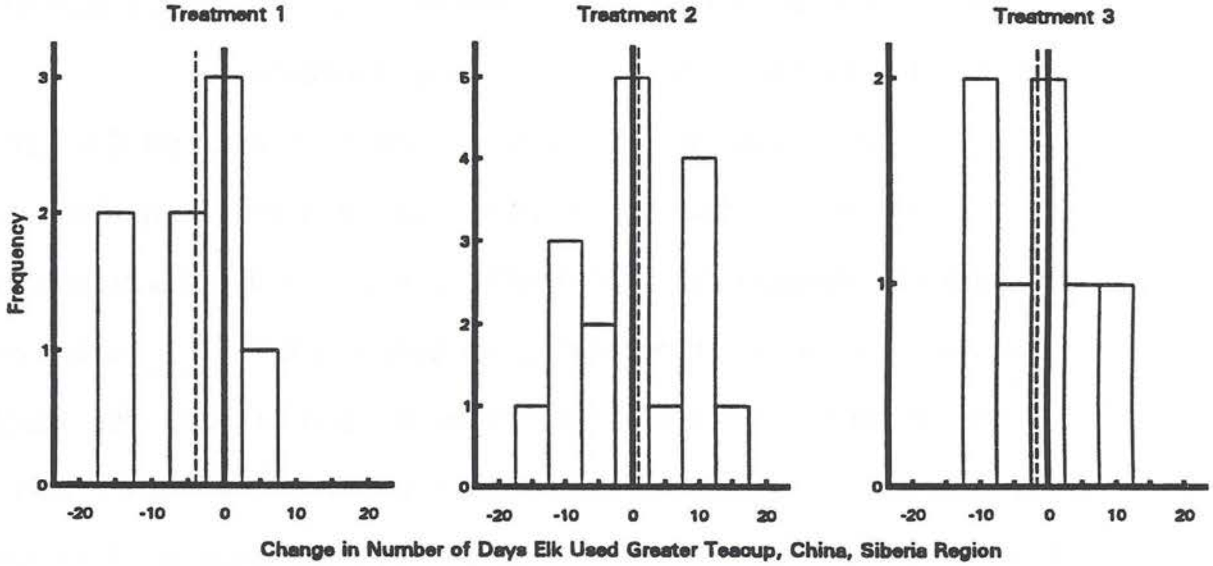


Fig. 2.10. Change in the number of days elk used Greater Tea Cup, China and Siberia Region over Treatments 1, 2 and 3. Solid vertical line marks no change and dashed line shows mean of all elk. For; Treatment 1, P = 0.20, Treatment 2, P = 0.85, Treatment 3, P = 0.50. For Treatment 1, n = 8; for Treatment 2, n = 17; and for Treatment 3, n = 7.

Table 2.5. Statistical power calculations for paired t-test used to measure the mean change in use (days) of the Greater Teacup, China and Siberia Region for Treatment 1, 2 and 3. Power for observed change in use for each treatment and my sample size is in bold print.

Treatment 1				Treatment 2				Treatment 3			
mean	*n*			mean	*n*			mean	*n*		
(days)	8	20	50	(days)	17	30	50	(days)	7	20	50
3.9	**0.23**	0.26	0.28	0.4	**0.04**	0.04	0.04	1.7	**0.09**	0.10	0.10
7	0.58	0.66	0.69	5	0.65	0.68	0.69	6	0.55	0.66	0.69
10	0.85	0.91	0.93	8	0.91	0.92	0.93	8	0.83	0.91	0.93
11	0.93	0.97	0.98	9	0.96	0.97	0.98	10	0.91	0.97	0.98

increasing treatment effects. On average, increasing sample size to 100 resulted in only a 5% increase in power for all 3 treatments.

Method 4. Changes in the number of elk observed in the Back Bowls - The number of elk observed in China Bowl and the entire Back Bowls declined after development. The best fitting model for the total number of elk observed in all the Back Bowls and China Bowl was M_T_K_T_, where *m* and *k* were the same for all years before treatment and all years after treatment (Fig. 2.11, Fig. 2.12, Table 2.6). With this model *m* decreased threefold from a pre-treatment value of 15.1 elk to a post-treatment value of 5.4 elk for the Back Bowls, and 11-fold for China Bowl, from 7.7 elk to 0.7 elk. The second best fitting model for the Back Bowls and China Bowl was M_T2K_T_. With this model, *m* increased in 1990 over 1989; however, *m* did not approach pre-treatment values. I was unable to reject the null model for, Sun Down, Sun Up, Tea Cup, and Siberia-Mongolia Bowls, the best fitting model was M___K___, where *m* and *k* were the same for all years.

The above changes in the number of elk observed from year to year were apparently not a result of weather changes. When I made comparisons between the number of elk observed and changes in weather, there was no clear relationship.

Method 5. Changes in elk sign in Tea Cup and China Bowl - Biologists involved in this segment of the study concurred that elk sign in China Bowl decreased from 1988 to 1989. Tracks in China Bowl indicated movement of elk through this bowl, but substantial use was not apparent. Elk sign in Tea Cup Bowl was more evident than in China Bowl and was nearly equal to that observed in 1988.

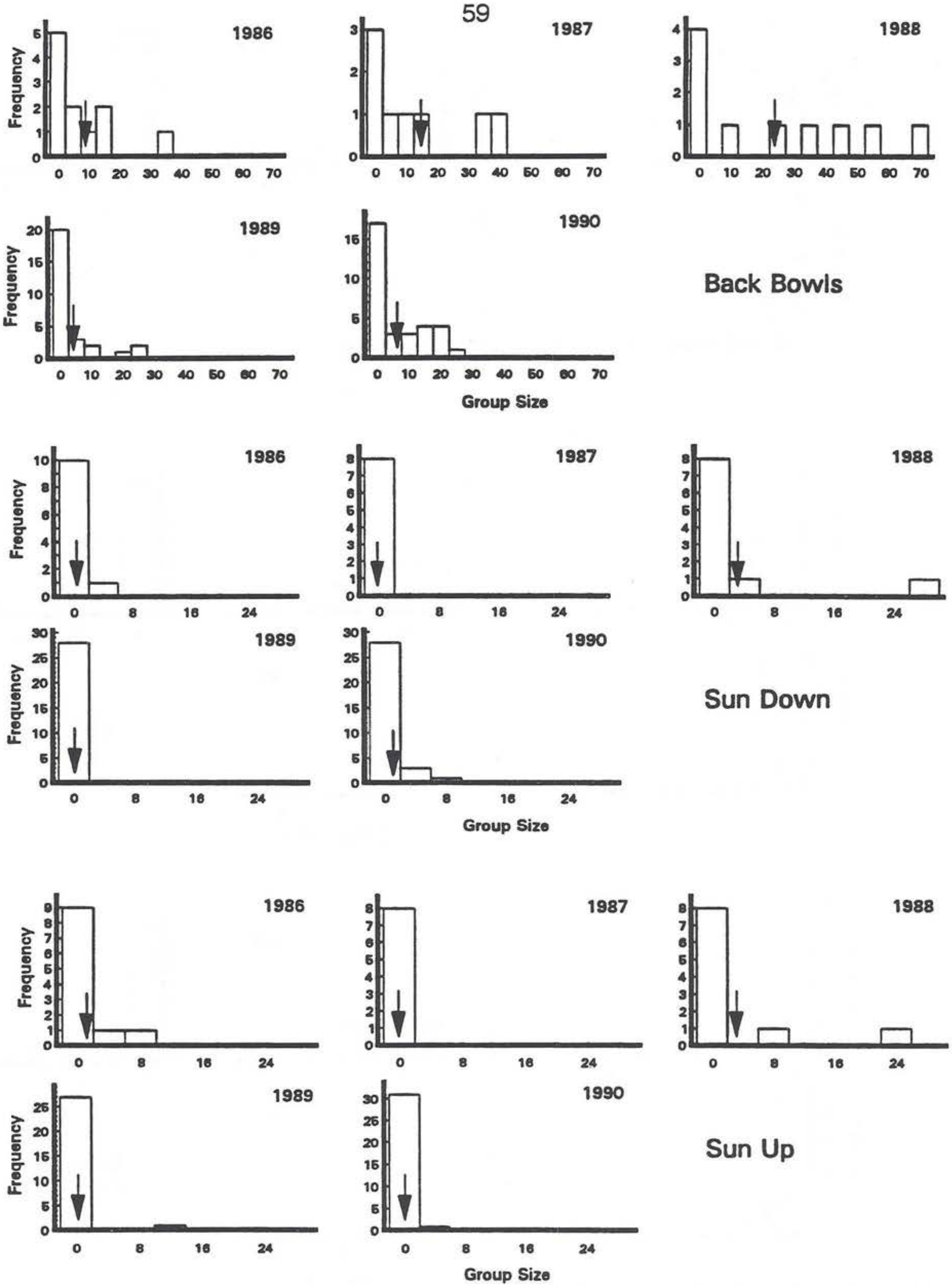


Fig. 2.11. Group sizes of elk seen in all the Back Bowls, Sun Down Bowl, and Sun Up Bowl for years 1986-1990. Years 1986-1988 were pre-treatment and years 1989-1990 were post-treatment. Arrow marks the mean of the number of elk seen. For; 1986 n = 11, 1987 n = 7, 1988 n = 10, 1989 n = 28, 1990 n = 32.

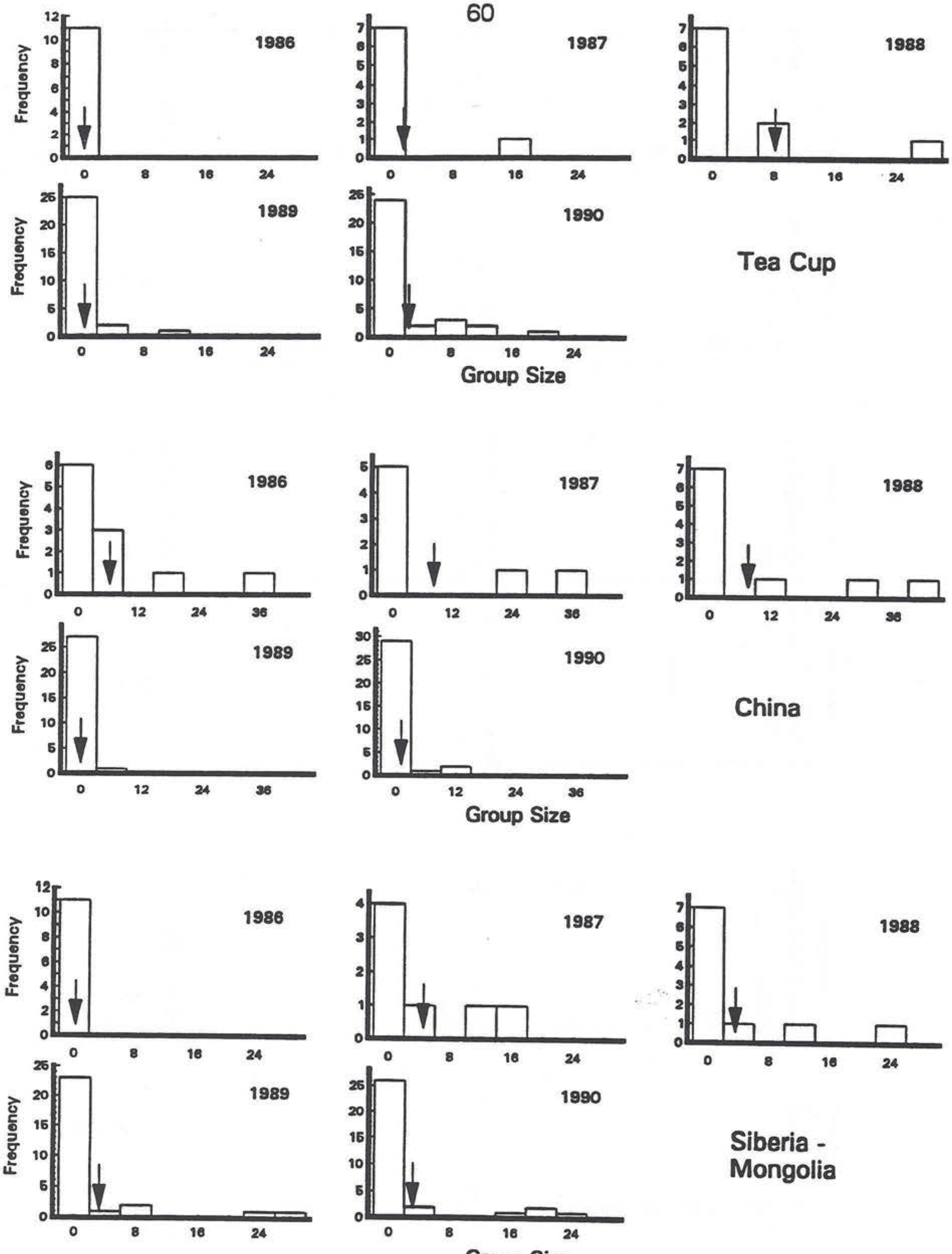


Fig. 2.12. Group sizes of elk seen in Tea Cup, China, and Siberia-Mongolia Bowls for years 1986-1990. Years 1986-1988 were pre-treatment and years 1989-1990 were post-treatment. Arrow marks the mean of the number of elk seen. For; 1986 n = 11, 1987 n = 7, 1988 n = 10, 1989 n = 28, 1990 n = 32.

Table 2.6. Output of negative binomial models from program SURVIV for number of elk seen in; Back Bowls, Sun Down Bowl, Sun Up Bowl, Tea Cup Bowl, China Bowl, and Siberia-Mongolia Bowl. The top 3 models are listed for each bowl in order of model preference. Model selection was based on Akaike Information Criteria (AIC) and ultimately likelihood ratio tests (α = 0.05). See Table 2.2 for definitions of models.

Model	Log-likelihood	DF	Akaike Information Criteria	Log-likelihood G-O-F
1) M_T_K_T_	-245.467	66	498.933	0.000
2) M_T2K_T_	-245.092	65	500.183	0.000
3) K_T_	-243.701	63	501.401	0.000
Sun Down				
1) M___K___	-52.629	68	109.258	0.998
2) K___	-48.162	64	108.324	0.999
3) K_T_	-48.091	63	110.182	0.999
Sun Up				
1) M___K___	-46.793	68	97.585	0.987
2) M_T_K_T_	-44.274	66	96.547	0.996
3) K_T_	-41.837	63	97.674	0.998
Tea Cup				
1) M___K___	-96.042	68	197.085	0.433
2) M_T2K___	-95.381	67	196.761	0.443
3) K___	-92.500	64	197.001	0.539
China				
1) M_T_K_T_	-115.500	66	239.000	0.012
2) M_T2K_T_	-114.971	65	239.943	0.011
3) M_T_	-113.894	63	241.787	0.011
Siberia-Mongolia				
1) M___K___	-125.243	68	254.486	0.120
2) M_T_	-120.927	63	255.926	0.178
3) M_T_K_T_	-125.230	65	263.374	0.049

Weather

Based primarily on data for precipitation in April and May (precipitation was most likely in the form of snow) I suggest the order of years from earliest to latest snow melt and plant green-up were 1988, 1989 and 1990 (Table 2.7) (Fig. 2.14). Data on peak stream flow also indicate later snow melt in 1989

Table 2.7. Summary of weather data I used to determine rates of snow melt for each year. Numbers for temperature and precipitation refer to deviation from 45 year mean. Photo-points were not completed in 1988.

	1988	1989	1990
May Temp. (°C)	+ 0.4	+ 1.5	+ 0.5
June Temp. (°C)	+ 2.9	- 0.2	+ 2.9
April Precip. (cm)	- 1.3	+ 1.4	+ 1.2
May Precip. (cm)	- 0.7	- 0.6	+ 0.4
Date of Peak Stream Flow	May 16	May 22 - 30	June 3
Photo-Points	-	-	Snow melt 5-9 days later than 1989

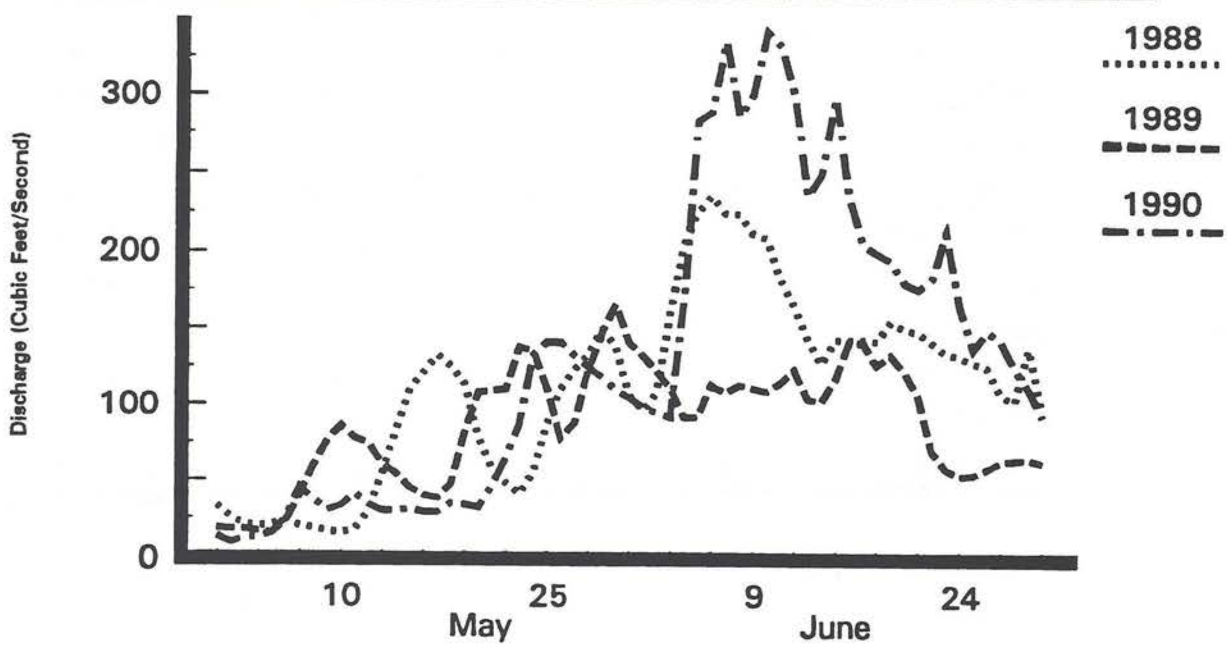
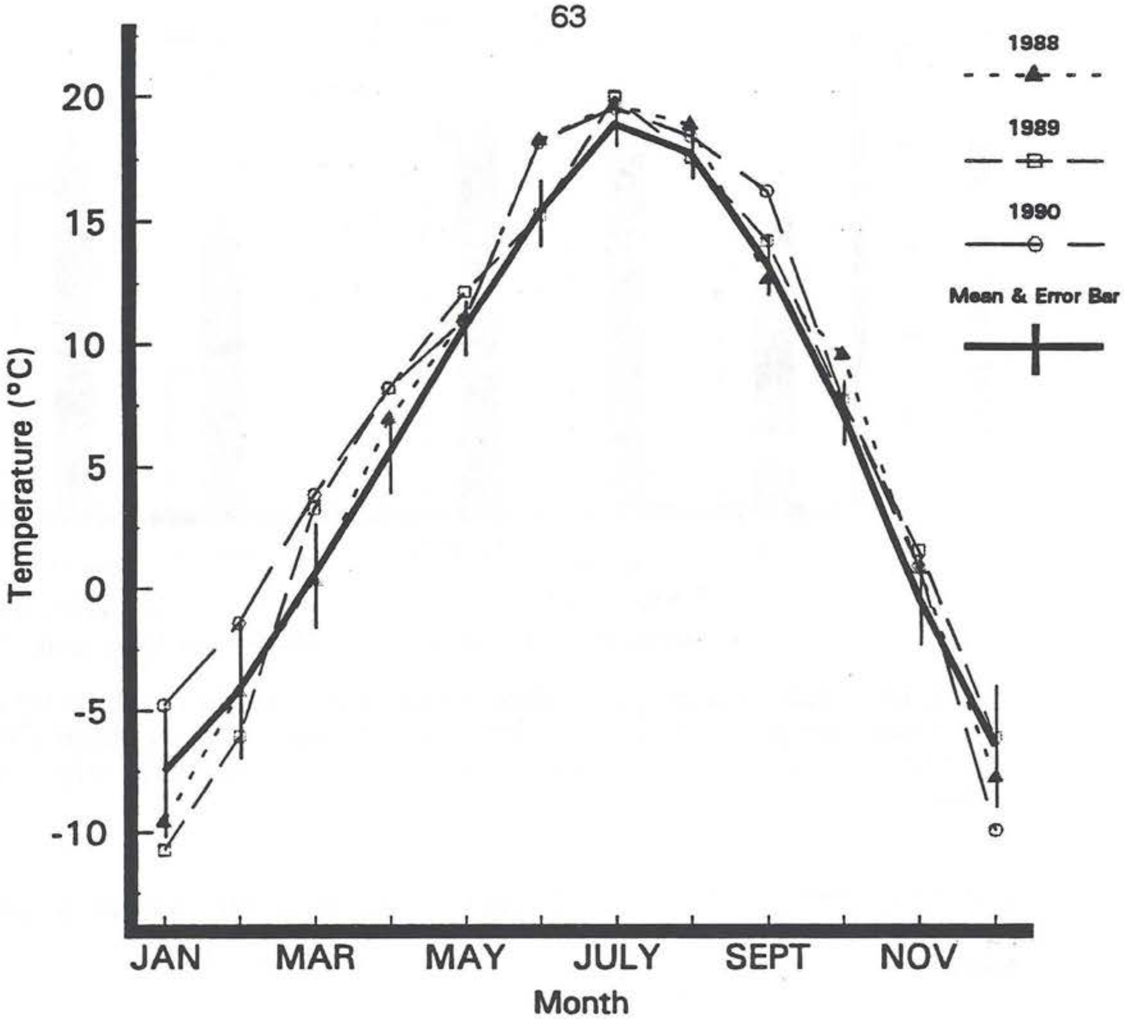


Fig. 2.13. Daily stream flow for Gore Creek-Minturn monitoring station for May 1 - June 30, 1988-1990. Peak flows index snow melt. Gore Creek is on the northern edge of the study site. No water diversion exists above gauging station.



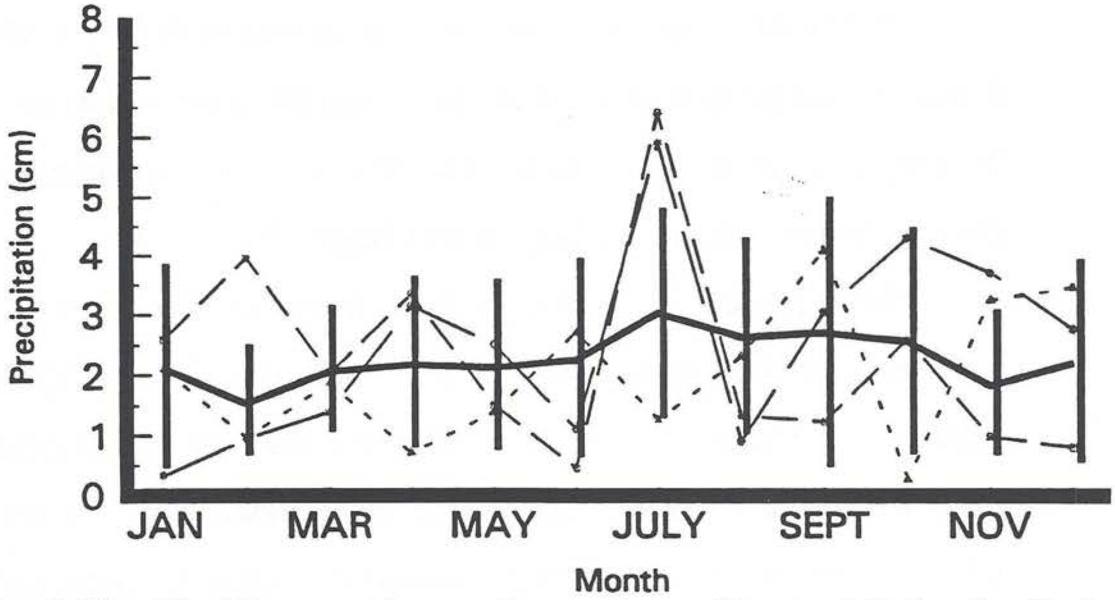


Fig. 2.14. Monthly mean temperature and monthly precipitation for Eagle, Colorado for years 1988-1990. Forty-five year average was plotted as bold line for both parameters. Error bars = 1 standard deviation of distribution.

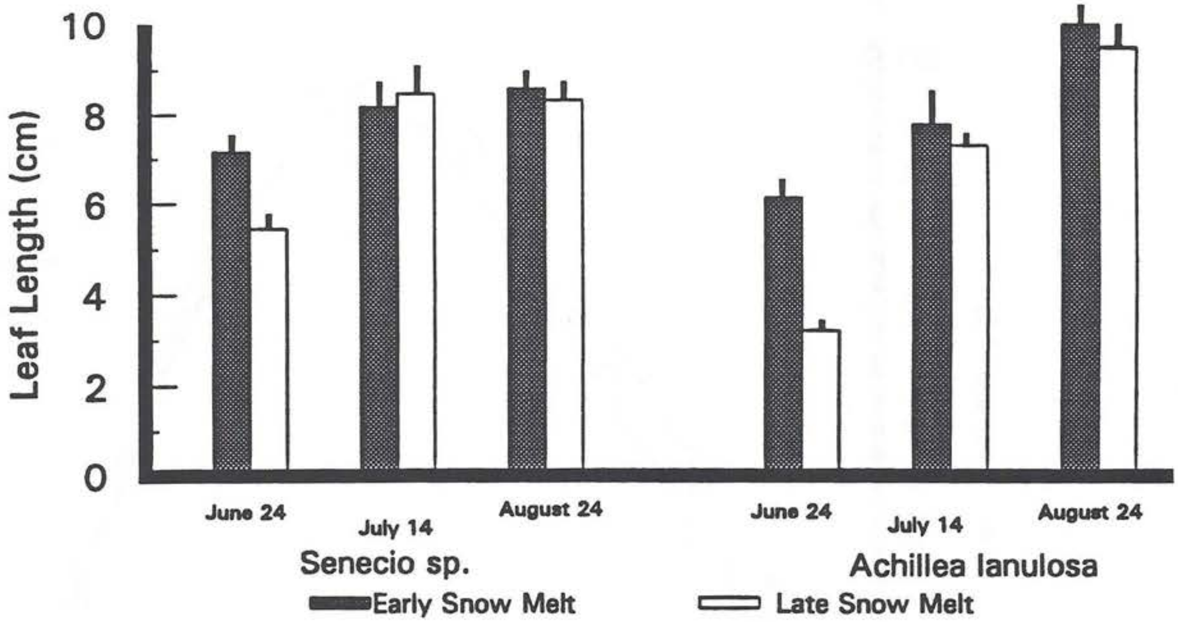


Fig. 2.15. Mean leaf length of *Senecio sp.* and *Achillea lanulosa* on early and late snow melt plots (7-10 days difference in melt rates) in upper China Bowl (elevation = 3,410 m) in 1989. Error bars = 1 standard error about the mean.

and 1990 (Table 2.7) (Fig. 2.13) (later peaks likely occur when snow pack is thicker).

Plant Phenologies

As one would predict, results from snow melt plots (Fig. 2.15) suggest that soon after snow melt (June 24) there was increased vegetation growth in the early snow melt plot; however, this difference in growth diminished as the growing season progressed (July 14 and August 24).

Heterogeneous patterns of snow melt caused difficulty in ascertaining the effects of skier compaction on snow melt rates. Inspection of the 3 photo-points indicated that for both 1989 and 1990, snow melt occurred 1-2 days later where snow was compacted for 2 photo-points. There was no noticeable difference on the third photo-point. Although snow compaction appeared to affect snow melt rates, it did not seem to affect plant green-up in any of the 3 photo-points.

DISCUSSION

In my 3 analyses of radio-telemetry data, I was unable to detect statistically significant changes in elk use patterns for any treatment, thus suggesting no treatment effects. However, as in habitat preference studies, large errors associated with telemetry locations (mean errors were 490 m for aerial locations and 609 m and 940 m for ground locations at Vail and Homestake, respectively) likely reduced my power to detect changes in geographic use patterns (White and Garrott 1986). Power calculations indicate that with this telemetry system, treatment effects need to be 2-5 times greater before power is appropriate (i.e., power > 80%).

Much smaller errors associated with visual observations of elk allowed me to detect more subtle changes in use patterns. Based on the model that best fit my observational data, elk use appeared to decrease threefold after development (post 1988) in all Back Bowls. However, when bowls were analyzed individually, China Bowl was the only area that exhibited a decrease in use, with an 11-fold decrease in the number of elk seen.

The second best fitting model for observational data indicates that elk increased use of all the Back Bowls in 1990 when compared to 1989. When bowls were analyzed separately, China Bowl and Tea Cup Bowl showed increases in elk use. The cause of this increase in elk use was likely due to the behavioral acclimation of elk to physical disturbances and/or the fact that elk were attracted back to these bowls by revegetation that had become established. Although elk use appears to have increased during the second year after development, observational data suggest that it was still much below pre-development levels. To further document whether or not elk are acclimating to disturbances, and if they do, to what degree of pre-development levels, I recommend that visual observations of elk be continued for at least 5-10 years after development. If this survey can not be completed every year, a survey every second or third year would still provide valuable information. To appropriately evaluate data collected from these surveys, changes in the number of elk observed should be compared to population data obtained from the Colorado Division of Wildlife.

Because several different physical disturbances occurred simultaneously, I was unable to determine which disturbance(s) elk responded to; however, I speculate that the larger decrease in elk use in China Bowl (than Tea Cup or Siberia Bowls) was likely due to one or more of the following: (1) There was generally 2-5 times as much disturbance in China Bowl as there was in Tea Cup or Siberia Bowl. (2) Disturbances in China Bowl typically occurred at lower elevations than in Tea Cup and Siberia Bowl, and elk appeared to prefer these elevations that became snow free and experienced plant green-up earlier each spring. Elk may also have been more sensitive to disturbances at these low elevations. (3) China Bowl was the only bowl with a chair lift, and elk may have responded to this lift.

Because photo-points indicated that snow melt did not occur more than 1-2 days later after skier-caused snow compaction at wind-compacted, sub-alpine sites, I do not consider snow compaction a significant factor causing elk use patterns to change under these conditions. Furthermore, it is unlikely that snow compaction at other sites in the Back Bowls affected elk use pattern. If compaction was the primary cause of observed changes, I would expect similar changes in elk use patterns (all 3 developed bowls generally experienced the same extent of snow compaction) in all bowls. Instead, elk use in Tea Cup and Siberia-Mongolia Bowls remained relatively constant, while it decreased in China Bowl.

Although results from my pilot study plots measuring plant phenologies indicate that a later or earlier snow melt of 7 days may affect plant phenologies, I am unable to speculate how this change may affect elk. Further studies are needed to document how snow compaction under various environmental conditions (e.g., slope, aspect, degree of compaction, exposure to winds, micro-topography) affects snow melt, plant phenologies, and elk.

Changes in weather (as it affects snow melt and plant green-up) between years were likely not a cause for observed differences in elk use patterns. If weather were a primary influence affecting use patterns, I would expect to see similar changes of elk use in all bowls.

My conclusions are similar to those of Hershey and Leege (1976), who suggest that elk may not prefer habitats that have been physically disturbed. Although elk appear to have used the most developed Back Bowl (China Bowl) less, they have not; however, completely abandoned the Back Bowls. Based on other studies addressing the effects of human disturbance on hunted elk (Hershey and Leege 1976, Perry and Overly 1976, Ward 1976, Lyon 1979a and b, Morgantini and Hudson 1980), I speculate that elk responses would have been greater had human activity been allowed in the Back Bowls during periods of elk use. By excluding human activity from developed areas during periods of concentrated elk use, the physical effects of ski areas on elk were likely minimized.

Three precautions must be taken when one makes inferences from my study. First, because only cow elk were radio-collared, inferences from radio-telemetry data should only be made to cow elk. Second, in this study I measured geographic use patterns of elk and how they changed in response to ski area development, but I did not measure the preferred parameter, fitness, or the ability of an individual to pass on genes. In theory, fitness is best measured by estimating survival and reproductive rates. Currently, studies measuring fitness require considerable finances and effort; however, future development of more sophisticated radio-transmitters using the satellite operated Global Positioning Systems (**GPS**) may greatly increase the quality of data collected, facilitating these studies. A GPS radio-transmitter could potentially be equipped with a mortality sensor, and could locate an elk [with an associated error less than 30 m (Hurn 1989)] several times an hour. Currently, GPS is used by the military and surveyors, but the system has not been modified for wildlife studies.

Finally, care should be taken when making inferences from this study to other ski areas. The vegetation in the Back Bowls at Vail is atypical of most ski areas. Before development, the sub-alpine Back Bowls were only 20% timbered, whereas most ski areas are 80-95% timbered beforehand. Elk may respond differently to changes in cover under these 2 different situations. If one accepts the optimal habitat model of 60% forage to 40% cover (Black et al. 1976, Thomas et al. 1979), timber removal from a habitat with

20% cover could decrease habitat quality, whereas timber removal from a habitat with 80-95% cover could increase quality.

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CHAPTER 3

CHANGES IN THE NUMBER OF ELK OBSERVED AFTER DEVELOPMENT OF 2 COLORADO SKI AREAS

Several biologists have suggested that elk *(Cervus elaphus)* are sensitive to physical and human disturbances and that they will alter geographic use patterns in response to roads (Hershey and Leege 1976, Perry and Overly 1976, Lyon 1979a, Morgantini and Hudson 1980), active logging, (Ward 1976, Lyon 1979b), and noise associated with mining (Kuck et al. 1985). I measured changes in the number of elk observed after the development of 2 adjacent Colorado ski areas to further document the response of a hunted population of Rocky Mountain elk (*Cervus elaphus nelsoni*) to physical and human disturbances.

STUDY AREA

Observations of elk were made in McCoy Park and Mud Springs, 2 adjacent drainages, situated in central Colorado, 15 km west of the city of Vail (39°36' N, 106°33' W) (Fig. 3.1). Both drainages are located between Beaver Creek and Arrowhead Ski Areas. A migratory elk population of approximately 150-300 animals (B. Andree, Colo. Div. Wildl., pers. commun.) uses this area each summer.

McCoy Park is approximately 4 km^2 with elevations ranging from 2,870

McCoy Park is approximately 4 km^2 with elevations ranging from 2,870 to 3,140 m (9,400 to 10,300 ft). The area is approximately 50% timbered, with quaking aspen (*Populus tremuloides*) and lodgepole pine (*Pinus contorta*) at lower elevations and subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*) at higher elevations.

Mud Springs is situated to the west of McCoy Park and is approximately 5.5 km^2, with elevations ranging from 2,310 to 2,870 m (7,600 to 9,400 ft). The lower 30% of Mud Springs is covered with shrubs, such as, serviceberry (*Amelanchier alnifolia*), chokecherry (*Prunus virginiana*), and snowberry (*Symphoricarpos oreophilus*). The upper 60% is timbered with quaking aspen and lodgepole pine. The remaining 10% of Mud Springs is comprised of meadows.

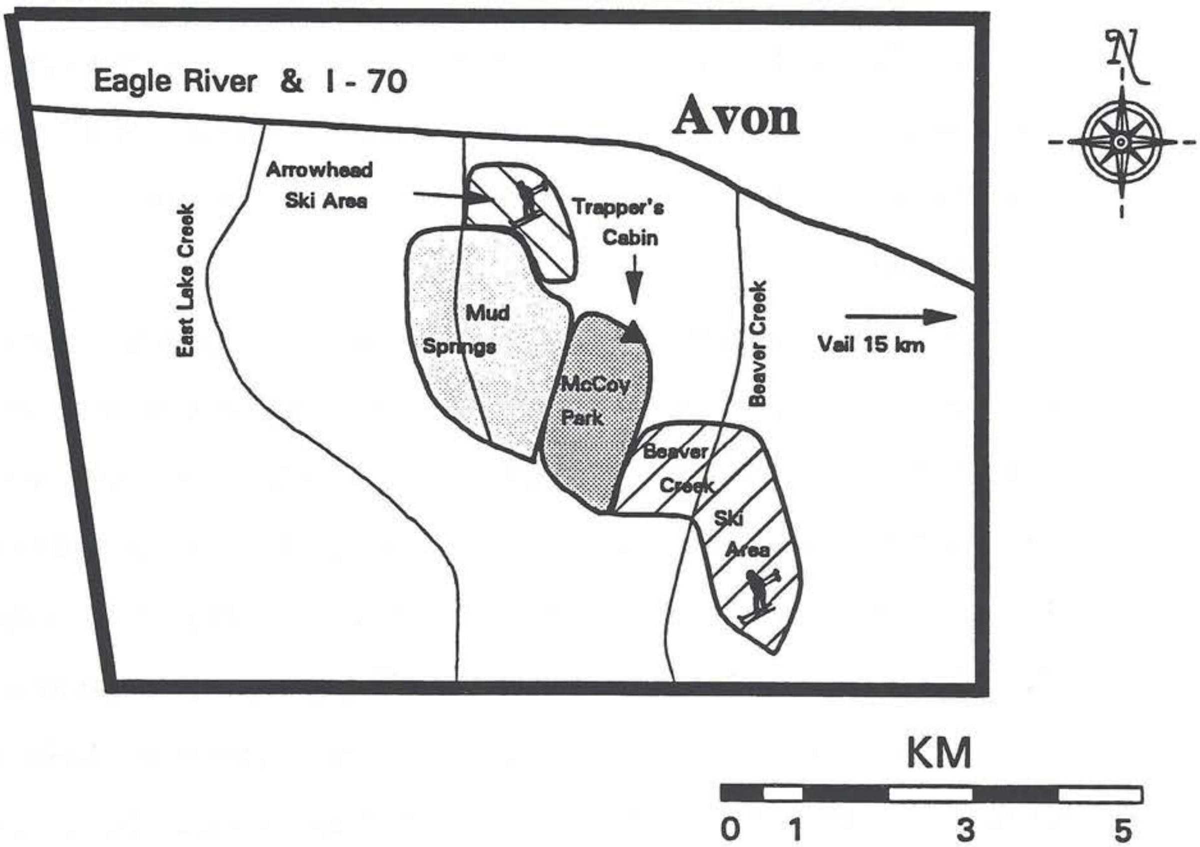


Fig. 3.1. Map of McCoy Park and Mud Springs near Beaver Creek and Arrowhead Ski Area.

METHODS

Treatments

Two developments occurred in and around McCoy Park and Mud Springs. The first took place in McCoy Park during Fall 1987, and involved the construction of Trapper's Cabin, a guest lodge built by Beaver Creek Ski Area (Fig. 3.1). From 1988 to 1990, this cabin was closed each spring until around June 20; from mid June until September the cabin was used frequently (Fig. 3.3). Up to 30 people used this cabin in the evenings, and during the day, guests were led on horse-back trips in and around McCoy Park.

The construction of Arrowhead Ski Area, a second development, occurred in the Summer of 1988. This ski area was constructed 1 km north of McCoy Park and Mud Springs. Construction activities included the use of heavy machinery, chain saws, and the burning of slash piles. Picnic platforms were also built in Mud Springs in 1988 and were used thereafter.

Data Collection

To detect changes in geographic use patterns, I used the number of elk observed in each drainage per visit as a response variable, from May 15 to September 1 for the years 1985 through 1990. Visits were made at either dawn or dusk every 5-10 days using (1) a combination of truck and foot, or (2) an airplane (Table 3.1). Data collection began in 1985 by District Wildlife Manager Bill Andree, Colorado Division of Wildlife, who gathered sex-age ratio data. Because only 2 visits were made in 1986, these data were deleted from analysis. From 1987 to 1988, former graduate student, Bill de Vergie continued these surveys. I completed the survey from 1989 through 1990.

Although each observer used slightly different methods for making observations, they all spent enough time in each area to document how many elk were present. Consequently, I have assumed that there was no observer bias.

Table 3.1. Proportion of visits (the number of visits are listed parenthetically) made to McCoy Park and Mud Springs each summer by location method. All surveys made from an airplane were made in the morning. Ground locations were made either in early morning or evening.

	1985	1987	1988	1989	1990
McCoy Park					
Air	58 (7)	38 (9)	35 (6)	46 (6)	33 (4)
Ground	42 (5)	62 (15)	65 (11)	54 (7)	67 (8)
Mud Springs					
Air	88 (7)	75 (12)	60 (6)	46 (6)	33 (4)
Ground	12 (1)	25 (1)	40 (4)	54 (7)	67 (8)

Analysis

Because the observational data were negative binomially distributed (i.e., smaller groups were observed more frequently than large groups), I chose an analysis based on the negative binomial distribution identical to that used for observational data in Chapter 2 (see Method 4 in Methods section of Chapter 2 for details on this analysis). The only difference in methods between these 2 chapters is that I used 11 models to test all possible changes in elk use patterns (Table 3.2), whereas I used 9 models in the previous chapter. My null hypothesis (null model) for both drainages was the following: H_0: There was no change in the mean number of elk seen per visit, *m*, after 1987.

Table 3.2. Eleven negative binomial models used to test differences in the number of elk seen in the McCoy Park and Mud Springs between years. With negative binomial statistics, m = mean, and k is a measure of dispersion. As data become clumped, $k \rightarrow 0$; as data approach a random distribution, $k \rightarrow \infty$.

Model	Model Description
M___K___	*m* and *k* were same for all years
M___	*m* was same for all years *k* was different for all years
K___	*m* was different for all years *k* was same for all years
M_T_K_T_	*m* was same for all years before treatment *m* was same for all years after treatment *k* was same for all years before treatment *k* was same for all years after treatment
M_T_	*m* was same for all years before treatment *m* was same for all years after treatment *k* was different for all years
K_T_	*m* was different for all years *k* was same for all years before treatment *k* was same for all years after treatment
M_T2K___	*m* was same for all years before treatment and 3rd year after treatment. *m* was same for 2 years after treatment *k* was same for all years
M_T2K_T_	*m* was same for all years before treatment and 3rd year after treatment. *m* was same for 2 years after treatment *k* was same for all years before treatment *k* was same for all years after treatment
M_T3K___	*m* was same for all years before treatment and 2nd and 3rd year after treatment, but different for 1st year after treatment *k* was same for all years
M_T3	*m* was same for all years before treatment and 2nd and 3rd year after treatment, but different for 1st year after treatment *k* was different for all years
ALL_DIFF	*m* and *k* were different for all years

If the null model was not rejected, I completed statistical power calculations using parameter estimates from the second best fitting model and tested how often this model was selected over the null model. Power calculations were computed using PROC SIMULATE in SURVIV (White and Garrott 1990); 500 simulations were completed. (See Method 3 in Methods section of Chapter 2 for a detailed definition of power.)

Goodness-of-fit of binomial models was acceptable ($P > 0.12$) for Mud Spring, but was poor for McCoy Park ($P < 0.000$). Goodness-of-fit for McCoy Park was low because, as discussed in Chapter 2, large group sizes created excessively large chi-square values. Without these few large groups, goodness-of-fit was acceptable. Because fit improved without data for large groups, it was not likely low because my data were not appropriate for the negative binomial distribution, but because the test for goodness-of-fit did not handle large values adequately.

Time of Use

One constraint in using analysis based on the negative binomial distribution is that the time elk observations are made is not incorporated into analysis. Elk may alter when they use an area, but as long as the mean number of elk observed remains constant, no change in use will be detected. For example, twice as many elk may use McCoy Park the first half of a summer, and may then decrease their use 2-fold the remainder of the summer, but as long as the average number of elk (m) remains the same, no change will be detected between 2 years. To detect whether or not elk changed the period of time when they used these areas, I plotted the mean number of elk observed during 7 time periods using histograms. Each time period was 15-16 days in length, and altogether they covered a period of time from May 15 to September 1. Histograms were the most appropriate way to plot my data because they allowed me to remove daily fluctuations in the number of elk observed, and they facilitated comparison between years. I described temporal changes in elk use patterns from interpretations of these histograms; no statistical analyses were performed.

Human Activity

To detect any patterns between levels of human activity and periods of elk use McCoy Park and Mud Springs, I used histograms (identical to the ones described above) to plot the proportion of nights that Trapper's Cabin was occupied during 1988-1990. Although Trapper's Cabin was not the sole source of human activity in this area, I used these data as an index. Other activities included day horse-back trips in McCoy Park, use of the Arrowhead picnic platforms, and use of a picnic area for Trapper's Cabin, on the western edge of McCoy Park overlooking Mud Springs. During my surveys, I documented all of these additional activities.

Weather

As discussed in Chapter 2, it is possible that weather changes between years influenced elk use patterns in McCoy Park and Mud Springs. To evaluate relationships between weather changes and changes in use patterns, I used weather data from: (1) Eagle weather station (via Colorado Climate Center, Fort Collins), (2) Gore Creek-Minturn stream monitoring station, and (3) photo-points established in the Back Bowls of Vail for 1989-1990 (see Chapter 2 for more details). Because changes in snow melt rates and precipitation most likely had the greatest effect on plant growth and, consequently, elk use patterns (Sweeny 1975), I limited my discussion to these factors.

RESULTS

Analysis

The best fitting model for McCoy Park indicated that elk use did not change after development. This model was M___, where *m*, the mean number of elk observed, was the same for all years, but *k*, which measures dispersion, was different for all years (Fig. 3.2, Table 3.3). In this model *m* = 13.7. The second best fitting model for McCoy Park was M_T3, where *m* was the same for 1985, 1987, 1989 and 1990, but different for 1988, and *k* was different for all years. Under this model *m* = 15.1 for 1985, 1987, 1989 and 1990 and *m* = 8.1 for 1988. The power calculations from SURVIV showed me that if model M_T3 were true, with the above parameter estimates, the power to reject the null model (M___) was low, only 6%.

The best fitting model for Mud Springs indicated that elk use decreased dramatically for 2 years after development and increased slightly the third year. This model was M_T2K_T_, where *m* was same for 1985 and 1987, *m* was same for 1988 and 1989, *k* was the same for 1985 and 1987, and *k* was the same for 1988-1990 (Fig. 3.2, Table 3.3). With this model *m* = 9.2 for 1985 and 1987, *m* = 0.2 for 1988 and 1989, and *m* = 2.2 for 1990.

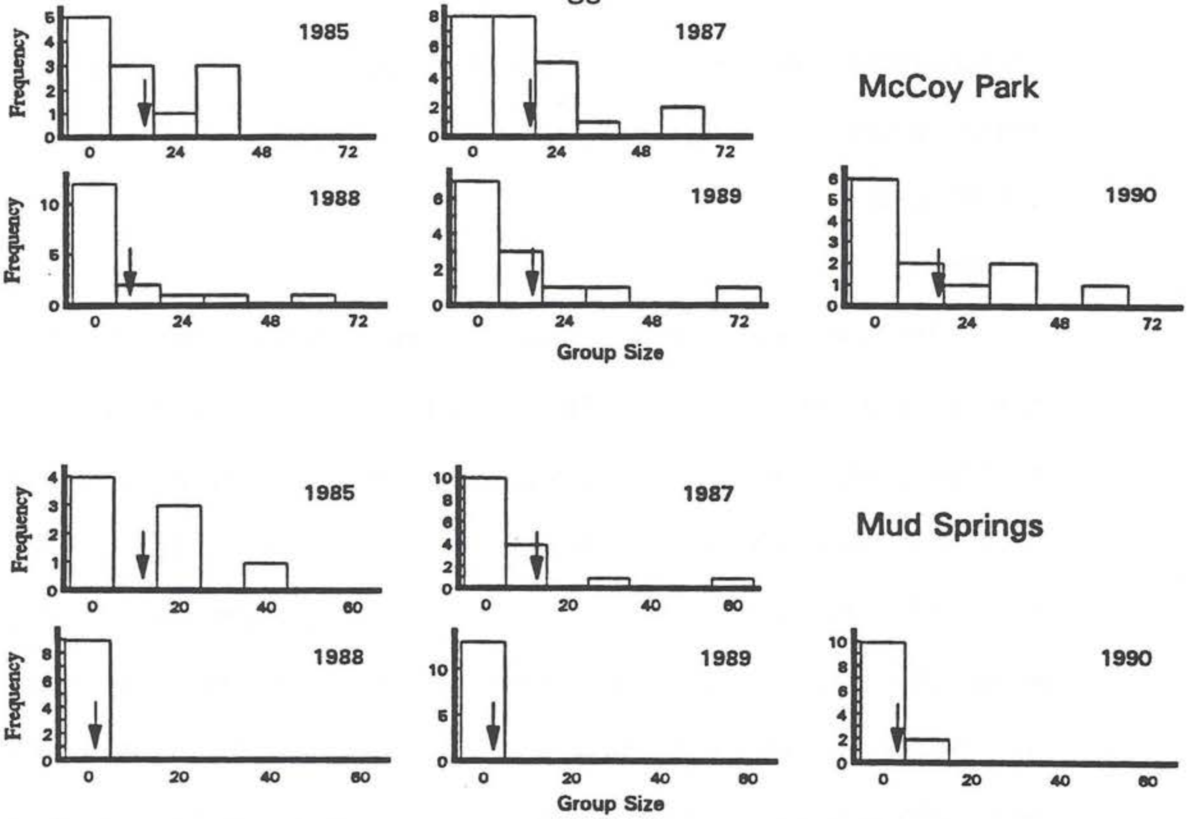


Fig. 3.2. Group sizes of elk seen in McCoy Park and Mud Springs for years 1985 and 1987-1990. Years 1985 and 1987 were pre-treatment and years 1988-1990 were post-treatment. Arrow marks the mean of the number of elk seen. For McCoy Park; 1985 n = 12, 1987 n = 24, 1988 n = 17, 1989 n = 13, 1990 n = 12. For Mud Springs; 1985 n = 8, 1987 n = 16, 1988 n = 10, 1989 n = 13, 1990 n = 12.

Table 3.3. Output of negative binomial models from program SURVIV for number of elk seen in McCoy Park and Mud Springs. The top 3 models are listed in order of model preference. Model selection was based on Akaike Information Criteria (AIC) and ultimately likelihood ratio tests (α = 0.05). See Table 3.2 for definitions of models.

Model	Log-likelihood	DF	Akaike Information Criteria	Log-likelihood G-O-F
McCoy Park				
1) M___	-231.975	64	475.950	0.000
2) M_T3	-231.765	63	477.531	0.000
3) M_T_	-231.905	63	477.811	0.000
Mud Springs				
1) M_T_K_T_	-95.507	66	199.015	0.118
2) M_T2K_T_	-93.743	65	197.486	0.162
3) K___	-93.786	64	199.571	0.139

Time of Use

Elk were observed in McCoy Park throughout the summer of 1985 and 1987 (Fig. 3.3). However, in 1988, the first year after development, no elk were seen after July 1. In 1989 and 1990 elk were observed later in the summer than in 1988 (until July 15); however, elk use decreased during late summer. At Mud Springs, elk were observed from early June through August in 1985 and 1987, but again, elk used this area less during mid-late summer after development occurred (post 1987). In 1988 and 1989 elk were not seen after June 1. In 1990, elk were observed later than the 2 previous summers, until July 15, but elk were not seen in late summer.

Human Activity

During 1988-1990, Trapper's Cabin was used from mid June through August. The cabin was occupied for 37%, 66%, and 51% of the nights for 1988, 1989, and 1990, respectively (Fig. 3.3). During 1989 and 1990, I did not observe any horse-back trips or use of the Arrowhead picnic platforms; however, on several occasions I did see people at the Trapper's Cabin picnic area.

Weather

Based on data from stream flow rates, spring precipitation, and photo-points, the order of snow melt, from earliest to latest years, were likely 1987, 1988, 1989, 1990 and 1985 (Fig. 3.4, 3.5). Cumulative precipitation for the months June-August, listed in order from least to most, was: 6.3 cm in 1988, 7.8 cm in 1985, 8.0 cm in 1990, 8.2 cm in 1989, and 8.5 cm in 1987.

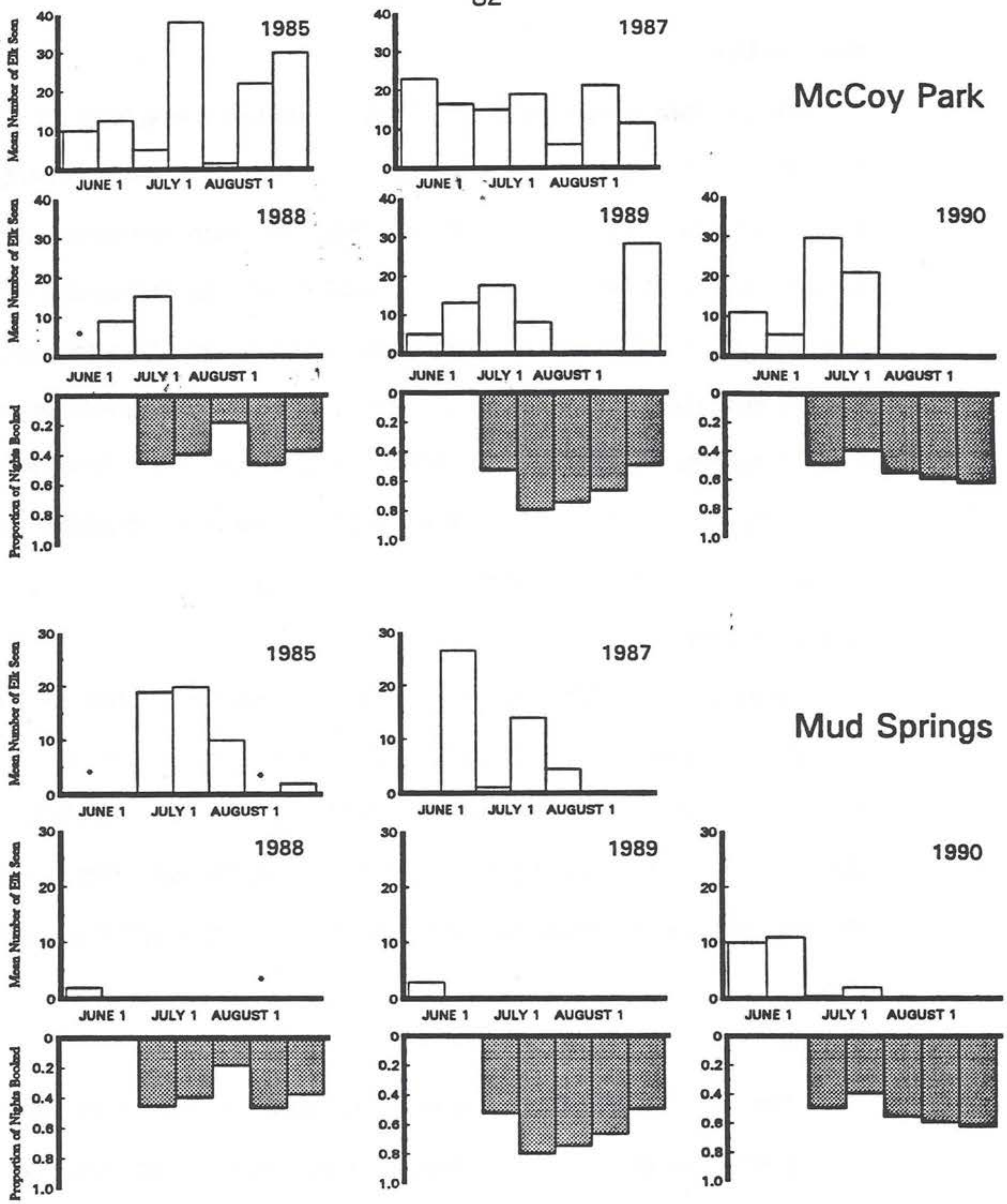
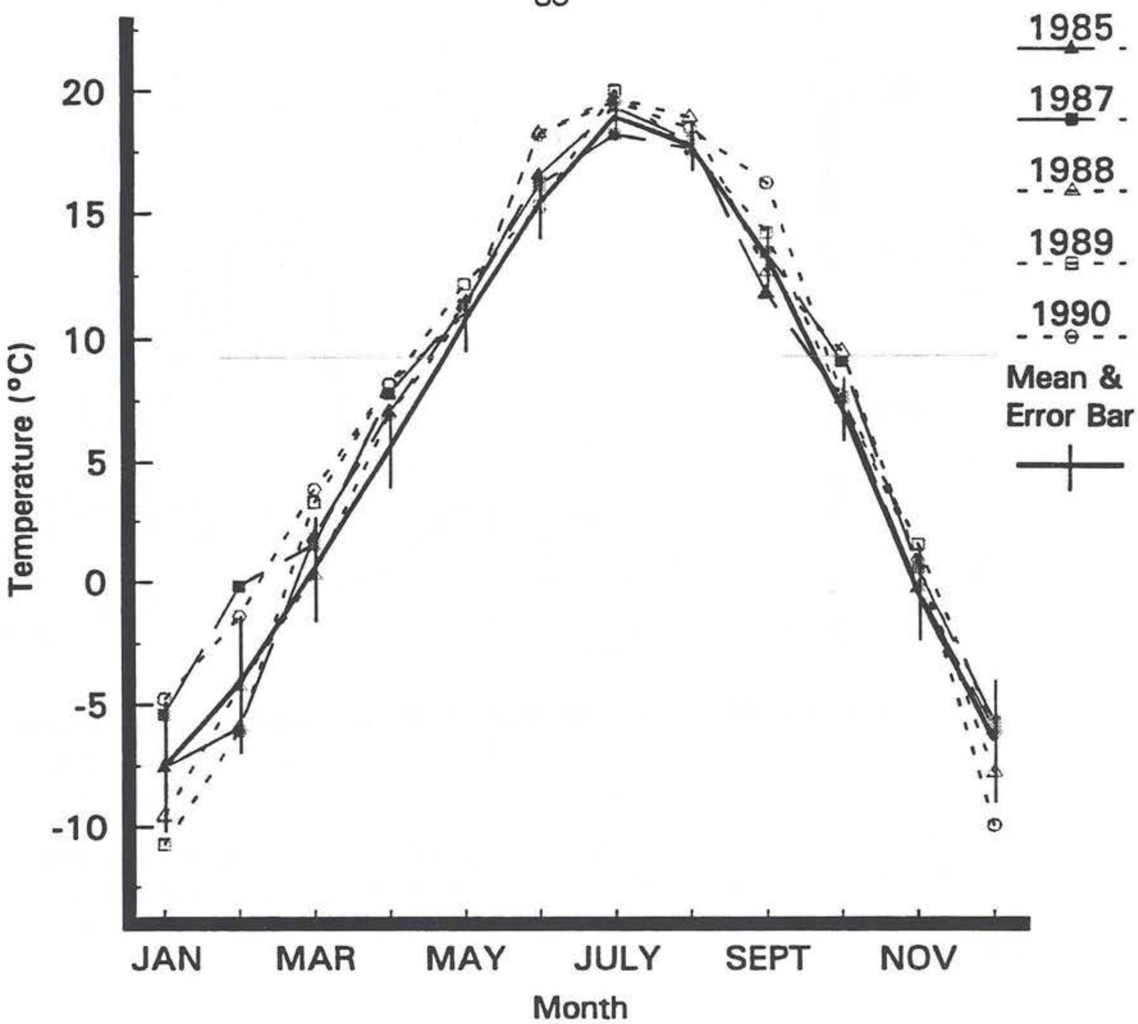


Fig. 3.3. Number of elk seen as related to human activity at Trapper's Cabin. Open histograms show the mean number of elk seen in McCoy Park and Mud Springs for 7 time periods between May 15-September 1 for years 1985 and 1987-1990. Years 1985 and 1987 were pre-treatment and years 1988-1990 were post-treatment. Asterisks mark time periods when no visits were made. For McCoy Park; 1985 *n* = 12, 1987 *n* = 24, 1988 *n* = 17, 1989 *n* = 13, 1990 *n* = 12. For Mud Springs; 1985 *n* = 8, 1987 *n* = 16, 1988 *n* = 10, 1989 *n* = 13, 1990 *n* = 12. Shaded histograms show the proportion of nights Trapper's Cabin was booked for 1988-1990.



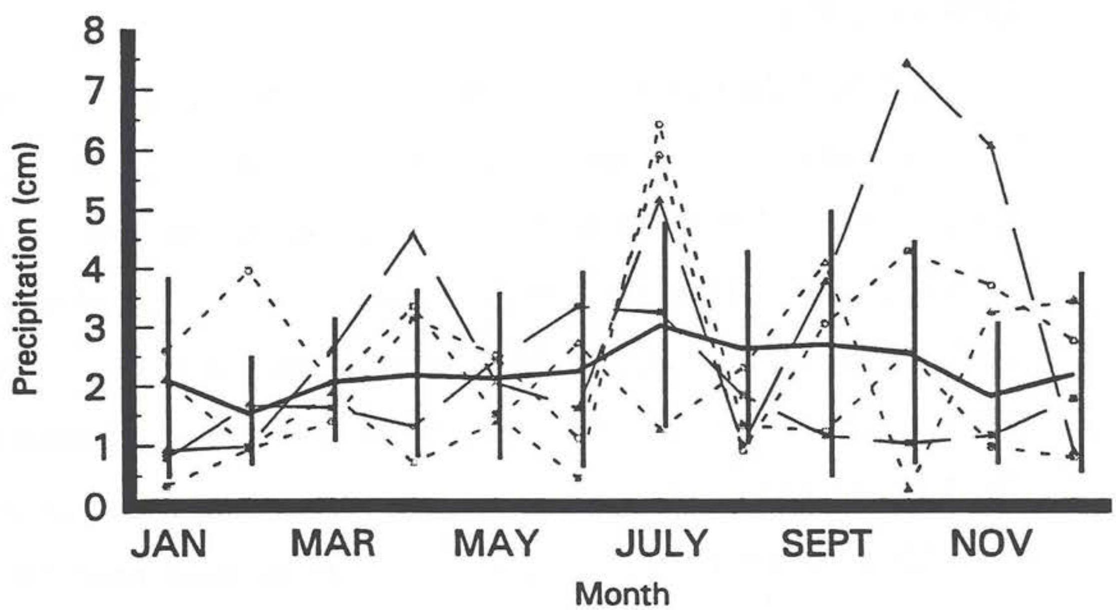


Fig. 3.4. Monthly mean temperature and monthly precipitation for Eagle, Colorado for years 1988-1990. Forty-five year average is plotted as bold line for both parameters. Error bars = 1 standard deviation.

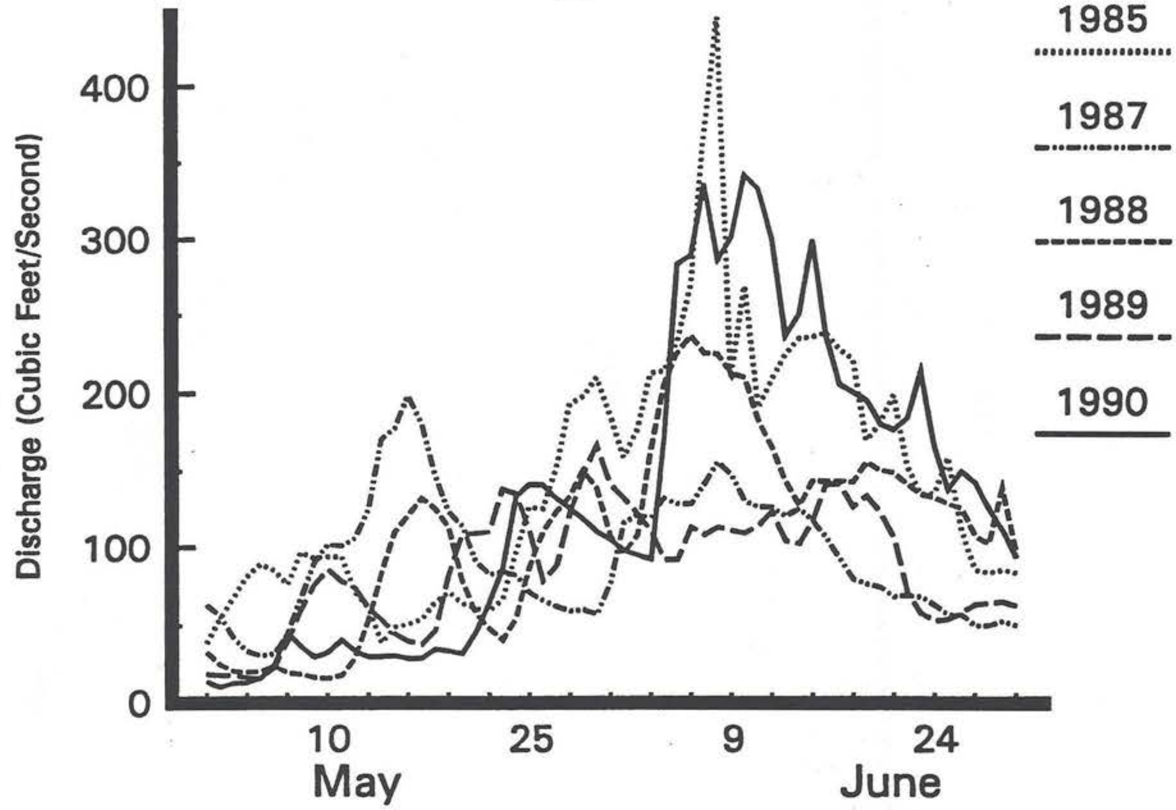


Fig. 3.5. Daily stream flow for Gore Creek-Minturn monitoring station for May 1-June 30, 1988-1990. Peak flows index snow melt. Gore Creek is on the northeast edge of the study site. No water diversions exist above gauging station.

DISCUSSION

Although the number of elk that used McCoy Park in 1988 was nearly half that of previous and later years (1985, 1987, 1989-1990), the best fitting negative binomial model suggests that elk use did not change in 1988. However, power calculations indicated that if use actually did decrease in 1988 that power of negative binomial analysis was low (6%). The apparent change in when elk used McCoy Park to time periods before Trapper's Cabin (Fig. 3.3) opened for each season indicates the elk changed use periods.

Elk in Mud Springs responded much more to developments than they did in McCoy Park. A 46-fold decrease in elk use occurred during the first 2 summers after development. During the third summer after development, elk use increased, but was still fourfold less than pre-development use. Elk also appeared to shift the time period during which they used Mud Springs from mid-summer (pre-1988) to early summer (post-1988).

Unfortunately, I was unable to ascertain exactly which activity caused these changes in elk use patterns. In 1988, changes were likely caused by human activity associated with Trapper's Cabin and/or the construction of Arrowhead Ski Area. Because construction activities at Arrowhead Ski Area ceased after 1988, low elk use in 1989 and 1990 was most likely due to activities associated with Trapper's Cabin. This conclusion is supported by the general shift in elk use in McCoy Park and Mud Springs to early summer, before Trapper's Cabin opened each summer. Observer bias likely did not influence changes in the number of elk seen, because the same observer was present during the 2 years when the greatest change in elk use occurred.

If activities associated with Trapper's Cabin were the primary cause in a change elk use patterns, it seems unusual that the largest change did not occur in McCoy Park, where Trapper's Cabin is located, but instead occurred in Mud Springs. Elk in Mud Springs likely responded more to developments for 1 or more of the following reasons: (1) Elk may have already acclimated, behaviorally, to human activities in McCoy Park. Prior to 1988, elk in McCoy Park probably experienced higher levels of human activity from nearby Beaver Creek Ski Area than those elk using Mud Springs. (2) Before development, elk which were more sensitive to human activity may have already changed use patterns in McCoy Park, but these same elk were still using Mud Springs. (3) Use of the picnic area overlooking Mud Springs by guests from Trapper's Cabin was a disturbance. (4) Other human activities associated with these developments may have occurred of which I was unaware. Surveys of McCoy Park and Mud Springs were made at dawn or dusk, and I may have missed other human activities during mid-day.

Increased elk use of McCoy Park and Mud Springs after 1988 may be due to: (1) behavioral acclimation of elk to human activity, and/or (2) cessation of activities associated with the development of Arrowhead Ski Area. Elk use approached pre-development levels in McCoy Park, but the average number of elk observed in Mud Springs was still 4 times less than that of pre-development.

Because there was not a clear relationship between snow melt rates, precipitation, and changes in the number of elk observed, I speculate that weather was not a primary influence. Low precipitation in 1988 may have influenced elk to use both these drainages less, but this does not explain why elk still used these drainages less in 1989 and 1990, when more precipitation fell.

In conclusion, this study supports the hypothesis, as proposed in studies on the effects of roads, logging, and mining on elk (Hershey and Leege 1976, Perry and Overly 1976, Ward 1976, Lyon 1979a, Lyon 1979b, Morgantini and Hudson 1980, Kuck et al. 1985), that these animals are sensitive to physical and human disturbances. Because it appears that elk in Mud Springs may be acclimating to disturbances, I recommend that surveys in this area continue for at least another 5-10 years. It is important to document whether or not elk use will ever approach pre-development use levels, and if so, how long does it take. If this survey can not be completed every year, a survey every second or third year would still provide valuable information.

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CHAPTER 4
CONCLUSIONS

In this thesis, I accomplished the following: First, I tested the accuracy of 2 radio-telemetry systems commonly used by many wildlife biologists. Second, using the above telemetry systems and changes in the number of elk observed, I measured the effects of physical disturbances resulting from ski area expansion on geographic use patterns of elk. Finally, in a similar study on a second study site, I documented the effects of both physical disturbances and human activity on geographic use patterns of elk.

In Chapter 1, I measured the error associated with a 2-element, hand-held antenna system and a belly-mounted airplane antenna system. Precision of the hand-held antenna (s = 5.43°) was better than that previously reported for this system in similar terrain and, in fact, was closer to previously reported precision for flat, non-timbered terrain. Contrary to Pace (1988, 1990), precision was constant, as related to different distances between transmitters and receiving stations. Significant bias of the antenna from 4 of 8 receiving stations (pooled bias = -3.21°) indicated that bounced signals were common in mountainous terrain. After estimating locations in TRIANG, I censored inaccurate locations by deleting locations with error ellipses above a determined size. After censoring locations, the Andrews Estimator had smaller associated errors than the Huber Estimator or MLE. The respective mean and 90% quantile of the distance between the true and estimated locations produced by the Andrews Estimator for the hand-held antenna system were 609 m and 1,105 m for the Vail study site and 940 m and 1,531 m for the Homestake site. The belly-mounted airplane antenna system performed better than the hand-held antenna system. The respective mean and 90% quantile of the distance between true and estimated locations was 409 m and 1,081 m.

Both of these antenna systems are frequently used by wildlife biologists, but errors associated with these systems are rarely measured, and often are considered insignificant. Results from this study, however, indicate that those errors may be large. Therefore, I strongly recommend that before initiating a study using radio-telemetry, biologists should evaluate whether or not the error associated with an antenna system is compatible with study objectives. For example, these antenna systems are appropriate for studies measuring gross changes in geographic use patterns of elk, but would not be appropriate for studies measuring more subtle changes in locations (e.g., habitat use studies).

In Chapter 2, I measured the effects of physical disturbances resulting from the expansion of Vail Ski Area on the geographic use patterns of elk. Using the telemetry systems evaluated in Chapter 1, I found no changes in geographic use patterns of elk after expansion. As discussed above, these telemetry systems are most appropriate for detecting gross changes in use patterns and are thus not effective for detecting subtle changes. However, a second data set, which included visual observations of elk, was more precise and allowed subtle changes in use patterns to be detected. With observational data, a threefold decrease in the mean number of elk seen in the Back Bowls of Vail was measured after development. When I analyzed each Back Bowl separately, no decrease in the number of elk observed was detected except for China Bowl, where an 11-fold decrease was measured.

Elk may have been more responsive to the development in China Bowl because of the following: (1) China Bowl was more developed than other bowls. (2) Development in China Bowl occurred at lower elevations than other bowls. (3) China Bowl was the only area with a new chair lift. Data from the second year after development suggest that elk may have partially acclimated, behaviorally, to these disturbances, and/or that plant growth from revegetation attracted them back to these bowls. Although I detected some changes in geographic use patterns, elk did not abandon the Back Bowls. The effects of physical disturbances may have been minimized by excluding human activity from the Back Bowls during periods of concentrated elk use.

One precaution must be taken when making inferences from this study to other ski area developments. Before development, the sub-alpine Back Bowls were only 20% timbered, whereas most ski areas are 80-95% timbered. Elk may respond differently to timber removal in sparsely timbered versus heavily timbered habitats (Black et al. 1976, Thomas et al. 1979).

In Chapter 3, I also measured the response of elk to development, but it differs from Chapter 2 in that I did not use radio-telemetered elk to measure a response, and development consisted of increased levels of human activity and physical disturbances (developments in Chapter 2 consisted only of physical disturbances). Using observational data, I found no change in the number of elk observed after development in McCoy Park; however, in Mud Springs elk use decreased 46-fold after development. I also made comparisons between time of year elk were observed in McCoy Park and Mud Springs and the time of year Trapper's Cabin was occupied. My results indicate that after development, elk altered their use patterns and decreased use of both drainages during mid-late summer.

It seemed unusual that the response of elk to developments was less in McCoy Park, where Trapper's Cabin is located, than in Mud Springs. This change at Mud Springs may have been due to one or more of the following: (1) elk in McCoy Park historically have been exposed to more human activity, and therefore may have previously acclimated, behaviorally, to disturbances, (2) elk, which may have been more sensitive to disturbances, had already changed use patterns in McCoy Park, but they were still using Mud Springs, (3) use of a picnic area for Trapper's Cabin near Mud Springs was a disturbance, or (4) other human activities may have occurred in Mud Springs of which I was unaware. Increased elk use of McCoy Park and Mud Springs the second and third summer after development may be due to the acclimation of elk to human activity and/or the cessation of disturbances associated with development of Arrowhead Ski Area. Because there was no clear relationship between snow melt rates, precipitation, and the changes in the number of elk seen, weather was probably not a primary influence in observed changes.

Results from Chapters 2 and 3 support the hypothesis which has been proposed in numerous studies (Hershey and Leege 1976, Perry and Overly 1976, Ward 1976, Lyon 1979a and b, Morgantini and Hudson 1980, Kuck et al. 1985) namely, that hunted elk are sensitive to physical disturbances and will avoid them. However, I have demonstrated that elk will respond differently to different types of disturbance. Elk using the Back Bowls responded to developments in China Bowl by decreasing their use or the area, but I detected no such response from elk in Tea Cup or Siberia Bowls. Similarly, elk using Mud Springs responded more than the animals using McCoy Park.

If biologists want to accurately predict how elk will respond to disturbances, further studies are needed. Data collected in Chapter 2 provide baseline information for such a study. In Chapter 2, I measured the effects of only physical disturbances on elk. My study was not confounded (as many studies have been) by human activity. A future study, measuring the response of elk only to human activity (e.g., mountain bikes, hikers, horse-back riders) would provide valuable insights to the importance and interaction of these 2 disturbances on elk. With proper finances, a well-designed study could be implemented.

Results from Chapter 2 and 3 indicate that elk may be acclimating, behaviorally, to both physical disturbances and human activity; however, elk use is still substantially lower than pre-treatment levels. In order to document to what level of pre-development use elk may acclimate, I recommend that data collection continue for the next 5-10 years. Ideally, data collection should continue each summer, but if funding is limited, data may be collected every 2-3 years. I have documented the immediate short term response of elk to development at ski areas. Now it is important to document the long term response of elk. To appropriately evaluate data collected from these surveys, changes in the number of elk observed should be compared to population data obtained from the Colorado Division of Wildlife.

One final precaution must be taken when making inferences from Chapters 2 and 3. Although geographic use patterns of elk were measured in response to disturbances, a measure of the preferred parameter, fitness, the ability of an individual to pass on genes, was not measured. Currently, studies measuring fitness require considerable funding and labor; however, the development of more sophisticated radio-transmitters using the satellite operated Global Positioning Systems (GPS) may greatly increase the efficiency and quality of data collected and reduce the labor and possibly the funding needed for such studies.

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APPENDIX A

BIBLIOGRAPHY: THE EFFECTS OF SKI AREA DEVELOPMENT ON THE ENVIRONMENT

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