Marten Use of Subnivean Access Points in Yellowstone National Park, Wyoming

Stuart Scott Sherburne
Utah State University

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MARTEN USE OF SUBNIVEAN ACCESS POINTS
IN YELLOWSTONE NATIONAL PARK,
WYOMING

by

Stuart Scott Sherburne

A thesis submitted in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Wildlife Science

UTAH STATE UNIVERSITY
Logan, Utah

1992
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Funding for this project was provided by the University of Wyoming National Park Service Research Center, the Utah Cooperative Fisheries and Wildlife Research Unit (USFWS), and Utah State University. I am grateful for their support. I would like to recognize and thank my committee members, Dr. Barrie Gilbert and Dr. James Gessaman, for their suggestions and comments. I especially appreciate the efforts and suggestions of my major professor, Dr. John Bissonette. His time and consideration were essential to the completion of this research.

I would also like to thank the members of the National Park Service, especially the residents of Canyon Village, in Yellowstone National Park. Their assistance and friendship were invaluable to me during my stay in Yellowstone. Without their logistical support I probably would still be stuck on my snowmobile. Thank you all.

Mike Rowell, Larry Studley, and Kevin Maloney assisted with field data collection. Larry also assisted me with scat analysis. Without their help and devotion of long hours in the field, my sample size would be greatly reduced. Gretta Curless and Tyler Perkins assisted with manuscript preparation. Susan Durham, Todd Crowl, and John Bissonette helped me with data analysis techniques. Doug Ramsey provided valuable assistance with Chapter IV.

Finally I must thank my wife Katie for all of her help with editing and formatting of the thesis. More importantly, however, I owe her my sincere thanks for tolerating the ups and downs associated with the completion of an M.S. at Utah State.

Stuart Sherburne
FOREWORD

This thesis is presented in four parts with chapters being submitted for publication to the Canadian Journal of Zoology (Chapter I), the Journal of Mammalogy (chapters II and III), and Landscape Ecology (Chapter IV). The purpose of this study was to determine why, when faced with an abundance of subnivean access points, martens used certain points and not others. Each of the chapters presented here addresses specific aspects of this question.

The differential use of subnivean access points by martens is a response to three factors: thermal cover, prey, and predator avoidance. In this thesis I examine subnivean access point use from the aspects of prey and, to some extent, thermal cover. At the beginning of this study, I hypothesized that martens used certain subnivean access points in order to obtain prey. Martens are very active animals that typically inhabit harsh winter habitats. While thermal cover is an important aspect of their biology, in order to survive martens must acquire an adequate amount of food.

Chapters I-III of this thesis investigate subnivean access point use by martens and in particular look at these two variables: thermal cover (CWD) and prey. In Chapter I, I show that martens use of access points is influenced primarily by subnivean prey biomass. Chapter II investigates the presence of red squirrel middens and their influence on access point use by martens. Chapter III describes a method for determining relative prey abundance at subnivean sites. Chapter IV shows a method for incorporating radio telemetry data directly into a GIS data base.
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ABSTRACT

Marten Use of Subnivean Access Points in Yellowstone National Park, Wyoming by Stuart Scott Sherburne, Master of Science Utah State University, 1991

Major Professor: Dr. John A. Bissonette
Department: Fisheries and Wildlife

Subnivean prey appeared to be the primary reason for subnivean access point use by martens. A logistic regression was used to create a predictive model for differential access point use. Prey biomass in grams and percent ground cover of coarse woody debris (CWD) were used as variables in the model. Goodness of fit of the multivariate model was 0.216; biomass was significant at $p = 0.0003$, CWD was significant at $p = 0.0718$. Mean values for prey biomass at used and unused access points were 174.2 g and 81 g, respectively, while mean values of CWD were 24.7% and 18.5%, respectively. Both CWD and prey can be used to predict access point use by martens. CWD provides access to the subnivean zone. Martens appear to key in on access points with higher levels of prey.

Red squirrel middens were found at 33% of used and 16% of unused access points ($p = 0.015$, $n = 90$). There was no significant difference in prey biomass or CWD based upon the presence or absence of a squirrel midden. Prey biomass was significantly related to access point use ($p = 0.0022$) and the relationship was strengthened when squirrels were included in the biomass estimates.
(p = 0.0001). It is likely that red squirrel middens were used as access points by martens because of
the opportunity to prey on red squirrels as a prey item.

Seed boluses were used to estimate the relative prey abundance at subnivean access points. Use of seed boluses in winter was correlated with prey abundance values obtained by snap trapping after the snow melt \((p = 0.0134, \phi^2 = 0.435)\).

A program for direct entry of raw telemetry data in a Geographic Information System (GIS) data base was developed. With this method telemetry data can be interpreted directly at a number of scales to determine habitat patterns using area rather than point data.

(46 pages)
CHAPTER 1
RELATIONSHIP BETWEEN MARTEN SUBNIVEAN ACCESS
POINT USE AND SUBNIVEAN PREY

Abstract: A predictive model, which includes subnivean prey biomass and percent ground cover of coarse woody debris (CWD) as variables in a logistic regression, is presented to explain martens use of snow tunnels. Both biomass and debris were included in the model because of their biological importance to martens in winter. Prey biomass yielded the best univariate predictive model (coef/se = 3.96, p = 0.0001); however, CWD has been shown by many authors to be an important variable for predicting martens access point use. I included CWD in a multivariate model because of its biological significance.

Log odds ratios were developed to aid in interpretation of the data. For every 50 g increase in prey biomass, martens were 1.37 times more likely to use that access point. As CWD increased by 5%, the probability of martens use increased by 112%. CWD is required to provide access to the subnivean zone and was found at both used and unused access points. Prey biomass is the cue that appears to determine which access points are used. My results suggested that CWD is an important variable because it provides structure that creates access to the subnivean zone; however, prey biomass is a better indicator for predicting differential marten subnivean access point use.

Introduction

American martens (Martes americana) occur primarily in mature coniferous habitat (Bateman 1986; Raine 1983; Soutiere 1979; Steventon and Major 1982). However, other habitats may be used by season (Koehler and Hornocker 1977; Steventon and Major 1982; Wynne and Sherburne 1984). Soutiere (1979) and Steventon and Major (1982) reported that martens foraged for fruits and berries in non-forested areas in summer. While there is some seasonal variation in habitat use, all authors agree that older coniferous forests are essential to marten survival and reproductive success. Martens seldom cross open areas greater than 100 m wide especially during
winter (Soutiere 1979; Steventon and Major 1982). Winter appears to be the most critical period for
their survival (Buskirk 1984; Zielinski et al. 1983).

In winter, martens require subnivean access (Buskirk 1984; Buskirk et al. 1989; Pulliainen
1981), but the mechanisms that determine the use of some access points and not others are not well
understood. Three factors have been postulated: food availability, escape cover, and homeothermy.
There is a strong relationship between the use of access points and CWD (coarse woody debris).
Buskirk et al. (1989) found that 49% of martens resting sites and 63% of resting episodes were
associated with CWD. Corn and Raphael (1991) found that CWD levels were significantly higher
(p<0.05) at used access points than at randomly sampled points. CWD provides structure that
breaks the snow surface, providing access to the subnivean zone where martens may escape low
ambient temperatures, find prey or escape from predators. Buskirk et al. (1989) suggested that
martens used subnivean access points primarily to reach CWD that provides thermal insulation.
Martens in Wyoming (Buskirk et al. 1989) were found to use resting (access) sites associated with
CWD when ambient temperatures were coldest, suggesting that use of access points decreases the
metabolic demand for maintenance of body temperature. Buskirk et al. (1988) found that martens
realized a 4% savings of energy per day by using sites associated with CWD. Studies of martens
temporal activity patterns, however, have shown that martens are most active at night during the
winter (Lensink et al. 1955; Zielinski 1981; Zielinski et al. 1983) when temperatures are coldest.
This pattern is not energetically beneficial from a thermoregulatory standpoint and implies that other
mechanisms may contribute to access point use.

Many authors have documented that martens and other mustelids have metabolic rates that
are from 20% to >100% higher than those of other mammals with similar body size (Brown and
(1972) attributed the increased BMR of weasels to their long and thin shape, which combined with
relatively thin and poorly insulative fur (Casey and Casey 1979) sacrifices energetic efficiency.
Harlow (1991) suggested that martens require several separate meals each day. This concurs with the findings of Buskirk and Harlow (1989) that martens have extremely limited fat reserves that are completely metabolized in less than 92 hours. Martens must be extremely active predators to insure that energy intake is equal to or greater than the metabolic costs of being long and thin (Brown and Lasiewski 1972; Buskirk and Harlow 1989; Harlow 1991).

Martens tend to hunt on a daily basis and their activity patterns in winter tend to be nocturnal. Zielinski et al. (1983) showed that martens activity coincided with the activity of their principal prey, microtines. These aspects of their natural history suggest a relationship between the use of subnivean access points and prey densities.

Goals and Objectives

The goal of this study was to identify the variables that influence subnivean access by martens. My primary objective was to examine the relationship between the location of subnivean access and subnivean prey abundance. I also attempted to determine the role of CWD in the choice of snow tunnels. I hypothesized that marten access point use should be directly related to increased levels of CWD and high prey densities. The implication is that either prey alone or prey and CWD are causal factors or covariates to causal factors influencing access point use by martens. I analyzed these relationships by testing the following predictions.

P1: Differential utilization of access points is positively correlated with clumped subnivean prey. If there is no prey below an access point, then I expected martens would not use that access point. Further, mean prey abundance at used access points should be higher than the mean prey abundance at non-used access points.

P2: There will be a positive relationship between access point use and the % cover of CWD. I expected to find higher use at points with higher levels of CWD.
Study Area

I chose the Canyon-Norris region of Yellowstone National Park as the primary study area because it contained a variety of habitats suitable for martens and also provided a suitable road network for telemetry and accessibility to marten habitat by foot. The major cover type of the area was lodgepole pine with small to moderately sized spruce-fir inclusions. During the summer of 1988, varying degrees of fire intensity created a mosaic pattern of burned, partially burned and unburned cover types. Elevation ranged from approximately 2500 m to 3500 m. Temperatures ranged from approximately 5°C to -60°C in winter and 25°C to -5°C in summer. Normal snow accumulation during winter was about 2 m, making this study area ideal for investigating subnivean access point use.

Methods

Sampling scheme

Used and unused access points within marten home ranges were sampled and compared. The following variables were measured: cover type, overhead cover density, subnivean prey density, percent cover, dead and downed coarse woody debris (CWD), and snow depth.

Access point sampling

During the winters 1990 and 1991, I determined access point use by snow tracking martens. I trapped individual martens and fitted them with 40 g radio transmitters (frequency 151.0-152.9 MHz). I randomly relocated each marten and then skied into the area and back-tracked the animal until 10 used access points were located or the tracks lost.

Unused access point sampling

Unused plots were selected within the home ranges of collared martens. I used a stratified random sampling method to avoid sampling areas that did not accurately represent marten habitat.
(i.e., meadows within home ranges). Plots were marked and habitat variables measured. I measured percent ground cover CWD and habitat variables at the center of each plot.

**Small mammal sampling**

I conducted small mammal trapping during the summer field seasons at the sites where winter access points were documented, as well as at unused access sites. Although their home ranges are smaller during winter, microtines do not tend to relocate during the summer (Cranford 1984; Herman 1984; Madison 1984). I expected that population levels would vary during summer; however, I kept the bias constant across all sites by sampling prey at all points within a 3-week period. Snap traps were placed 5 m apart in a grid of 25 stations, centered on used and unused access points. These grids were trapped for 3 days and the number of small mammals captured was recorded. Prey were identified by species to allow calculations of prey biomass based upon average weights of individuals within a species.

**Analysis**

A Student's t-test was used to compare prey biomass and CWD between used and non-used access points. Multivariate analysis techniques were used to identify relations between the measured variables and access point utilization. Categorical interdependence methods, including $G^2$ analysis and logistic regression techniques, were used to determine if dependency relationships existed between access point use, prey density, and CWD. Prey biomass was transformed in an effort to make the distribution more normal using a square-root function prior to analysis. Because significance of results does not allow assessment of the strength of association between variables, odds ratios were calculated for prey biomass and CWD to describe the strength of the association and allow a direct interpretation of the influence of each variable upon access point use.
Results

Prey biomass and CWD were significantly greater for used access points when compared with unused access points. Mean prey biomass was 174.2 g/25 m² and 81.0 g/25 m² at used and unused points, respectively, (df = 142, t = 4.55, p < 0.0001), while mean percent ground cover of CWD was 24.7% and 18.5%, respectively, at used and unused access points (df = 102, t = 2.39, p = 0.0166).

Univariate logistic regression results showed that prey biomass was an excellent predictor of differential access point use (coef/se = 3.96, p = 0.0003). Univariate logistic regression also showed CWD to be an adequate predictor of differential access point use (coef/se = 2.32, p = 0.0226). A multivariate model was then created using access point use as the response variable and CWD and prey biomass as explanatory variables (Figure 1.1). The fit of the model was adequate (p = 0.216) with biomass showing excellent predictive power (coef/se = 3.74, p = 0.0003). CWD did not show significance at the α = 0.05 level in the multivariate model (coef/se = 1.81, p = 0.0718). Log odds ratios showed that martens were 1.37x more likely to use an access point with every 50 g increase in biomass and 1.12x more likely for every 5% increase in CWD.

Discussion

Martens use of subnivean access points was associated strongly with high prey biomass and to a lesser extent with increasing CWD (Table 1.1 and 1.2). Both CWD and prey biomass yielded acceptable univariate logistic regression models. Because both variables appeared to be important, I chose to perform a multivariate logistic regression to evaluate the combined effects of CWD and prey biomass. Statistical significance changed minimally for biomass and the significance of CWD was not as strong in the multivariate model.

CWD provided martens with access to the subnivean zone. Buskirk (1984) and Buskirk et al. (1989) have shown that CWD may provide thermal benefits resulting in energy savings of energy (Buskirk et al. 1989). Martens have a long and slender body shape and thin fur and it would be
reasonable to expect them to use CWD for a thermal advantage. In my study area, potential subnivean access points were abundant within marten home ranges. Martens tended to bypass a number of potentially available subnivean access points before using a seemingly similar point. My results suggest that while CWD provides access to the prey base by providing structures that intercept snow fall, thus creating passages, it is the presence of prey that dictates differential access point use by martens. I found no significant relationship between prey biomass and CWD levels.

Because of their high metabolic rate, martens must acquire a number of separate food items per day (Harlow 1991). Korhonen et al. (1983) found that mink required 20% more food than polecats, correlating greater motor activity and better hunting ability. While the elongate shape of mustelids increases their ability to obtain subnivean prey, it sacrifices energetic efficiency (Brown and Lasiewski 1972). Martens must have a mechanism for obtaining prey that at least compensates for their loss of energy to the environment. Because of their activity patterns and metabolic rate, martens should select points that provide them with the greatest probability of finding prey.

When the used and unused points were compared, prey biomass and CWD were the only variables that differed significantly. Prey biomass consistently showed a stronger relationship to access point use than CWD. As prey biomass at access points increased, the probability that martens would use that point increased by a factor of $1.37^n$ with every (n)50 g increase. A point with 150 g of prey biomass was 2.57x more likely to be used by martens than a point with no prey. At the same time, an access point would be used 1.40x more for a 15% increase in percent ground cover CWD. While both of these log odds probabilities are positive, biomass has a stronger effect upon use of a point by martens.

Martens appeared to be able to discriminate between access points with high prey levels and those that were not. Martens chose to use those access points with high prey biomass significantly more often.
Literature Cited


TABLE 1.1 Observed (and expected) use by martens of access points: Relation to the amount of CWD present at each access point

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<td>low</td>
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<td>22 (23.3)</td>
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<td>TOTAL</td>
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TABLE 1.2  Observed (and expected) use by martens of access points: Relation to the amount of prey biomass at each access point

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<tr>
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<td>66</td>
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Fig. 1.1. Predicted probability of access point use. Logistic curve with associated 95% confidence intervals. Area of circles is proportional to levels of CWD.
CHAPTER 11

RELATIONSHIP OF SUBNIVEAN ACCESS POINT USE BY MARTEN TO RED SQUIRREL MIDDENS

ABSTRACT. -- Martens require access to the subnivean zone during winter in order to obtain prey. In Yellowstone National Park, I noted that a number of subnivean access holes were associated with red squirrel middens. In this paper I address the question: Does the presence of red squirrel middens influence subnivean access point use by marten.

Thirty-three percent of all used access points were associated with middens as compared to 16% for unused access points (Kendall's tau $t = -0.2293, p = 0.015$). Small mammal biomass (without squirrels) was significantly related to used access when tested with a separate variance estimate $t$-test ($t = -3.0697, df = 88, p = 0.0022$). When red squirrels were included, i.e. when a midden was present at the access point, the relationship was strengthened ($t = -3.9723, df = 88, p = 0.0001$). Scat analyses ($n = 69$) identified red-backed voles ($Clethrionomys gapperi$) 35.5%, red squirrel 21.1%, lagomorphs 16.6%, and unknown sciurids 9.0% as the major prey species consumed by marten. There was no difference in coarse woody debris (CWD) levels regardless of whether squirrel middens were present or absent ($t = 0.1363, df = 88, p < 0.8921$). Likewise small mammal biomass (minus squirrels) did not differ whether or not middens were present or absent ($t = 0.9771, df = 88, p < 0.3311$). Access use was not related to percentage CWD when tested using a separate variance estimate $t$-test ($t = -1.5959, df = 88, p < 0.1126$).

Throughout North America, martens ($Martes americana$) consume mostly small mammals and require access to the subnivean zone during winter to obtain prey. Their use of subnivean access points has been well documented (Buskirk 1984; Buskirk et al. 1989; Koehler and Hornocker 1977). The presence of CWD on the forest floor provides subnivean structure and creates access through snow layers. Several explanations have been proposed for access point use, including
homeothermic benefits (Buskirk et al. 1989) and facilitated prey searching (Bateman 1986; Campbell 1979; Hawley 1955; Weckworth 1955).

Buskirk (1984) and Martin (1987) reported a large number of subnivean resting sites were associated with squirrel middens and suggested that middens may have homeothermic importance. In recent work in Yellowstone National Park, I noted that a number of used and unused access points were associated with red squirrel (*Tamiasciurus hudsonicus*) middens. I also found red squirrel and other sciurids in a large proportion of marten scats. In this paper I compare access point use with 1) the presence or absence of middens; 2) the percent ground cover of CWD; and 3) the associated prey base to determine if the presence of red squirrel middens influence marten use of specific subnivean locations.

METHODS AND STUDY AREA

The study area was located in the Canyon region of Yellowstone National Park, Wyoming. The area was comprised primarily of various age class lodgepole pine stands (*Pinus contorta*) with some old growth areas of both lodgepole and spruce-fir forest (*Picea engelmannii, Pseudotsuga menziesii*). Data were collected during the winter and summer of 1990.

Access point use was determined by snow tracking martens during the winter field season. I measured relative prey abundance at all points by snap trapping during the summer. Number and species of small mammals captured were recorded and relative abundance and biomass estimates determined for all points. I did not trap red squirrels; rather I conservatively considered one squirrel to be present at each midden. All middens showed evidence of recent use and were defined as a deposit of fresh seed bracts with at least one associated subterranean hole. A midden was recorded as present if it was within 5 m of the access point. CWD was measured as percent cover during the summer. Scat contents were identified using guard hair scale and medulla patterns (Moore et al. 1974). Results were recorded by frequency of occurrence and proportion of diet.
Variables used for comparison were access class (used, non-used), prey biomass (with and without red squirrel), percent cover of CWD, and squirrel midden presence or absence. Prey biomass values were transformed using a square root function.

RESULTS

Thirty-three percent of used access points had red squirrel middens within 5 m, while 16% of unused access points had red squirrel middens within 5 m of the point. The Kendall’s tau measure of association was $\tau = -0.2293, p = 0.0151$. I found no significant difference between percent cover of CWD at access points with or without middens, $t = 0.1363, df = 88, p < 0.8921$; nor was percent cover of CWD associated with access point use (Fig. 2.1). A t-test with separate variance gave $t = -1.5959, df = 67, p < 0.1126$, suggesting that something besides the structure of a midden or the % cover of CWD at an access point was important to access point use.

I examined whether small mammal biomass (minus squirrels) differed between access points with and without middens. Prey biomass was the same at access holes with or without middens, $t = 0.9771, df = 88, p < 0.3311$ (Fig. 2.2). However, I found a significant positive relationship between use of an access point and prey biomass (square root) ($t = -3.0679, df = 88, p = 0.0022$) (Fig. 2.2). I found that when red squirrels were present, martens showed a higher frequency of access point use, $t = -3.9733, df = 88, p = 0.0001$ (Fig. 2.3).

Scat analyses showed that red squirrel comprised 21.1% of the total volume of 69 scats. Unidentified sciurids comprised an additional 9.0%, further suggesting the importance of prey in influencing access point use (Fig. 2.4).
DISCUSSION

The significant relationship between access point use and middens suggests that middens are important to marten. Buskirk et al. (1989) showed a strong relationship between middens and marten resting sites. I examined whether features associated with middens may have accounted for the observed difference at used and unused access points. No relationship existed between CWD or prey biomass without red squirrel added and the presence of middens. In a previous paper (Chapter I) I showed relative prey abundance to be the key difference influencing use of access points. The increase in access point use when red squirrels were added suggested that the presence of a red squirrel positively influenced access point use by marten.

Martens may utilize larger prey items during winter (Clem 1975; Lensink et al. 1955; Soutiere 1979; Zielinski et al. 1983) and it is probable that this is due to the increased energetic benefit of a large prey package. Threader et al. (1991) suggested that it is energetically advantageous for female martens to obtain large prey items. Red squirrel averaged 195 g while red-backed voles averaged 20 g (Streubel 1989). Thus a red squirrel yields almost 10x as much biomass as a red-backed vole and is a very favorable prey item from an energetic standpoint. My data show that the only characteristic of a midden that influenced marten use of that point was the red squirrel itself. There was no relationship between prey biomass and middens ($p=0.3311$) or percent cover CWD and middens ($p=0.8921$). The strong relationship between prey and access point use adds credence to this suggestion. When the prey biomass at access points with middens included a red squirrel, the relationship between prey and access use became stronger ($p=0.0001$). It has been shown that middens provide a thermal benefit for martens (Buskirk 1984; Buskirk et al. 1989) and that red squirrel are a prey item (Buskirk and MacDonald 1984; Martin 1991; Weckworth and Hawley 1962; Zielinski et al. 1983). My results suggest that prey availability is also an important factor. Red squirrels are an important prey item and the presence of a midden significantly influences use of subnivean access points by martens.
LITERATURE CITED


Fig. 2.1--Relationship between coarse woody debris, middens and access points.

Fig. 2.2--Relationship between prey biomass, middens, and access points.
Fig. 2.3--Relationship between prey biomass (including red squirrel) to use of access points.

Fig. 2.4--Marten scat contents % volume.
CHAPTER III
SEED BOLUS USE AS AN INDICATOR OF
SUBNIVEAN SMALL MAMMAL ABUNDANCE

ABSTRACT. -- Determining small mammal abundance under snow poses formidable problems. Yet, knowledge of the food base for subnivean foraging carnivores can provide insights into important ecological relationships. During a study of marten use of subnivean access points, I attempted to measure the relative abundance of small mammal prey using measures of association between small mammal use of seed boluses and their relative abundance in late spring/early summer. I found a significant relationship between bolus use and prey biomass ($x^2 = 12.739, p = 0.0126$). The method accounts for 43% of the variance between bolus use and prey biomass; however, further experimentation is required to enhance the usefulness of this technique. This method appears to be a valuable tool for estimating subnivean prey levels in a non-destructive manner.

I studied subnivean access point use by martens in Yellowstone National Park, Wyoming during the winters of 1990 and 1991. To obtain small mammal estimates in winter, I set out seed boluses to estimate winter prey abundance and compared that estimate (bolus use) with population estimates determined by summer snap trapping grids. All of the methods of subnivean sampling described by Schmid (1984) required excavation of the trap site or placement of traps prior to snowfall. I was interested in determining prey numbers at subnivean points used by martens, and these methods were either too destructive to the foraging area of the marten (the pattern of subnivean passages would be disrupted by excavation) or inappropriate (access use is determined during the winter by snow tracking and thereby cannot be determined prior to snowfall). Dispersal of small mammals occurs primarily in the fall and spring (Myers and Krebs 1971; Sullivan 1977; Tamarin 1977; Van Vleck 1968). Home ranges of small mammals (microtines) tend to decrease in size in winter; however, their locations normally do not shift until after the snow melt (Cranford
1984; Herman 1984; Madison 1984). Many of the prey species utilized by martens in Yellowstone National Park tend to colonize during winter (Madison 1984; West and Dublin 1984). This study examines relative prey abundances in winter compared with post snow melt snap-trapping prey estimates.

**METHODS**

Paraffin wax was melted in a saucepan and mixed with commercial birdseed. The mixture was poured into muffin tins. During cooling, lengths of nylon cord were inserted to facilitate placement of boluses at subnivean access points. Boluses were weighed, placed into subnivean access holes, and left for three nights. Weight loss caused by chewing was measured to the nearest gram and the difference in weight recorded as bolus use.

Snap traps were used to determine relative prey abundance at subnivean access points in the summer. A 25-trap grid was centered around the access point. Traps were placed 5 m apart in a 5x5 grid and the site trapped for three nights. The number of small mammals trapped was recorded as an index of relative prey abundance.

**RESULTS**

Prey biomass was compared with bolus use in a categorical format to determine if a correlation existed between levels of bolus use and levels of prey biomass (Table 3.1). I found a significant relationship between bolus use and prey biomass ($x^2 = 12.739, p = 0.0126, \phi^2 = 0.435$). The $\phi^2$ statistic represents the relative strength of association between bolus use and prey biomass and is identical to the square of the Pearson correlation coefficient ($r^2$) (Agresti 1984). Boluses were used more heavily as prey biomass increased. My method explained 43% of the variance in the model ($\phi^2=0.435$) and showed that prey estimates obtained during spring and summer trapping appear to be indicative of prey abundance at these points during winter.
DISCUSSION

The use of seed boluses to assess relative prey abundance in winter allows qualitative estimation of prey bases over large areas without major disturbances to the sites being examined. In areas where snow depths typically range greater than 1 m, my method allows indirect sampling of prey with minimal effort and expense, and most importantly, with minimal physical impact upon the data collection point.

Caution is advised in interpreting results from indirect sampling methods. The method is not without shortcomings, as much of the variation between bolus use and prey biomass was not explained by my model. For example, the use of the boluses by non-target species such as snowshoe hare, marmot, or avian species may bias interpretation of bolus use. I noted use by all three, which resulted in an unevenly biased comparison with summer estimates. When these signs were evident, the bolus was not used in calculations. When use of the bolus by non-target species is possible, some assessment of uneven bias should be made. It may be necessary to use additional boluses.

Natural mortality and dispersal patterns of species must also be addressed as these factors may account for variation between bolus use and prey abundance. For example, as martens continue to use an access point, prey numbers would be expected to decline and early bolus use may not be representative of the decreased prey numbers trapped after snow melt. Group nesting in winter has been recorded (Madison 1984) and some winter dispersal does occur (Myers and Krebs 1971). However, home ranges do not tend to shift (Cranford 1984; Herman 1984).

I suggest the following ways to increase the method’s accuracy. Boluses could be placed at individual access points at different time intervals and with early and late values documented. Late use could be compared with summer trapping estimates, and then early values used to estimate maximum prey numbers to correct for the effects of prey loss by mortality and dispersion. This approach may also help correct for the effect of larger prey utilizing boluses and biasing use values.
Alternatively, my method could be tested in conjunction with methods described by Schmid (1984). This would allow a direct comparison of bolus use to subnivean prey estimates.

Small mammal trapping in the spring or summer should be conducted immediately after snow melt to minimize the effects of dispersal and reproduction. Grids need to be scaled to ensure that the trapped grid covers the subnivean area delineated by the coarse woody debris at the site. The presence of larger species that are not sampled by snap trapping must be noted and when possible the effects of these species on seed bolus use should be recorded and bolus use adjusted accordingly.

My method does not explain all of the variation found between summer and winter prey abundance measures. It does provide an alternative to time- and labor-intensive subnivean trapping methods.

**LITERATURE CITED**


Table 3.1 -- Comparison of observed (and expected) bolus use levels with summer prey biomass estimates at subnivean access points.

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</tr>
<tr>
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<td>4 (4.9)</td>
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<tr>
<td>TOTALS</td>
<td>28</td>
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1. Introduction

Radio telemetry data commonly have been used to locate free-ranging wildlife species in order to determine habitat use patterns and delineate home ranges (see Cochran 1980). Locating an animal in the field consists of transporting a mobile telemetry receiver to different field locations and recording the compass azimuth of the strongest transmitter signal. Commonly three bearings are plotted and their intersection considered the location of the animal. Usually exact intersection of the azimuths is not achieved because of error. The imputed point location lies somewhere within a triangular polygon (Fig. 1). The assumption is that the geometric center of the triangle is the best estimate of animal location. Commonly, the location is recorded as a point in space, with calculated error polygons. Biologists usually treat location data as a set of points with an understood error. Nams and Boutin (1991) have pointed to problems with this technique when more than two bearings are used in relocations where precision is paramount.

Error in telemetry triangulation can come from a number of sources including: a) movement of the animal as the technician travels to each receiving location, b) distance from receiver to transmitter, c) unspecified equipment malfunction, d) weak transmitter signal, e) type of antenna used, and f) human errors. In my experience, errors of types a and b are the most difficult to control; errors c-f are more easily addressed. For some time telemetry software programs have been available for microcomputers (Dodge and Steiner 1986; Juneja et al. 1991; Stuwe and Blohowiak 1985; White and Garrott 1984). However, with the increasing sophistication of GIS technology and methodology, it is now possible and practical to enter telemetry field data (i.e., bearings and receiving location coordinates) directly into a GIS database. The benefits for examining spatial use patterns by wildlife include the following: a) other layers of information, including vegetation type, soil types, legal descriptions, etc., can be entered and analyzed with the
original spatial information, and b) for those telemetry studies that propose to infer habitat affinities, GIS offers the advantage of working with the location polygon, i.e., the area within the polygon, rather than the imputed point location that traditional analyses use. Hence, the problems detailed by Nams and Boutin (1991) can be avoided. This method allows an immediate assessment of habitat use patterns. Furthermore, telemetry data can be combined directly with digital satellite information, which can be used to identify habitat types, reducing vegetation sampling effort. With the recent emphasis on landscape level studies (Bissonette et al. 1989; Forman and Godron 1986; Turner and Gardner 1991), this would seem to be a significant advantage. I am unaware of any currently available software that allows direct entry of telemetry data into a GIS data base.

This paper proposes a method for plotting field bearings and locations directly on a computer-compatible habitat map. I show how to use a GIS data base to identify differential habitat use directly from the triangle polygon formed by each set of bearings. A geometric algorithm is developed to interpret the bearing accurately. The resulting locations are not point locations of individual animals at a particular time, but rather the area occupied during the time period the three bearings were taken. Location polygons are combined into one digital layer with the animal ID, date, and time of bearing recorded as attributes. They then can be examined at multiple spatial or chorological scales (Zonneveld 1990). The technique avoids the most difficult errors associated with using point locations, namely those due to animal movement, and distance from receiver to transmitter. The movement of the telemetered animal is included within the polygon, and the errors associated with distance are much less important biologically because polygons are used to characterize general location, and not imputed point locations.
2. Methods

2.1 Data sets

Radio telemetry data were collected on martens (*Martes americana*) from January-March, and June-August 1990 in the Canyon region of Yellowstone National Park, WY. Martens were fitted with telemetry transmitters (Telonics Mod-075) and relocated daily. Relocations were determined within a maximum time period of one hour by triangulation (three bearings) with a minimum of 30 and a maximum of 150 degrees between any two paired bearings. Each set of three bearings was assigned a unique identification number comprised of the date and animal ID to create a relocation polygon record representing a single animal location (Table 4.1). Relocation bearings were taken from 80 known receiving stations in the study area. The receiving stations were a standardized set of geographic locations from which bearings were recorded during each field trip. These locations were cross referenced to the relocation data base by using the receiving station number. Mean telemetry error was determined using transmitters placed at known locations and calculated to be $\pm 9$ degrees (95% C.I.). The UTM (Universal Transverse Mercator) easting and northing coordinates of each uniquely numbered receiving station were recorded and stored in a data file (Table 4.2). Each location record was paired with the corresponding receiving station numbers, telemetry bearings, time of day, and date (Table 4.1). Relocation polygons varied in size, depending upon distance between transmitter and receiver and accuracy of bearing. Approximately 120 relocations were plotted.

2.2 Methodology

Triangular relocation polygons are formed using simple geometry to calculate the intersections of three bearings taken from known receiving locations. The algorithm follows a simple three-step process to 1) read a set of bearings for each relocation, 2) relate each bearing to the geographic location coordinates (X,Y) of its corresponding receiving site, and 3) calculate the
intersection point of each mutually exclusive pair of bearings. To determine intersection points, slope and intercept values are calculated for each receiving location and bearing. Slope is equivalent to the cosine of the bearing divided by sine of the bearing. Finding the intercept requires the calculation of slope. Because the receiving locations are recorded as UTM's, the calculations for slope and intercept use the UTM coordinates of $X=0$, $Y=0$ as the origin for the functions.

\[
S = \frac{\cos(\theta)}{\sin(\theta)}
\]

\[
I = (-1 \times (X \times S)) + Y
\]

Where:
- $S$ = Slope
- $I$ = Intercept
- $\theta$ = Bearing
- $X$ = Easting coordinate
- $Y$ = Northing coordinate

After the slope and intercept are calculated for each bearing, an intersection point for each mutually exclusive pair of bearings within one relocation is calculated. With three bearings ($\theta$) for each relocation set, there are three combinations ($\theta_1$ and $\theta_3$, $\theta_2$ and $\theta_3$, and $\theta_1$ and $\theta_2$). The calculations of the X and Y coordinates for the intersection points of each pair of bearings are shown below. For generality, each pair of bearings is identified by $j$ and $k$ subscripts. This calculation is carried out for each mutually exclusive pair of bearings.

\[
X' = \frac{(I_j - I_k)}{(S_k - S_j)}
\]

\[
Y' = \frac{((S_j \times I_k) - (S_k \times I_j))}{(S_j - S_k)}
\]

Where:
- $X'$ = Easting intersection of the $j,k$ pair of bearings
- $Y'$ = Northing intersection of the $j,k$ pair of bearings
- $I_j$ = Intercept for the $j$ bearing
- $I_k$ = Intercept for the $k$ bearing
Each bearing pair has its own X' and Y' intersection; three intersections form the three-sided polygon representing the estimated animal location. Each polygon is attributed with the relocation ID (Table 4.1).

2.3 Error Polygons

Telemetry relocation involves error. Therefore, it is highly probable that animals were actually located in an area larger than that circumscribed by the polygon represented by the "true" bearing. Error polygons are used to represent the area in which the animal was located with a 95% confidence value.

Calculation of an error polygon around the relocation polygon is achieved by adding and subtracting the telemetry error from the original bearing. The error determined in my study was +/- 9 degrees. Fig. (4.1) shows the true bearing tried for one relocation and the associated error bearings. From this diagram, it is obvious that only "one side" of a pair error per true bearing is used to determine the boundary of the error polygon. Choosing the correct error bearing is essential. If the wrong error bearing is chosen, there is a possibility that the relocation polygon can be bisected by the error polygon. I chose the correct error bearing as follows. The coordinates of the center of the relocation polygon were calculated by averaging the three coordinate pairs defining the polygon.

\[
X_{cen} = \frac{\sum_i^3 X_i}{3} \\
Y_{cen} = \frac{\sum_i^3 Y_i}{3}
\]

Where:

- \(X_{cen}\) = Easting coordinate of relocation polygon centroid
- \(Y_{cen}\) = Northing coordinate of relocation polygon centroid
- \(X_i\) = Easting coordinate of the ith polygon corner
- \(Y_i\) = Northing coordinate of the ith polygon corner

\(S_j\) = Slope for the j bearing
\(S_k\) = Slope for the k bearing
\[ y_i = \text{Northing coordinate of the } i^{th} \text{ polygon corner} \]

The bearings between the three original relocation points and the polygon centroid was calculated using the following formula:

\[ \theta_i' = \arctan \left( \frac{X_{cen} - X_i}{Y_{cen} - Y_i} \right) \]

Where:

\[ \theta_i' = \text{bearing between the } i^{th} \text{ relocation site and the polygon centroid.} \]

Since the arctangent ranges between 0 and 90, there is a possibility that this function can result in a negative number if the polygon centroid falls in the second or fourth quadrant of the cartesian coordinate grid. If the bearing is less than 0, 360 degrees must be added to it to calculate the true bearing between 0 and 360. The decision rule is that the correct error bearing is the one with the greatest difference between it and the polygon centroid bearing calculated above.

\[ \theta_{error} = \max \left[ |\theta_i' - (\theta_{+9} \text{ or } \theta_{-9})| \right] \]

Where:

\[ \theta_{error} = \theta_{+9} \text{ or } \theta_{-9} = \text{The correct error bearing to form the error polygon} \]

The original relocation bearing for each of the three relocation sites +/- 9 degrees.

3. Applications

Previous alternatives for incorporating telemetry data with GIS systems involved digitizing telemetry bearings or entering the location coordinates as determined by any number of methods or available software programs, i.e., MCPAAAL (Stuwe and Blohowiak 1985), and HOMERANGE (Samuel et al. 1985). Satellite telemetry allows the entry of locations into remote sensing data bases (Fancy et al. 1988), at considerable expense. In translating an imputed point to GIS, the information is digitized as a pixel, thus attributing area to a location. One advantage of my method is that the
error in telemetry defines the minimum resolution for analysis with GIS layers. My approach allows the formation of location and error polygons within a GIS environment. The entry of raw telemetry data into a GIS system reduces the time and error inherent with other methods using additional steps. Overlay procedures can be carried out immediately following polygon formation to determine habitat characteristics. It is possible to use an electronic data recorder in the field and download directly to a microcomputer, thereby increasing speed and accuracy over traditional keyboard data entry methods. My method allows immediate interpretation and analysis of land use patterns by telemetered animals. Patterns of use that can be analyzed are limited only by the scale and number of GIS layers available in the data base. Most state and federal lands either have or are building GIS data bases, making this method useful and attractive to natural resource managers.

4. References


Table 4.1. Relocation data base

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Fig. 4.1. Bearings, location polygon, and error polygon for 1 animal location. $X_iY_i$ represents the location of the observer taking the bearing (solid lines). The dotted lines represent the $\pm 9^\circ$ error associated with each bearing.