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MT. GRAHAM RED SQUIRREL MONITORING PROGRAM

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INTRODUCTION

This report is a compilation, analysis, and interpretation of data collected during 1991 by the University of Arizona Mt. Graham Red Squirrel Monitoring Program. Some of the data collected during 1989 and 1990 is also presented and analyzed to place the 1991 data in perspective. The Monitoring Program is required by the Mt. Graham International Observatory (MGIO) Management Plan to monitor the Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) populations near the proposed telescopes and access road to determine whether or not the construction and operation of the telescopes has any effect on the red squirrel. The report is divided into three sections dealing with the major aspects of research being conducted by the Monitoring Program: Population Biology, Behavior, and Microenvironment of New Forest Edges. The microenvironment study is not complete and a full analysis is not included in this report; only a preliminary description of that data is presented. All of the data collected by the Monitoring Program is available for scrutiny; no part of this report may be used or reproduced in any form without permission.

Description of the Monitored Areas

The MGIO telescope complex is being constructed near Emerald Peak in the Graham Mountains of southeast Arizona. The area surrounding the telescope sites and access road to a distance of 300 m is referred to in this document as the construction area. For the purpose of comparison, the Monitoring Program also monitors the population biology and behavior of red squirrels on two other areas of the Graham Mountains. These areas are referred to as the non-construction areas.

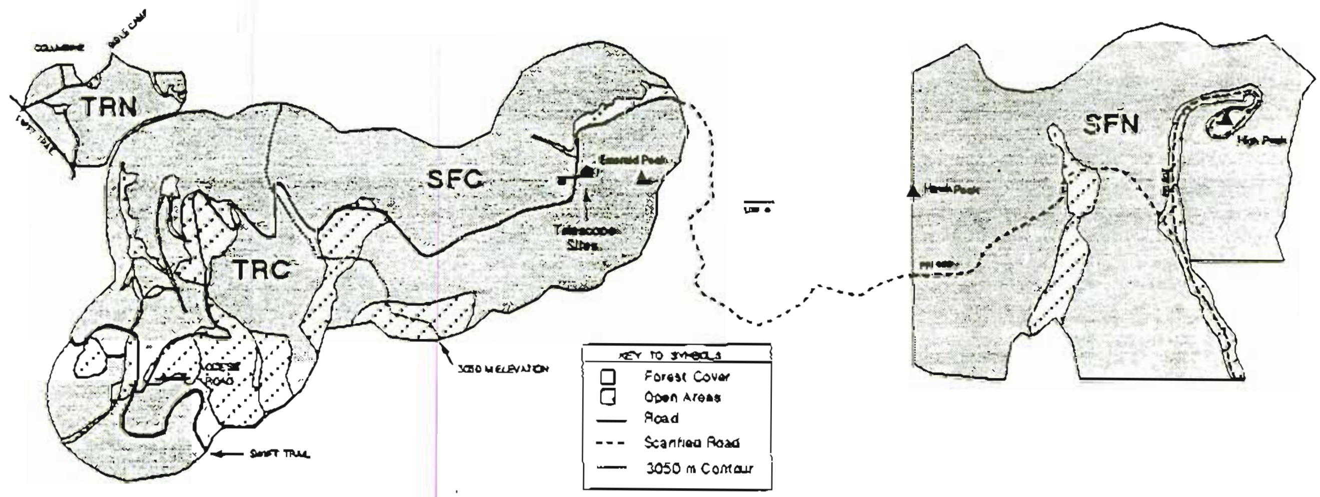
The border of the construction area was defined in the MGIO Management Plan as a line 300 m from the proposed telescope sites and the access road. This boundary encompasses a total area of approximately 180 hectares (ha) from the top of Emerald Peak westward and southward to the junction of the new access road and State Highway 366. The construction area is divided into two areas of almost equal size. The 3050 m elevation contour is used to delineate the two areas and approximates the boundary of two coniferous forest habitat types found on the Graham Mountains: transitional coniferous habitat (TR) and spruce/fir habitat (SF). These habitat labels are used to designate different portions of the construction and non-construction areas. The transition habitat construction area (TRC) consists of all of the western portion of the construction area below 3050 m elevation (approximately 91 ha). The forest cover on the TRC area varies in species composition and dominance. The primary tree species in this area are: Douglas fir (*Pseudotsuga menziesii*), corkbark fir (*Abies lasiocarpa* var. *arizonica*), Engelmann spruce, (*Picea engelmannii*), ponderosa pine (*Pinus ponderosa*), white pine, (*Pinus strobiformis*), and aspen (*Populus tremuloides*). The TRC area encompasses a large area (approximately 48 ha) of natural and manmade meadows, which are unsuitable for red squirrel habitat. The spruce/fir habitat construction area (SFC) is the eastern portion of the construction area above 3050 m elevation (approximately 89 ha); forest cover on this area is primarily SF forest, dominated by Engelmann spruce and corkbark fir.

An area approximately 0.75 kilometers east of the east boundary of the construction area, on the east side of Hawk Peak and including most of Mt. Graham, was originally chosen as the non-construction area. The west boundary of this area was defined as a line running north and south from the top of Hawk Peak down to an elevation of 3050 m on the south and to the hiking trail on the north. The north boundary follows a hiking trail eastward to a point below Mt. Graham, then crosses over the ridge on the NE corner of that peak and continues down the east side of the area along the 3050 m contour. The south boundary also follows the 3050 m elevation contour to a point approximately 1 km below Mt. Graham then crosses over old FR 507 to connect to the east boundary (Figure 1). This area of approximately 122 ha is now referred to as the Spruce/Fir Habitat non-construction area (SFN). The forest cover on the SFN area is primarily spruce-fir.

In September 1989, a small area of TR habitat (approximately 22 ha), north and west of the TRC area, was added to compare the behavior of squirrels in similar habitat to those on the TRC area (Young 1991). This area, referred to as the Transition Habitat non-construction area (TRN), is adjacent to northwest boundary of the TRC area and is bordered on the west by Swift Trail (SH366). The borders of the TRN area were not as arbitrary as were those for the TRC, SFC, and SFN areas, but were determined primarily by drawing a line at a radius of approximately 100 m around the known midden sites. The size of this area was increased to 25 ha in 1990 to include 3 new middens north of the Bible Camp Road (Figure 1).

The four monitored areas differ in size, species composition, and the amount of forest cover on each area. Approximately 50 percent of the TRC area has a forest overstory while all other areas have 85 to 90 percent forest overstory. The quality of the habitat for red squirrels also varies considerably (Coronado National Forest 1988).

Figure 1. Diagrammatic map of the areas on the Graham Mtns. monitored by the University of Arizona - Red Squirrel Monitoring Program.



POPULATION BIOLOGY

Introduction

Population biology is the most important and relevant data collected by the Monitoring Program because any effect construction or operation of MGIO has on the behavior of the red squirrel, or red squirrel habitat, will eventually be expressed through changes in population parameters.

Population parameters are relatively easy to measure, to quantify, and are less subject to interpretive differences than behavior observations. Therefore, population parameters provide a sound basis to assess the impact of MGIO construction activities and operation on the survival of the Mt. Graham red squirrel.

Because the monitored areas vary in geographic size and habitat quality, the number of middens and squirrels also vary. The total number of squirrels on each area, therefore, is not a reasonable comparison among populations. Differences in the measured population parameters must be independent of the size and quality of the areas to make valid comparisons concerning the population biology of squirrels on each area.

Food resources, also, are an important component to determine the quality of the monitored areas as squirrel habitat. Currently we have no quantitative assessment of the food resources (primarily cone crops) available to the squirrels on each of the monitored areas. By comparing changes in populations without considering potential differences in food resources, we rely on the assumption that the monitored areas within each habitat are similar in their production of food. While this is generally a reasonable assumption, it does not allow us to distinguish between changes in population parameters caused by differences in food resources and changes caused by the construction and operation of MGIO. Therefore, some effects of the construction of MGIO may be confused with environmental effects on the squirrel populations.

The objective of monitoring population biology is to detect effects of construction activities on red squirrel numbers, distribution, and reproductive success. Four measures of relative abundance or distribution of the red squirrel populations were used to determine potential effects of construction activity on the changes in squirrel populations: 1 - Midden occupancy, 2 - Turnover of middens, 3 - Distribution of middens and squirrels, and 4 - Reproductive activity and success. The data on midden occupancy and distribution of middens and red squirrels is very reliable because it is based on complete counts of the populations of each monitored area, not estimated from samples. The data on turnover of middens and reproductive activity and success is limited because we do not have adequate identification of individual animals nor are we able to track individual squirrels. These data could be improved by trapping and uniquely marking individuals, which was resumed in late 1991, and by using telemetry techniques to track individual animals.

Methods

Red squirrels gather and cache conifer cones in a selected location that is referred to as a midden, which is easily recognized by the accumulation of cones and cone scales (C.C. Smith 1968; Vahle 1978). Middens are an excellent indicator of red squirrel distribution and may provide a reasonably accurate estimate of population size because red squirrels are territorial and generally solitary (C.C. Smith 1968; Vahle 1978). Some red squirrels may also use one or two secondary middens that are smaller and are used in conjunction with the primary midden, which they also defend. All middens in the monitored areas are classified as either occupied or unoccupied, and an occupied midden also represents the presence of a red squirrel. The primary midden and associated secondary middens are considered as a single midden for the purpose of monitoring red squirrel demographics and populations.

Approximately half of the red squirrel middens were located and classified by U.S.D.A. Forest Service, Arizona Game and Fish Department, or University of Arizona personnel during surveys conducted prior to the initiation of the Monitoring Program in August 1989. The remaining middens on the monitored areas were located by personnel on the Monitoring Program. All the monitored areas are surveyed twice a year (spring and autumn) to locate newly established middens. In addition, new middens are located as they are discovered during other monitoring activities. All known midden sites are marked with numbered metal tags and black and orange striped flagging tape.

The location of all known middens were plotted as accurately as possible on enlargements of USGS 7.5 minute quadrangle topographic maps. To improve accuracy, all of the middens on the TRC and TRN areas and some on the SFC area were mapped by measuring distances between middens and landmarks using a 50 m tape and compass. The location of each midden, roads, and other physical features were defined as coordinates on a Cartesian grid superimposed over the enlarged maps. These coordinates were used to reproduce maps of the monitored areas (Appendix A) and to compute local density and nearest neighbor distances. The accuracy of the midden maps is estimated at better than ±10 m, based on the difference between the calculated nearest neighbor distance and the actual measured distances. However, during the 1992 field season a Global Positioning System will be used to improve the accuracy of midden locations to ±2 m.

Midden Occupancy

Most of the data on the number and distribution of the occupied middens were collected during the regular monthly census of each area. A census consisted of visiting each known midden site to assess red squirrel activity and to determine whether or not the midden was occupied. "Occupied" middens are used to represent squirrels for the purpose describing the red squirrel population. If a midden appeared to be occupied, an attempt was made to visually verify the presence of a red squirrel and to determine its gender, age, and reproductive condition. During winter months, visual verification often was not practical, and determinations were made primarily on the basis of the presence and age of feeding signs, tracks, and other signs of red squirrel activity. Consequently, the winter censuses are not as accurate as censuses taken during the rest of the year. However, better census data could be obtained by using telemetry and radio collared squirrels, but, only if all squirrels on the monitored areas are individually marked.

For the purpose of determining red squirrel population size and spatial distribution, a midden was considered to be unoccupied when no red squirrel was present or when the occupancy was in doubt ("N" and "P" notations in Appendix C). Therefore, the population sizes are conservative and represent the "minimum number known alive" (Krebs 1989). That means: there may have been more squirrels on the monitored areas than reported, but not fewer. Midden sites with resident female red squirrels were visited at least twice during each 10-day field session in 1991 to collect data on lactation, litter emergence, and litter size.

Changes in spring and autumn squirrel populations were analyzed for year-to-year differences when squirrel populations were at their respective lowest and highest number for the year. G-tests for Model I (no marginal totals fixed) and Model II (one marginal total fixed) RXC contingency tables were used to test differences in the number of middens occupied relative to the total number of middens on each area; sampled randomization

G-tests were used where the expected frequency for one or more cells was less than five (Sokal and Rohlf 1981).

The overwinter survival of squirrels was estimated by comparing the proportion of the middens occupied in November with the proportion of those same middens occupied the following spring when midden occupancy was low. Consequently squirrels that moved from an occupied midden to one that was classified as unoccupied in November were excluded, as well as squirrels that moved into the area during winter, which probably underestimates over-winter survival. With the resumption of trapping and marking in late 1991, the disappearance of marked squirrels can be used to measure mortality and midden turnover.

Midden occupancy was also examined for differences in the likelihood of a midden being occupied as a function of distance from construction. For this, occupancy of middens was compared in 3, 100 m wide zones (0-100 m, 100-200 m, and 200-300 m) extending away from the access road and telescope sites on the construction areas. For comparative purposes the occupancy of middens within similar zones from Forest Roads 507 and 669 on the SFC area were also examined. Differences in the proportion of middens occupied within each zone were tested against the proportion occupied in other zones for the month of November, and for year-to-year changes (Nov. 1990 - Nov. 1991) using RXC contingency tables and G-tests or sampled randomization G-tests.

Turnover of resident squirrels was estimated annually. A turnover at a midden was considered to take place when the resident squirrel was replaced by another squirrel. However, because of restrictions imposed by the U.S. Fish and Wildlife Service following a 1989 trapping related mortality, no red squirrels were trapped and marked animals until autumn of 1991. Consequently, it was necessary to identify individual squirrels by gender and age to determine when a resident squirrel was replaced. Therefore, turnover rate may be underestimated when the resident squirrel was replaced by another squirrel of the same gender and age. The proportion of middens where turnovers occurred were tested for differences between areas by the use of RXC contingency tables and G-tests or sampled randomization G-tests.

Distribution of Middens and Squirrels

To adequately describe the spatial distribution of all middens and occupied middens (red squirrels) three different methods were used: crude density, local density, and distance to nearest neighbor.

Crude density represents the total number of middens or squirrels per unit area. No allowance was made for differences in habitat quality among the monitored areas, and statistical tests are not appropriate. However the crude density of middens and squirrels was plotted to provide a visual representation of the actual versus potential midden occupancy.

Local density is method that describes a population density on a very limited, or local, basis and allows different populations to be compared when there are uncontrolled habitat variables. Local density represents the number of neighbors for each midden and was determined by counting the number of occupied and unoccupied middens within 100 m of the focal, or center, midden. Because our local density method is based on the location of midden sites, which are sessile, it is similar in concept to "distance models" of neighborhood modelling used by plant ecologists to describe and compare plant populations (Czárán and Bartha 1992). A circle with a radius of 100 m encloses 3.14 hectares, which is slightly less than the average home range of Mt. Graham red squirrels (Froehlich 1990). It is also approximately the maximum distance that a human can recognize and accurately locate a red squirrel "chatter" call (pers. obs.). The local density of squirrels may exceed the midden local density.

The local densities for June and November of each year were tested by analysis of variance (ANOVA) and the Student, Newman, Kuels multiple range (SNK) tests (Sokal and Rohlf 1981; Snedcor and Cochran 1988).[1]

Nearest neighbor distance (NND) is used to describe and compare the spatial distribution of populations and communities of plants and animals (Clark and Evans 1954; Krebs 1989) and is used to calculate an index of aggregation (Clark and Evans 1954) to compare the distribution patterns. The index ranges from 0 to 2.15; where 0 represents a completely aggregated population (i.e. all individuals are in the same place), 1 represents a randomly distributed population, and 2.15 represents a totally uniform distribution of individuals. The values for the index of aggregation should be viewed with caution because they are calculated for a total area that is arbitrarily determined by a rectangle enclosing all of the middens in each area and uses a

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[1]Local density as calculated for this report does not include the focal (central) midden due to the manner in which the computer program handles the data. Local densities in previous reports were calculated by hand and do include the focal midden. For comparative purposes, the local densities of middens and squirrels have been recalculated for all months using the computerized data base.

correction factor to correct for the lack of a boundary area (Donnelly 1978). Like local density, nearest neighbor distance is determined for each midden and squirrel and compared statistically among areas by using ANOVA and SNK tests (Sokal and Rohlf 1981; Snedcor and Cochran 1988).

Reproductive Activity and Success

Reproductive data was collected at all opportunities. The reproductive status of females was determined by examining the condition of the nipples through binoculars and recorded as non-reproductive, lactating, or post-lactating. However, it is not always possible to distinguish non-breeding females from pregnant individuals by visual observation unless you have the animal in-hand. The nipples of non-reproductive (nulliparous) females are not swollen or pigmented and are not visible through the fur. The nipples of pregnant females become swollen at the base, and if multiparous, they may be darkly pigmented, but they may not be visible through the fur. Therefore pregnant animals are classified as non-reproductive. The nipples of lactating females are swollen and elongated, may be pigmented, and are easily seen protruding through the fur; suckling offspring often wear away the fur around the nipples. Nipples of a post-lactating female become flattened, are generally darkly pigmented, and are visible through the fur.

Some natal nests were located away from the midden site and were discovered by following lactating females, which was not a very successful technique. Many females located their natal nests within the main snag at the midden site. Known natal nests were observed during visits to the respective midden sites to determine the date of litter emergence and litter size. Because the natal nests were visited at three to four day intervals, the litter emergence date was determined within less than one week. Litter emergence dates were also used to estimate the breeding dates and to provide another means to estimate the length of the breeding season. The gestation period of red squirrels is approximately 33-35 days (Ferron and Prescott 1977; Lair 1985), and the juveniles generally leave the natal nest at about 37-39 days of age (Layne 1954; Nice et al. 1956; Ferron 1980, 1981). Therefore, conception can be assumed to be approximately 70 to 74 days prior to emergence of the juveniles.

Litter size at emergence was used as a measure of reproductive success in lieu of disturbing the natal nest to obtain nestling counts. Consequently the number of females listed as "unsuccessful" at rearing litters may be higher than actually occurred, because some litters were not observed at or near the time of emergence. Trapping and tagging individual squirrels will allow for the collection of data on lifetime reproductive success of individual females and their offspring.

The reproductive success of females on the construction areas was also examined in relation to distance from construction. The distance of each female's midden from construction was calculated from the coordinates of the midden site and the closest point of construction activity (telescope site or access road) by the same method used to calculate nearest neighbor distances. Kruskal-Wallis tests (Sokal and Rohlf 1981) were used to test for differences in the distance to construction for females in the different reproductive classes.

The reproductive status of male squirrels was also determined by visual assessment. As the reproductive season approaches, the testes recrudesce and descend into the scrotum, the scrotum becomes darkly pigmented, enlarged, and highly visible. The reproductive status of males, recorded as testes scrotal or non-scrotal, was noted whenever one was observed.

Trapping and tagging of red squirrel was resumed in late-1991 after being suspended in 1989. Methods of trapping and handling red squirrels are dictated by the U.S. Fish and Wildlife Service. Squirrels were trapped using Tomahawk Live-traps baited with peanut butter. Captured squirrels were handled by the Halvorson (1972) method and fitted with numbered metal ear tags. The ear tags also had color coded plastic washers attached for identifying individual squirrels from a distance. In an effort to minimize the risk to the squirrels, open traps were kept under surveillance at all times, and squirrels were handled immediately after capture. Squirrels were tagged while in the "Halvorson cone" and immediately released after determining the gender of the squirrel.

Results

Surveys to locate new midden sites were conducted in late-May and late-October 1991. New middens were also located during all months of the year while conducting other field work. A total of 40 midden sites were discovered in 1991; 39 were newly established, that is appeared where no midden had been previously recorded, and one that was overlooked during previous surveys. With the addition of the TRN area in 1989 and the discovery of new and overlooked middens, the total number of midden sites increased from 78 in June 1989 (Davis 1989) to 176 in November 1991 (Table 1). The greatest increase in "newly found" middens was 30 middens discovered between June and November 1989, which was due to the intense surveys of the monitored areas by the monitoring crews.

A midden census was conducted during each month of 1991, except during March and December when weather conditions were too severe. The number of middens and number of red squirrels, as represented by occupied middens, has increased on all areas since November 1989. Total middens increased from 108 to 176 and total red squirrels increased from 35 to 124. The greatest increase in middens was 22 on the TRC area, but the greatest increase in red squirrels was 37 on the SFN area (Table 2).

Red Squirrel numbers in 1991 were at their lowest level in April and May, and followed the same trend as in 1990 (Fig. 2) (Appendix B). By November 1991, population numbers on all areas equalled or surpassed the numbers present at the end of 1990.

1990 and 1991 Midden Occupancy

Within habitat types, the proportion of occupied middens was essentially the same in 1990 and 1991, regardless of time of year, on construction and non-construction areas (Table 3). However, midden occupancy between the TR and SF habitats was seasonally inconsistent. The TR habitat had a higher proportion of middens occupied in June 1990 and November 1991 than the SF habitat, but were essentially the same in November 1990 and June 1991 (Table 4; Appendix C).

There were no differences in the proportion of middens occupied between or within November 1990 and November 1991 for the 0 to 100-m, 100 to 200-m, or 200 to 300-m distances from construction activity at the MGIO location or from the access road in either habitat type (Tables 5a, 5b, 5c). Nor were there any differences for similar distance zones from Forest Roads 669 and 507 in the SFN area (Tables 5d, 5e).

There were no differences in the over-winter survival (November 1990 to May 1991) in midden occupancy between construction and non-construction areas on either the TR or SF habitats. However, survival was apparently greater (P=0.008) in the SF habitat than in the TR habitat (Table 6).

Fifty-two middens in TR habitat, and 74 middens in SF habitat had the potential for turnovers of the resident squirrel in 1991. Of these middens, 17 (33%) in TR habitat and 33 (45%) in SF habitat were occupied by more than one squirrel during the course of the year. There was no difference in the likelihood of a turnover between construction and non-construction areas in the TR or SF habitat (Table 7).

Spatial Distribution

Crude Density -- The crude density of middens on all the monitored areas has increased since 1989 with the greatest increases in the TR habitat areas (Appendix D). The crude density of middens in November 1991 ranged from 0.42 (SFC) to 0.92 middens/ha (TRN). The crude density of squirrels has also increased on all areas, from 1989 to 1991 and followed the same trend as middens (Fig. 3).

Local density -- To determine local densities and nearest neighbor distances of middens on the monitored area, it was necessary to tabulate some middens that were off the monitored areas. These middens were only used to calculate data for a focal midden on a monitored area. Local density represents the number of middens (or squirrels) within 100 m of the focal midden (or squirrel). Local density of middens ranged from 0 to 8 in November 1991; the local density of squirrels ranged from 0 to 7. Local density of middens has increased on all monitored areas since 1989, with the largest increase in the TR habitat (Fig. 4; Appendix D). The local density of squirrels also increased (Fig. 4; Appendix D).

The average local density of middens and squirrels followed the same pattern in November 1991 as November 1990 (Young 1991). The TR habitat had a greater local density of middens and squirrels than the SF habitat and the density on the TRC area was greater than on the TRN area. There were no differences in the local density of middens or squirrels between SFC and SFN areas (Table 8; Appendix E).

Nearest Neighbor Distance -- The nearest neighbor distances for both, middens and squirrels, on the monitored areas has decreased since 1989 (Appendix D). The TRN area middens had the shortest nearest neighbor distance, and the TRN and TRC were both significantly shorter than the SFN and SFC areas, which were essentially the same (Table 8; Appendix F). The nearest neighbor distance for squirrels did not follow the same pattern. Squirrels within the construction and Non-Construction areas on the TR habitat had essentially the same distance to their nearest neighbor, and were not significantly closer than squirrels on the SFC area. Although the squirrels on both areas in the SF habitat had similar distances to their nearest neighbor, the SFN squirrels were significantly farther apart than the squirrels in the TR habitat (Table 8; Appendix F).

The index of aggregation for the middens on all the areas from June 1990 through November 1991 indicates that middens are distributed in a random pattern on all areas (Table 9; Appendix D). The distribution of squirrels is similar except on the SFC area, where squirrels were more aggregated than random and more aggregated than the distribution of available middens in 1991. There was a tendency for squirrels on all areas to be distributed in a more aggregated pattern than the middens (Table 9; Appendix D).

The tendency toward aggregation of squirrels is further demonstrated by the local density of occupied versus unoccupied middens. Occupied middens had an average of 2.7 other middens within 100 meters; significantly more than did unoccupied middens (2.0). Occupied middens also had more occupied middens (=squirrels) within 100 m than did unoccupied middens (Table 10; Appendix G). Occupied middens were closer to their nearest neighboring occupied midden than were unoccupied middens (Table 10; Appendix G). Thus, it appears that red squirrels prefer to occupy midden sites with more and closer neighboring sites.

Reproductive activity and success

The earliest record of a lactating female in 1991 was on 22 April and the latest date was on 1 September (Table 11). Twenty litters were observed at or near the time of emergence from the natal nest, though an accurate litter size was not obtained in all cases. Litters were first observed in early to mid-June on all areas, except on the SFC area where litters were not seen until 12 August. The latest litters to emerge were observed between mid-August through 22 September (Table 12).

Calculating back from the emergence of litters, the breeding dates for females ranged from 21 March to 14 July. Males were observed to be sexually active from 5 February to 4 October. However, using data on lactating females, the breeding season was from 9 April to 9 August.

There were 59 females of possible breeding age identified in 1991 and 36 showed signs of reproductive activity (Table 13). Although all areas had essentially the same proportion of breeding females, a slightly higher proportion of females on the construction areas in both the TR and SF habitat appeared to have bred.

In 1991, litter size was obtained for 15 litters within a few days of emergence from the natal nest. Litter size ranged from 1 to 4, with an overall average of 1.93 (Table 14). There was a trend for females in TR habitat to have larger litters than those in SF habitat, however, there were no significant differences. The SFC area had the highest litter production success (Table 13).

Reproductive activity and success also were examined relative to distance from construction activity. There were 22 females on the TRC and SFC areas in 1991. The average distance from construction at the telescope sites or access road was 206.0 m and ranged from 39.2 to 424.7 m. Distance from construction did not appear to have any effect on whether or not females lactated or produced litters (Table 15; Appendix H). Some measurements extend beyond 300 m because the map locations of middens are estimated and measured distances were not corrected for slope.

Trapping and Tagging

Trapping and tagging of red squirrels resumed on 22 September 1991. Eleven squirrels were successfully captured and tagged. No squirrels were injured or appeared to suffer adverse effects from handling. Trapping was discontinued for the year on 22 October with a total of 195 trap-days. Two marked squirrels disappeared from the SFC area by the end of November 1991; all other marked red squirrels were still resident at their respective middens (Appendix I).

Discussion

Gross population data and crude density are difficult to interpret in relation to construction because they do not account for differences in quality and quantity of red squirrel habitat available on each monitored area. The crude density of middens on all areas in 1991 increased as a result of the increase in squirrel populations and the establishment of new middens (Table 1, Figure 3). Because the density of squirrels cannot exceed the density of middens on an area, Figure 3 shows the relative midden occupancy on each area. The large increases of middens in the TR habitat are indicative of the rapid increase in the squirrel populations. Out of 102 additional middens located since November 1989, 65 were located in TR habitat and 37 were in SF habitat. Most of the "newly found" middens were located in 1989, with 24 out of 30 located in TR habitat. In 1991, only 1 "newly found" midden was discovered which indicates that most of the old undiscovered middens have been found. Most of the "newly established" middens (25 of 39 in 1991) have been located in TR habitat (Table 1).

Midden maps show that middens are not distributed uniformly (Appendix A). For example, on the TRC area middens are concentrated in the northwest corner of the area. There are also large parts of all areas with no middens, which increases the variance of the local density. The occupancy of middens appears to be related to midden density -- occupied middens had both higher local densities and shorter nearest neighbor distances. This influence of the density of middens on the likelihood of a midden being occupied must be considered when interpreting differences in occupancy between and within the monitored areas. The occupancy of middens in the first 100 m surrounding the access road and telescope sites has remained low since 1989, which may be due to the density of middens in this area. Very few middens within 100 m of construction activity have any neighboring middens within 100 m of them, and based on the pattern discussed above, it would be expected to have low occupancy rates. Further, the road location was deliberately designed to avoid squirrel middens by at least 61 m (200 ft). Therefore, few middens should be observed within 100 m of the road.

Within the construction areas, midden occupancy did not increase when the distance from construction activity increased, as was observed in 1990. Construction activity in 1991 was of longer duration and greater intensity than in 1990, consequently, it appears that the differences in the 1990 midden occupancy may have been the result of differences in dispersal activity, source of immigrant populations, or differences in habitat quality. Apparently, construction activity did not have any effect on middens being occupied or unoccupied, or on overwinter survival. The TR habitat consistently had a greater proportion of middens occupied. Squirrels in the SF habitat, however, had a 24 percent higher overwinter survival rate than squirrels in the TR habitat (Table 6).

In November 1991, there was no indication that construction activity influenced local density of middens or squirrels because the densities were either higher on the construction areas or equal to the non-construction areas and nearest neighbor distances showed similar trends.

1991 was the first year that construction took place during spring and summer, which is the primary reproductive season for red squirrels. However, there is no indication that construction activity had any effect on the reproductive success of the squirrels. The breeding season apparently began in March and went through August; males became reproductively active in February and remained so through September, which is similar for other red squirrel populations (Obbard 1988). There did not appear to be any difference in the onset of breeding activity either between construction and non-construction areas or between habitats. It is important to remember that this data is all based on visual signs observed through binoculars, which limits the quantity and quality of reproductive data. Better data will be available with the resumption of trapping and tagging of individual animals. Periodic retrapping of selected individuals would be useful to verify reproductive condition.

Although 34 lactating females, and 15 emerging litters were observed in 1991, there are only a few observations for each area. Unfortunately, these data has such wide variations that it is not prudent to draw any conclusions that construction activity had any effect on litter production. Nor should any comparisons be made with 1990 data, because there were fewer observations, none of which were made on the SF habitat (Table 14). However there may be some trends that bear watching: litters on the construction areas were slightly larger than litters on the non-construction areas and a higher percentage of females on these areas were successful at rearing litters to emergence (Tables 13 and 14). Data on location of natal nests and litter size could possibly be improved by the use of telemetry methods.

There is, also, an apparent trend in litter size between habitat types. Females in the TR habitat tended to have slightly larger litters than females in the SF habitat, which may have been due to differences in the age structure. In 1991, a large proportion of the females in the SF habitat were yearlings, while the females in TR habitat were adults; yearling females typically breed later and have smaller litters than older females (Rusch and Reeder 1978; Zirul 1970; Becker 1992). This observation is supported by the 1991 population growth patterns by plotting the number of juveniles living with their mothers over time for each habitat type. Two distinct peaks in the number of juveniles are separated by approximately two months that represent a difference in the timing of reproduction between habitats (Fig. 5). The earlier peak is associated with reproductive activity on the TR areas, while the later peak is associated with the SF populations. Because most of the SF females were yearlings and a larger proportion of the TR females were adults, it is possible that this difference was a function of the age structure. If this is the case, the pattern should disappear as the age structure of the populations become more similar.

Studies conducted on populations of red squirrels in other geographic regions have demonstrated that the food supply, primarily conifer seeds, is a major regulating factor on red squirrel populations (Rusch and Reeder 1978: Sullivan 1990: Sullivan and Sullivan 1982). Food supply and total energy content also influences the reproductive effort and success of female red squirrels (Becker 1992). The Mt. Graham red squirrels are undoubtedly influenced by food supply as well, however, we do not presently have a quantitative method to evaluate the cone crop and the amount of food available to the squirrels in any one year. Cone crop estimates on Mt. Graham have been rated by the Forest Service since 1989. However, the rating system only qualifies the cone crop as none, very light, light, medium, or heavy with anything above 20 to 50 cones per tree is rated as heavy. It does not permit comparison of the available food resources between monitored areas because it is generalized for the total area. Cone production varies from species to species, and can vary within a species on a local scale. For example, corkbark fir produced a light to good cone crop in TR habitat in 1989, 1990, and 1991, but there was virtually no corkbark fir cone production in the SF habitat during any of those years (pers. obs.). Because food supply is a critical factor in the population dynamics of red squirrel populations, local variations in cone production have the potential to produce local changes in populations that have no relationship to the construction of MGIO. We are investigating methods that may provide quantitive data on food production for each area.

Table 1. Total number and discovery status of red squirrel middens on each of the monitored areas.

Year	Area	Middens on area: Old	Newly Found	Newly Established	Total
Nov. 1989	TRC	2	18	2	22
	TRN	0	6	2	8
	SFC	25	3	0	27[1]
	SFN	51	3	0	51[2]
	Total	78	30	4	108
Nov. 1990	TRC	22	1	2	25
	TRN	8	4	5	17
	SFC	27	0	4	31
	SFN	51	6	6	63
	Total	108	11	17	136
Nov. 1991	TRC	25	0	19	44
	TRN	17	0	6	23
	SFC	31	0	6	37
	SFN	63	1	8	72
	Total	136	1	39	176

[1] One pair of middens was combined into one midden.

[2] Three pair of middens were combined into three individual middens.

Table 2. Proportion of the total area, total number of middens, and total population of squirrels found on each of the monitored areas for June and November, 1989 - 1991. Percentages are rounded to the nearest unit. Juveniles living with their mothers are not included in the number of squirrels.

			Nov 1989				Jun 1990				Nov 1990				Jun 1991				Nov 1991			
	Area		Middens		Squirrels		Middens		Squirrels		Middens		Squirrels		Middens		Squirrels		Middens		Squirrels	
	ha	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
TRC	91	28	22	20	16	46	22	20	10	43	25	18	16	18	26	18	15	19	44	25	38	31
TRN	25	8	8	7	6	17	10	9	4	17	17	13	14	16	18	12	10	13	23	13	19	15
SFC	89	27	27	25	7	20	27	24	3	13	31	23	17	19	34	23	19	23	37	21	24	19
SFN	122	37	51	47	6	17	52	47	6	26	63	46	42	47	68	47	36	45	72	41	43	35
Total	327		108		35		111		23		136		89		146		80		176		124	

Table 3. Proportion of middens occupied on construction and non-construction areas in 1990 and 1991.

	1990		1991	
	June	November	June	November
TRC	45 %	64 %	58 %	86 %
TRN	40 %	82 %	56 %	83 %
G =	1.046	0.165	0.020	0.165
P =	0.305	0.737	0.902	0.737
SFC	10 %	55 %	56 %	69 %
SFN	10 %	67 %	53 %	60 %
G=	0.003	1.231	0.079	0.275
P =	0.972	0.317	0.802	0.632

Table 4. Proportion of middens occupied in TR and SF habitats during 1990 and 1991.

	1990		1991	
	June	November	June	November
TR Habitat	44 %	71 %	57 %	85 %
SF Habitat	10 %	63 %	54 %	61 %
G =	12.740	1.409	0.104	11.861
P =	**0.001**	0.242	0.755	**0.001**

Table 5a. Differences between 1990 and 1991 in the proportion of middens occupied within 100m distance zones from construction activity on the TRC area.

Construction 0 - 100 meters from Middens			
TRC	Occupied	Unoccupied	Total
Nov. 1990	2	1	3
Nov. 1991	4	2	6
	G= 0.000 / P= 1.000[1]		

Construction 101 - 200 meters from Middens			
TRC	Occupied	Unoccupied	Total
Nov. 1990	4	2	6
Nov. 1991	13	1	14
	G= 2.065 / P= 0.239[1]		

Construction 201 - 300 meters from Middens			
TRC	Occupied	Unoccupied	Total
Nov. 1990	10	6	16
Nov. 1991	21	3	24
	G= 3.398 / P= 0.079[1]		

1 Sampled Randomization G-test

Table 5b. Differences between 1990 and 1991 in the proportion of middens occupied within 100 m distance zones from construction on the SFC area.

Construction 0 - 100 meters from Middens

SFC	Occupied	Unoccupied	Total
Nov. 1990	1	4	5
Nov. 1991	3	4	7
	G= 0.712 / P= 0.553[1]		

Construction 101 - 200 meters from Middens

SFC	Occupied	Unoccupied	Total
Nov. 1990	7	3	10
Nov. 1991	9	2	11
	G= 0.404 / P= 0.616[1]		

Construction 201 - 300 meters from Middens

SFC	Occupied	Unoccupied	Total
Nov. 1990	9	7	16
Nov. 1991	12	7	19
	G= 0.173 / P= 0.730[1]		

1 Sampled Randomization G-test.

Table 5c. Occupancy of middens in 100 m distance zones from construction on the TRC and SFC areas in 1990 and 1991.

	Distance (m)	Occupied	Unoccupied	Total
TRC Nov. 1990	0-100	2	1	3
	101-200	4	2	6
	201-300	10	6	16
		G=0.044; P=0.983[1]		

	Distance (m)	Occupied	Unoccupied	Total
TRC Nov. 1991	0-100	4	2	6
	101-200	13	1	14
	201-300	21	3	24
		G=2.123; P=0.411[1]		

	Distance (m)	Occupied	Unoccupied	Total
SFC Nov. 1990	0-100	1	4	5
	101-200	7	3	10
	201-300	9	7	16
		G=3.533; P=0.200[1]		

	Distance (m)	Occupied	Unoccupied	Total
SFC Nov. 1991	0-100	3	4	7
	101-200	9	2	11
	201-300	12	7	19
		G=2.973; P=0.252[1]		

1 Sampled Randomization G-test.

Table 5d. Differences between 1990 and 1991 in the proportion of middens occupied within 100 m distance zones from Forest Roads 507 and 669 on the SFN area.

FR's 507 or 669 0 - 100 meters from Middens			
SFN	Occupied	Unoccupied	Total
Nov. 1990	17	7	24
Nov. 1991	18	9	27
	G= 0.103 / P= 0.786[1]		

FR's 507 or 669 101 - 200 meters from Middens			
SFN	Occupied	Unoccupied	Total
Nov. 1990	12	10	22
Nov. 1991	13	14	27
	G= 0.199 / P= 0.642[1]		

FR's 507 or 669 201 - 300 meters from Middens			
SFN	Occupied	Unoccupied	Total
Nov. 1990	11	1	12
Nov. 1991	10	2	12
	G= 0.387 / P= 0.640[1]		

1 Sampled Randomization G-test.

Table 5e. Occupancy of middens in 100 m distance zones from construction on the SFN area, November 1990 and 1991.

	Distance (m)	Occupied	Unoccupied	Total
SFN Nov. 1990	0-100	17	7	24
	101-200	12	10	22
	201-300	11	1	12
		G=5.673; P=0.072[1]		

	Distance (m)	Occupied	Unoccupied	Total
SFN Nov. 1991	0-100	18	9	27
	101-200	13	14	27
	201-300	10	2	12
		G=5.000; P=0.103[1]		

1 Sampled Randomization G-test.

Table 6. Over-winter survival in midden occupancy, 1990 - 1991.

Habitat/Area	Number of middens occupied: November 1990	Number of middens occupied: April/May 1991	% Survival
TRC	16	9	56 %
TRN	14	8	57 %
			G=0.002 P=0.969
SFC	17	14	82 %
SFN	42	34	81 %
			G=0.016 P=0.935
TR Habitat	30	17	57 %
SF Habitat	59	48	81 %
			G=6.907 P=0.008

Table 7. Proportion of middens where the resident squirrel was replaced by another squirrel during 1991.

Area	No turnover	Turnover	G-test
TRC	23	12 (34%)	G=0.125
TRN	12	5 (29%)	P=0.724
SFC	14	12 (46%)	G=0.039
SFN	27	21 (44%)	P=0.843
Habitat			
TR	35	17 (33%)	G=1.824
SF	41	33 (45%)	P=0.177

Table 8. Local Densities and Nearest Neighbor Distance of middens and squirrels on the monitored areas in November 1991. Means with the same letter in each column are not statistically different (ANOVA, SNK multiple range test).

	Middens			Squirrels		
		Local Density (Number within 100 m)	Nearest Neighbor Distance (m)		Local Density (Number within 100 m)	Nearest Neighbor Distance (m)
Area	n	Mean ± SE	Mean ± SE	n	Mean ± SE	Mean ± SE
TRC	44	3.9 ± 0.37 a	59.7 ± 5.43 ab	38	3.5 ± 0.33 a	60.2 ± 7.75 a
TRN	23	3.0 ± 0.36 b	53.0 ± 3.99 a	19	2.5 ± 0.31 b	63.1 ± 4.84 a
SFC	37	1.8 ± 0.25 c	77.9 ± 7.25 c	24	1.5 ± 0.18 c	72.7 ± 8.58 ab
SFN	72	1.8 ± 0.13 c	71.0 ± 3.06 bc	43	1.1 ± 0.14 c	88.1 ± 4.90 b
Total	188[1]	2.5 ± 0.13	66.0 ± 2.39	124	2.1 ± 0.14	70.5 ± 3.36

[1] This includes some "off area" middens which are within 100 m of some of the "on area" middens and are included in the calculation of LD and NND for some middens.

Table 9. Index of aggregation of middens and squirrels on the monitored areas.

		Middens		Squirrels	
Date	Area	Index Aggr.	Corrected[1] Z	Index Aggr.	Corrected[1] Z
June 1990	TRC	1.101	-0.020	0.778	-1.782
	TRN	1.112	-0.234	0.848	-1.175
	SFC	1.063	-0.227	1.223	-0.270
	SFN	0.996	-0.801	1.224	0.008
Nov. 1990	TRC	0.990	-0.843	0.906	-1.337
	TRN	1.076	-0.301	0.898	-1.351
	SFC	1.020	-0.572	0.820	-1.893
	SFN	1.041	-0.215	1.037	-0.366
Jun 1991	TRC	1.067	-0.228	0.943	-1.097
	TRN	1.024	-0.622	0.703	-2.138
	SFC	1.038	-0.398	0.832	-1.884
	SFN	1.046	-0.121	1.026	-0.496
Nov 1991	TRC	0.920	-1.630	0.857	-2.193
	TRN	0.931	-1.302	1.006	-0.743
	SFC	1.016	-0.598	0.763	-2.590*
	SFN	1.031	-0.308	0.989	-0.870

[1] Corrected for lack of boundary area, (Donnelly, 1978). Z must be greater than 2.240 or less than -2.240 to be significant.

* Indicates deviation significantly different from random distribution.

Table 10. Local density and nearest neighbor distances of occupied and unoccupied middens, November 1991.

		Middens		Squirrels	
Midden Status	n	Local Density $\bar{x}$ ±SE	Nearest Neighbor Distance $\bar{x}$ ±SE	Local Density $\bar{x}$ ±SE	Nearest Neighbor Distance $\bar{x}$ ±SE
Occupied	124	2.7 ±0.3	62.8 ±5.3	2.1 ±0.3	71.9 ±7.3
Unoccupied	52	2.0 ±0.5	76.0 ±11.3	1.5 ±0.5	97.3 ±17.7
ANOVA		F=4.17 P=**0.0428**	F=5.84 P=**0.0167**	F=4.59 P=**0.0335**	F=10.11 P=**0.0017**

Table 11. Range of dates of first lactation by female red squirrels on the monitored areas in 1991. Earliest - first date of the year on which a female on the area was observed to be lactating for the first time, Latest - latest date of the year on which a female was observed to be lactating for the first time, median - median date of first lactation for the female population on the area, range - number of days over which females were observed to begin lactation.

AREA	n	Earliest	Latest	Median[1]	Range
TRC	7	14 May	1 Sep.	11 June	110 days
TRN	5	16 May	13 June	18 May	28 days
SFC	7	13 June	31 July	27 June	48 days
SFN	15	22 Apr.	09 Aug.	21 May	117 days

1 Kruskal-Wallis (Chi^2 approximation): X^2=10.909, DF=3, P=**0.0122**

within TR Habitat: X^2=2.3886, DF=1, P=0.1222
within SF Habitat: X^2=5.4636, DF=1, P=**0.0194**

Table 12. Range of dates of emergence of litters from their natal nests on the monitored areas. Earliest, latest, median, and range as above, except for dates of emergence of litters.

AREA	n	Earliest	Latest	Median	Range
TRC	4	13 June	10 Aug.	21 June	58 days
TRN	3	11 June	22 Sep.	15 June	103 days
SFC	6	12 Aug.	06 Sep.	15 Aug.	25 days
SFN	7	03 June	05 Sep.	23 July	94 days

Kruskal-Wallis (Chi^2 approximation): X^2=5.2146, DF=3, P=0.1567

Table 13. Number and proportion of females that lactated and that were successful at rearing litters to emergence in 1991.

Area	Total Females	Lactating Females		Litters Emerged	
	n	n	%	n	%
TRC	10	8	80	3	30
TRN	7	5	71	2	29
SFC	12	8	67	5	42
SFN	30	15	50	5	17
Total	59	36	61	15	25
		G=	3.654		1.906
		P=	0.301		0.592

Table 14. Litter size ($\bar{x}$ and range) of squirrels on the monitored areas in 1990, 1991 and years combined.

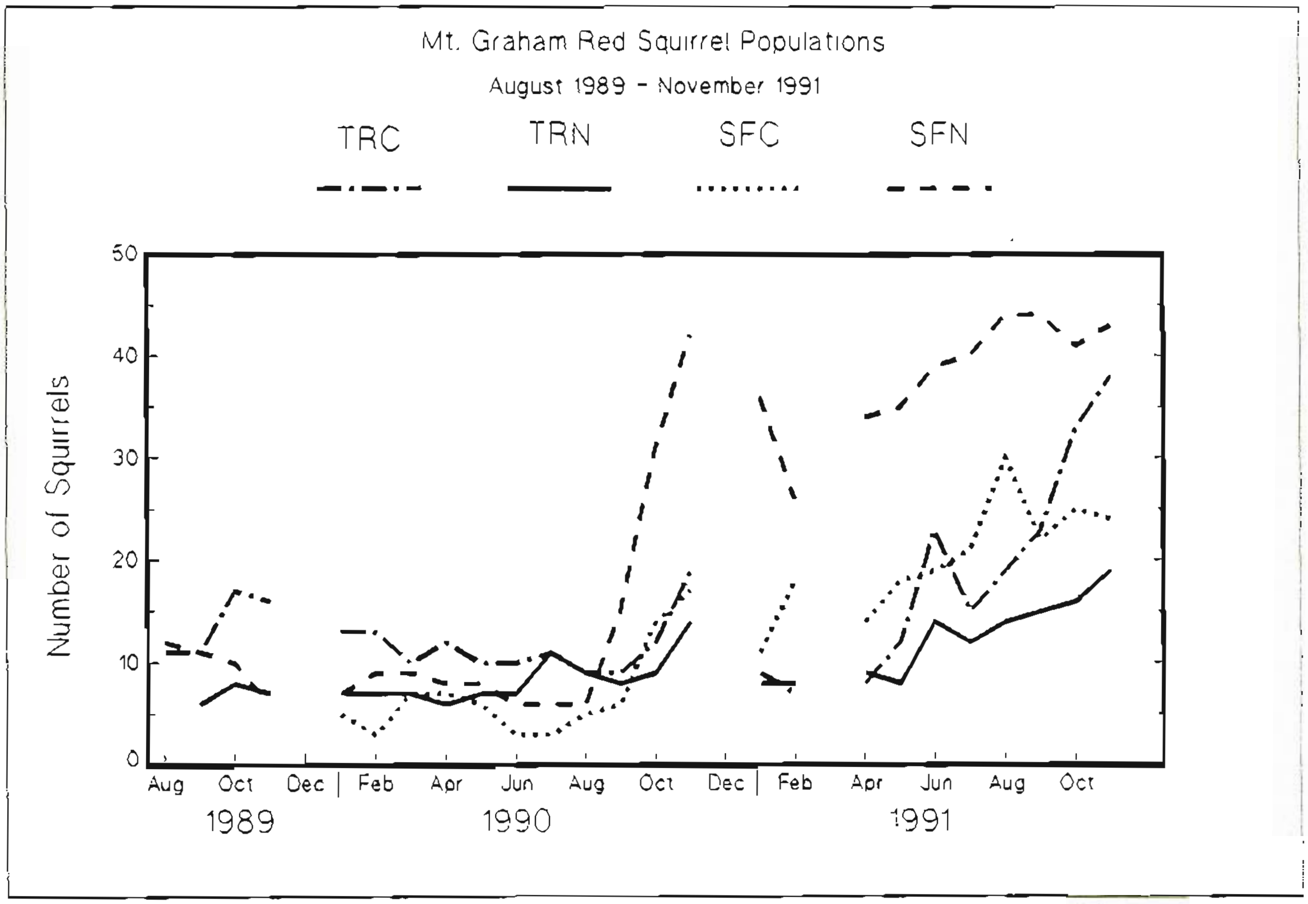
	1990			1991			1990+1991		
	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range
TRC	3	2.67	2-3	3	2.67	2-4	6	2.67	2-4
TRN	3	2.67	2-3	2	2.00	1-3	5	2.40	1-3
SFC	0	-	--	5	1.80	1-3	5	1.80	1-3
SFN	0	-	--	5	1.60	1-3	5	1.60	1-3
Kruskal-Wallis (Chi-square approximation)				X^2=2.819 P=0.534					

Table 15. Reproductive activity and success of females on the construction areas, relative to distance from construction.

			Distance (m) from construction		
		n	$\tilde{x}$	minimum	maximum
TRC	Non-reproductive	2	185.9	102.7	269.0
	Lactating (no litter emerged)	5	165.1	39.2	336.6
	Lactating (litter emerged)	3	266.3	198.7	303.4
SFC	Non-reproductive	4	191.2	95.8	309.9
	Lactating (no litter emerged)	3	264.9	153.9	424.7
	Lactating (litter emerged)	5	195.3	101.5	409.3

Kruskal-Wallis test (Chi-square approx.) X^2= 1.586, P=0.426

Figure 2. Red squirrel populations on the monitored areas, from August 1989 to November 1991.



BEHAVIOR

Introduction

The objective of monitoring the behavior of red squirrels is to detect changes in the behavior pattern caused by the construction and operation of the MGIO. The behavior of individual squirrels is highly variable from day-to-day and even from one minute to the next. Consequently, it is not possible to objectively determine whether an individual squirrel is acting "normal" at any given time or place. Therefore, the composite behavior of squirrel populations on the construction areas was compared with the behavior of the populations on the non-construction areas to describe differences in behavior patterns.

The behavioral data were used to look for differences in two aspects of behavior among populations; levels of activity (or activity patterns), and time budgets. Due to the low density and wide dispersion of squirrels on the monitored areas, we used indices of activity to estimate levels of activity in lieu of more traditional comprehensive measures of activity patterns (e.g. the number of squirrels active at different times of day). The level of activity was estimated from samples of the squirrels' activity during specific times of day. Time budgets describe the partitioning of the activity pattern into specific behaviors (e.g. how much time is spent feeding, foraging, or resting). The time budgets used in this analysis are derived from samples of the total activity and are not comprehensive, as they do not attempt to account for total daily activity.

Red squirrels cache large numbers of cones, as a food reserve to use over-winter, and often rely on caches made during years of good cone crops to see them through several years (M.C. Smith 1968). The number and the quality of cones cached are important for the survival of individual squirrels. Part of the behavior monitoring is directed toward determining whether or not construction activity may indirectly influence squirrel survival by affecting the incidence of cone caching behavior.

Methods

Data Collection

Behavior data were collected by conducting 2-hour observations at occupied red squirrel middens. Midden is used in the context of the areas immediately surrounding the actual "midden" or refuse pile, including the snag or nest tree and extending approximately 10 m from the center of the refuse pile. The observations were paired, with one person observing at a

Figure 3. Crude density of middens and of squirrels for each of the monitored areas.

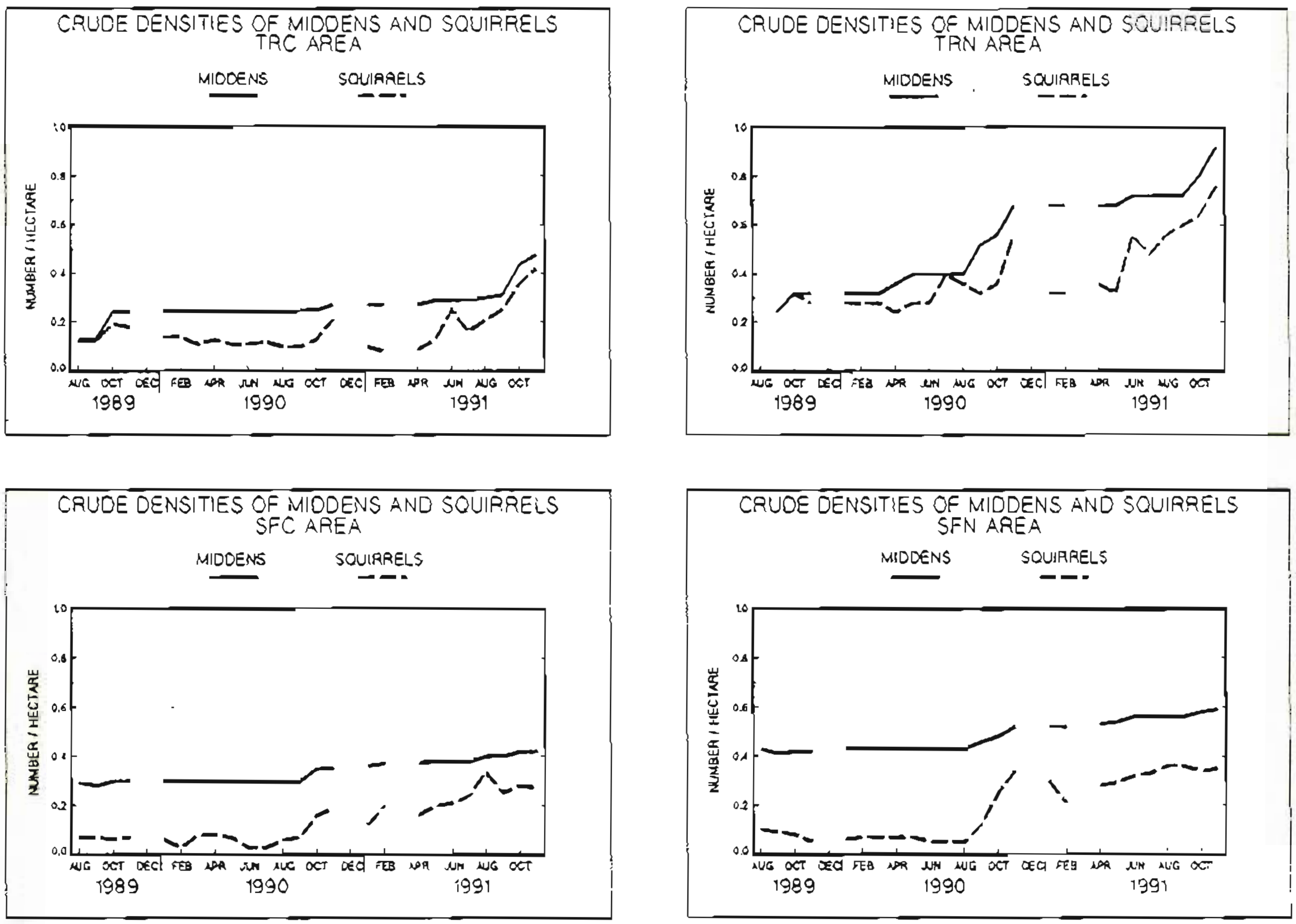
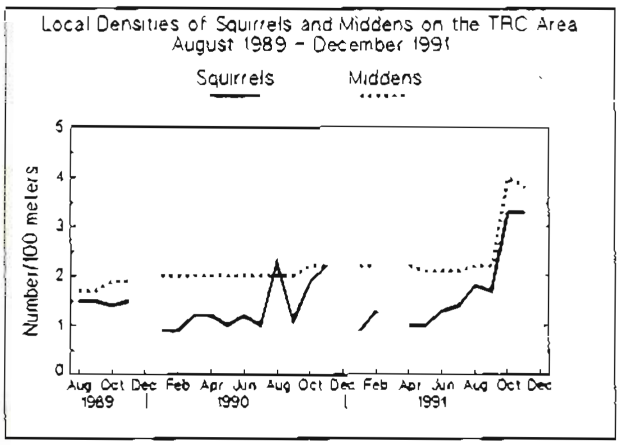
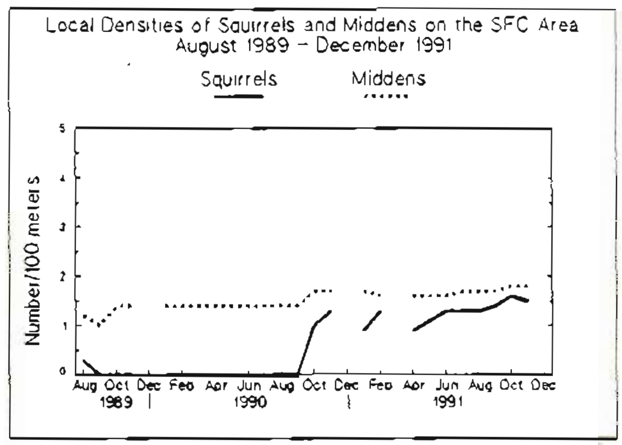
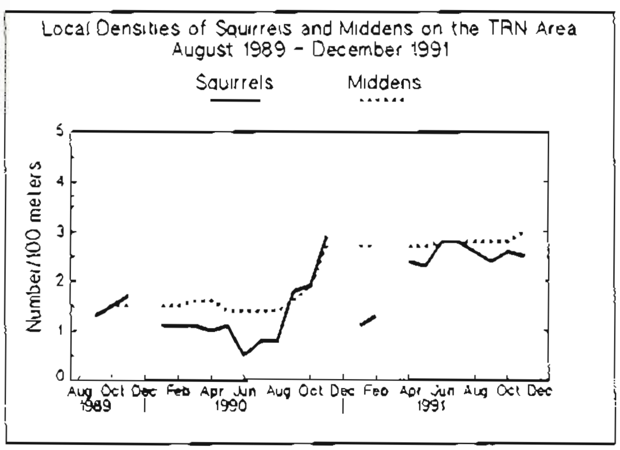


Figure 4. Local densities of middens and squirrels for each of the monitored areas. The Y-axis scales are the same in all figures.







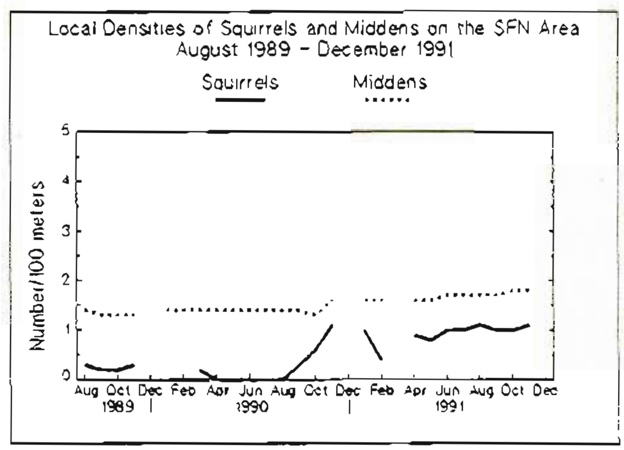
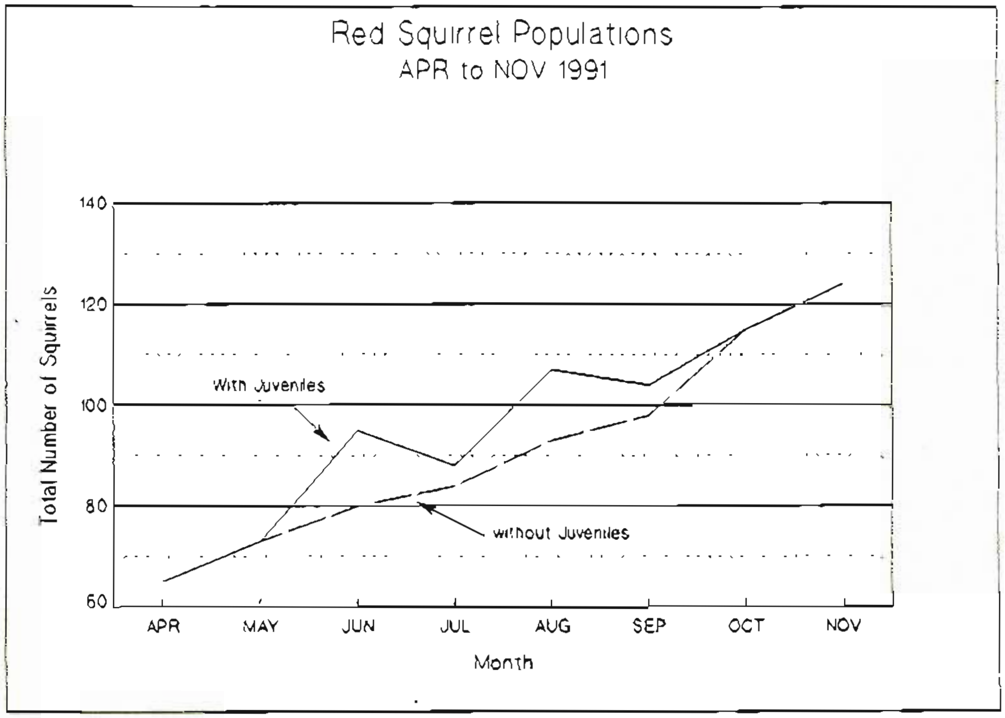
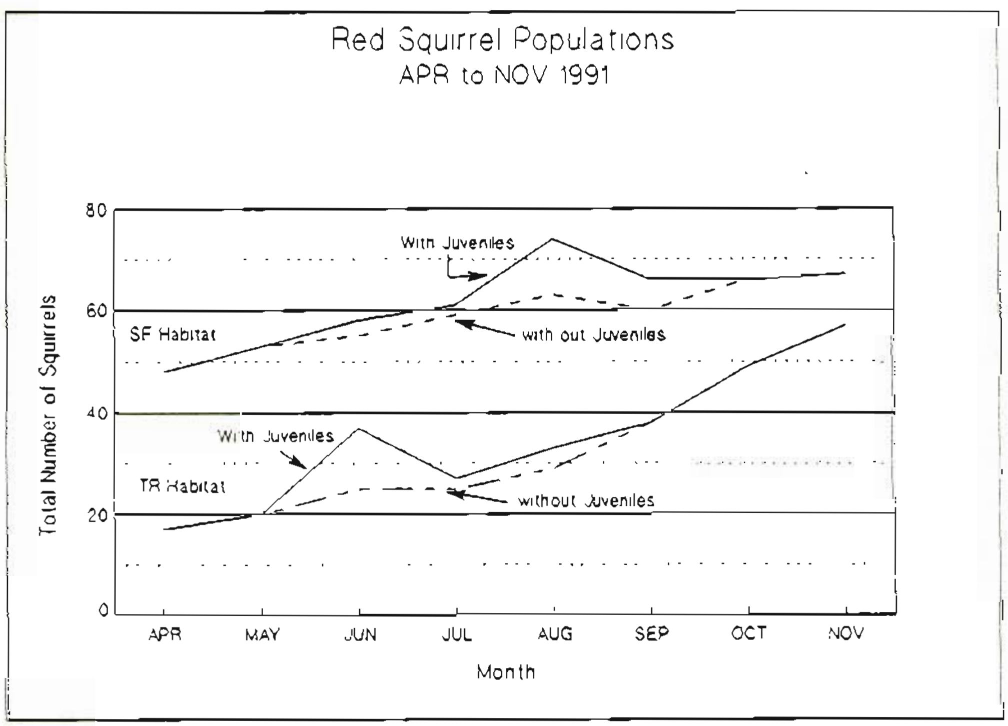


Figure 5. Plot of red squirrel populations showing the number of juveniles living at their mothers' midden; a) all areas combined, b) areas separated by habitat.





midden on a construction area while another person observed at a midden on a non-construction area in the same habitat type. The gender of most squirrels was known in 1991, and the observations were paired by the gender of the squirrels when possible. Three pairs of observations were conducted daily at 0800, 1100, and 1400 h. The observer sat within about 10 m of the midden at a location affording the best view of the area surrounding the midden.

During observations, all of the activities of all squirrels within 10 m of the midden were recorded to the nearest 0.25 minute on standardized record sheets (Appendix J). All activity was recorded as one of 19 behavior categories -- including "out of midden area" (beyond 10 m). "Out of sight - in midden" means that the squirrel was within the 10 m area of the midden, but it is not visible to the observer. The occurrence of all vocalizations by red squirrels inside and outside the of the midden area were recorded as they occurred (Table 16). The raw data from the observation records were summarized on separate sheets (Appendix K) and the summarized data entered into computerized files. The summaries tally the data used for analysis of the level of activity as well as for time budgets.

Cone caching activity is the best method to estimate the stored food resource without disturbing the middens. During the 2-hour behavior observations, all instances of cone caching were recorded to determine relative rates of cone caching. When possible, the species of cone was also recorded. The frequency of cone caching and the total number of cones cached on the monitored areas during the 1990 and 1991 were compared. Cone caching activity was observed, but not specifically recorded in 1989.

Data Analyses

All of the behavioral data were analyzed by the season of the year (spring = April, May, June; summer = July, August; autumn = September, October, November) to reduce seasonal variation in some aspects of behavior, such as caching and territorial defense (Ferron et al. 1986). The effort to pair observations by gender on construction and non-construction areas was done to reduce possible gender variation even though differences in age and sex classes were not found to be significant in previous studies, even during the breeding season (Ferron, et al. 1986). Therefore age and sex variables were not considered in the analysis. Owing to possible seasonal differences in the activity patterns, and to the various construction activities in the different habitats (construction activity in the TR area only consisted of traffic on the access

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road versus earth-moving and concrete work in the SF area), the time budgets of squirrels were analyzed within habitats. In 1989 and 1990, all construction activity occurred from September through November; in 1991, construction took place during the peak of the reproductive season (late-spring and summer) as well as autumn.

The analyses of the behavior data make extensive use of non-parametric statistics because the data usually are not normally distributed, have unequal variances, and small sample sizes. The exception are the analyses of activity indices where sample sizes are generally larger and the data are paired. Such data allows more powerful parametric statistics (a paired t-test in this case) to be used. In all analyses, an α of 0.05 was used as the level of significance. Specific analyses are indicated for each type of data. A discussion on the resolving power in relation to sample size of the parametric statistics used in the analysis is given in Appendix P.

Level of activity -- The level of activity between squirrels on construction and non-construction areas was compared by using the amount of time the resident squirrel spent at the midden site, amount of time in the nest, the number of visits to the midden, and interval between visits during an observation period and vocal behavior as indices of the level of activity. Vocal behavior consisted of the number of chatters, squeaks, barks, and time barking (Tbark). Observations of less than 120 minutes and those where no squirrel was observed were not used. Paired t-tests (Snedecor and Cochran 1980), which take advantage of the paired nature of the observations to control for abiotic effects, such as weather, time of day, and season, were used to compare the level of activity of squirrels on construction and non-construction areas. If there was no effect from construction activities, the indices of activity for squirrels on the construction areas should not differ from the indices of activity on the non-construction areas.

Time budgets -- The data for comparing time budgets, consists of the amount of time spent in any of the 19 activity categories, except "Out of midden area", and accounts for the entire "in midden" behavior during a 2-hour observation period. However, all 19 activity categories were grouped into four broad categories of similar or related activities for the initial analyses and were also analyzed by individual category (Table 16). Non-parametric, Kruskal-Wallis tests were used to detect differences in the amount of time spent on the grouped and individual categories by squirrels on the construction and non-construction areas.

Cone caching -- Cone caching behavior on construction versus non-construction areas was compared by testing for differences in the occurrence of cone caching during observations (G-tests) and the total number of cones cached during those observations in which caching was observed (Kruskal-Wallis test).

Results

Observations began on 21 May 1991 and were discontinued due to snow and cold temperatures on 22 October 1991. A total of 506 observations (1012 h) at 106 midden sites were recorded through spring, summer, and autumn during periods when construction was and was not occurring (Table 17). However, there were no periods when construction did not occur during spring observations. Construction and non-construction periods are tested separately for the summer and autumn seasons, but there were too few non-construction observations in summer to make any definitive conclusions about activity during that period.

Level of Activity

The only differences in the level of activity during spring in the TR habitat were vocal; squirrels on the non-construction area chattered and barked more than squirrels on the construction area. Although squirrels on the non-construction area barked more frequently, the amount of time spent barking did not differ significantly (Table 18; Appendix L). Squirrels in SF habitat on the non-construction area spent more time in their nests than squirrels on the construction area, but did not differ in any other index of activity during spring (Table 18; Appendix L).

The level of activity in TR and SF habitats were similar on all areas during construction periods in summer (Table 18; Appendix L). Unfortunately, there were insufficient data on all areas when no construction activity occurred, and it is not appropriate to draw any conclusions concerning squirrel activity patterns during this period.

Squirrels in SF habitat squeaked more on the SFN area than on the SFC area during the autumn construction period (Table 18; Appendix L). Squirrel activities in SF habitat were similar on construction and non-constructions areas in the absence of construction activity (Table 18; Appendix L). Squirrels on the TRC area spent more time at the midden and vocalized (squeaks, barks, and time barking) more than the TRN squirrels during periods when there was no construction activity. However squirrels in the TRN area made more visits to their middens than TRC squirrels (Table 18).

Broad behavior categories -- There are no apparent patterns of differences in time budgets between squirrels on the construction and non-construction areas except in the TR habitat during autumn 1991 when there was no construction activity (Table 19; Appendix M). During that period, squirrels on the construction area spent more time out of sight in the midden area, and less time on food-related or passive activities than did squirrels on the non-construction area.

During spring when construction was occurring, squirrels on the TRN area spent more time in defensive activities than did squirrels on the TRC area. Squirrels on the SFC and SFN areas did not differ in any of their spring activities.

During the summer construction period, squirrels on the TRC area spent more time out-of-sight (in or out of the midden) than did squirrels on the TRN area. There were no differences in the time budgets of squirrels on the construction and non-construction areas in SF habitat during any season, regardless of construction activity.

Individual behavior categories -- There is no consistent pattern to any of the differences in time budgets of individual behavior categories between squirrels on the construction and non-construction areas, in different seasons (Table 20; Appendix N). The most consistent difference in time budgets is that squirrels on the non-construction areas spent more time basking than did squirrels on the construction areas during construction periods in summer, and during non-construction periods in autumn. TRN area squirrels also basked more during non-construction periods in summer, though the sample size during that time is too small (n=3) to be conclusive. Time budgets differed most on the TR areas during autumn in periods with no construction, just as in the analysis of the broad behavior categories.

Cone caching

During spring and summer 1990 caching behavior was noted during only 3 of 210 (<2%) observations. During the autumn 1990 bumper cone crop, caching behavior was observed during 103 of 206 observations (50%). In contrast to 1990, caching behavior was frequently observed during the 1991 spring (26%) and summer (39%), but less frequently in autumn (39%) observation periods. Spring and summer caching activity was primarily cones left from the 1990 crop that had blown down or were clipped from the trees during the previous late-autumn and winter and were under the snow all winter. These cones, as well as a few freshly clipped cones, were collected and cached as the snow melted away. Cones cached in autumn 1991 were primarily new cones from corkbark fir, Douglas fir and white pine. Squirrels in SF habitat collected 1990 Engelmann spruce cones in autumn 1991 as well as some new spruce cones.

The amount of time squirrels spent caching did not differ between construction and non-construction areas during any season regardless of construction activity in 1990 or 1991 (Table 20 above). There were no differences between construction and non-construction areas, in the proportion of observations where caching behavior was observed, during autumn 1990 or any season of 1991 (Table 21; Appendix O). The number of cones cached by squirrels on the construction and non-construction areas were similar during all seasons, except during spring 1991 in the TR habitat when more cones were cached by squirrels on the non-construction area than on the construction area (Table 22; Appendix O).

Discussion

Comparisons of activity indices indicate that there were no specific changes in the behavior of the squirrels due to construction activity during any season in 1991. In most cases, squirrel behavior was seasonally the same in all areas regardless of construction activity. Further, when differences did occur, they were not what might be expected as a result of construction related disturbances. For example, the only observed behavioral differences in the TR habitat areas during construction periods were the number of chatters and barks -- more vocalizations were heard in the non-construction area than in the construction area. The local density of squirrels on the non-construction area was about twice as high as on the construction area -- 2.3 versus 1.0 (Appendix D-2, April-June 1991). Squirrels on the non-construction area also had shorter distances to their nearest neighbors than did squirrels on the construction area during that time period (Appendix D-2, April-June). Because the chatter call is used primarily for territorial defense against other red squirrels (C.C. Smith 1978), squirrels with more, and closer, neighbors and therefore more potential competitors would be expected chatter more frequently than squirrels with fewer neighbors.

Although the number of barks may also be related to squirrel density, it is more difficult to interpret because red squirrels bark at the presence of predators and humans, as well as other red squirrels (C.C. Smith 1978). Consequently, the greater amount of barking observed on the TR non-construction area only indicates that those squirrels were more agitated than squirrels on the TR construction area during the spring 1991 construction periods.

Squirrels on the SF non-construction area spent more time in their nests (10.77 min./ per observation) than squirrels on the SF construction area. However, there was no difference in the amount of time squirrels on either area spent at their middens and conversely, away from their middens. Although the squirrels on the non-construction area were less active while in the midden, there was no difference in the amount of out-of-midden activity. This observation may indicate a higher level of vigilance by SFC squirrels while at the midden, perhaps as a result of the construction activity.

The largest number of differences in the time budget on the TR areas occurred in autumn 1991, when no construction activity was occurring (Table 21). The squirrels in the construction area spent nearly one hour more per observation period at their middens than the non-construction area squirrels, while non-construction area squirrels made more visits to the midden. The non-construction area squirrels were also more vocal than the construction area squirrels; though the amount of territorial chattering was similar, the non-construction area squirrels squeaked and barked more often. It is difficult to speculate that any differences in behavior among squirrels on the TR habitat were a result of construction activity because the only construction activity in 1991 was road traffic -- all major construction activity in 1991 was on the SF habitat.

Cone caching activity was similar on construction and non-construction areas except for spring 1991 when TRN red squirrels were observed caching more cones than red squirrels on the TRC area (Table 22). However, there does not appear to be sufficient evidence that construction activity had any effect on the amount of cones cached by squirrels. Caching behavior appears to occur throughout the year and any time during daylight hours, at least in a year following a good cone crop. Cone caching appears to be a sporadic activity because a squirrel may not cache any cones for several hours, and then cache more than 100 cones in a short period of time. This may, in part, be due to the way different species of cones are harvested. A squirrel first clips a large number of cones from Engelmann spruce and Douglas fir trees, which are relatively small; allows them to fall to the ground; and then carries them, generally one at a time, to the midden. This results in long periods of no caching activity at the midden, followed by bursts of caching activity. Corkbark fir cones are relatively large and red squirrels often clip one cone at a time and carry them immediately to the midden. Some corkbark fir cones grow in clusters and the squirrels clip and cache entire clusters in one trip. Only a few white pine cones were observed being cached, but in each case the squirrels appeared to clip and drop one or two cones and then retrieve and carry them to the midden.

Differences between habitats in the total number of cones cached may be due to differences in the food quality and quantity of the species of cones. Corkbark fir and white pine cones are considerably larger and probably contain more food value than Engelmann spruce cones. Although the squirrels in TR habitat appeared to have cached a smaller number of cones than squirrels in the SF habitat, they may have cached the same amount of energy owing to the larger size of each cone cached. Additional data is needed to determine the relative food quality, especially energy content, of the various cones species.

The behavior data is very difficult to interpret, especially when a pattern of aberrant behavior is expected, in this instance due to construction activities. Although we have observed differences in behavior between red squirrels on the construction and non-construction areas, they are not consistent and, generally, not what would be expected. For example, if construction activity was a disturbance, the effected individuals would be expected to show more evidence of alarm (barking and chattering), seeking seclusion, or avoiding the source of disturbance. Further, such behavior would be expected to be reflected in the population distribution and reproductive success, which did not occur. The squirrels within the respective TR and SF habitats behaved essentially the same. Although, there were differences in red squirrel behavior between the TR and SF habitats, it was anticipated that this might occur.

Observed differences in behavior do not necessarily imply that it is detrimental. For instance, basking behavior, which we interpret as a non-stressful, relaxed activity, occurred at different rates on construction versus non-construction areas frequently in 1991 (Table 20). Basking was observed most frequently on the non-construction areas during periods when construction activity was not present. During periods of construction activity, basking was observed at similar frequencies on construction and non-construction areas. Also, consider the difference in the time squirrels spent in their nest during the spring in the SF habitat when construction activity was occurring (Table 18). The non-construction area squirrels spent more time than the construction area squirrels in their nest. It is difficult to rationalize that spending more time out of the nest (interpreted as an increase in vigilance) by the construction area squirrels at the nest could adversely affect their survival, especially considering that the majority of their behavior appeared to ignore construction activity.

Behavioral differences due to construction activity did not result in any detected differences in midden distribution (Table 5), in over-winter survival (Table 6), or in reproduction success

(Tables 12, 13, 14, and 15). Although the squirrels on the TR habitat had apparently lower over-winter survival than squirrels on the SF habitat, there were no differences in survival between construction and non-construction area populations within habitats (Table 6).

It does not appear there is any evidence to suggest that construction activity during any season from 1989 through 1991 had any impact on the general behavior or cone caching activity of red squirrels in the monitored areas that would affect the survival of the population. The differences in activity patterns were apparently random and generally of minor magnitude. In almost all cases, differences in activity were not what might be expected as a result of construction disturbance. The differences in time budgets of squirrels on the construction and non-construction areas also appeared to be sporadic and random, and present no clear pattern of behavioral changes that can be directly attributed to construction activity.

Table 16. Categories of red squirrel activities used to record behavior observations and to summarize and analyze behavior patterns.

	Broad Categories	Individual Categories
1)	Food Related Activities	Feeding Foraging Caching
2)	Defensive Activities	Territorial behavior w/ red squirrel Territorial behavior w/ other species Other interactions w/ other species Response to human presence Response to predator presence Alert
3)	Passive Activities	Breeding Play Basking Grooming In cavity/nest Other Maintenance Unusual Moving
4)	Out of Sight	Out of sight - in midden Out of midden area

Also recorded:
All vocalizations, within and outside the midden area
All incidents of caching, type of cone cached

Table 17. Summary of the number of observations by area, season and construction activity for 1989 through 1991. Observations lasting less than 120 minutes were not used for statistical analyses.

Spring - April, May, June
Summer - July, August
Fall - September, October, November

		Construction			No Construction		
Year	Area	Spring	Summer	Fall	Spring	Summer	Fall
1989	TRC	-	-	160	-	-	42
	TRN	-	-	166	-	-	26
	SFC	-	-	101	-	-	22
	SFN	-	-	95	-	-	28
	TOTAL	-	-	522	-	-	118
1990	TRC	2	7	16	15	22	21
	TRN	2	7	16	15	22	21
	SFC	0	9	52	35	14	14
	SFN	0	9	52	37	14	14
	TOTAL	4	32	136	102	72	70
1991	TRC	15	10	10	0	3	12
	TRN	15	10	10	0	3	12
	SFC	45	76	68	0	3	11
	SFN	45	76	68	0	3	11
	TOTAL	120	172	156	0	12	46

Table 18. Summary of differences in red squirrel activity in the Transitional Coniferous (TR) and Spruce-Fir (SF) forest habitats.

SEASON	SPRING		SUMMER				AUTUMN			
HABITAT	TR	SF	TR		SF		TR		SF	
CONST	Y	Y	Y	N	Y	N	Y	N	Y	N
sample size	15	43	10	3	74	3	10	11	66	11
T_{midden}	ns	ns	ns	*	ns	*	ns	C>N	ns	ns
T_{nest}	ns	N>C	ns	*	ns	*	ns	ns	ns	ns
# Visits	ns	ns	ns	*	ns	*	ns	N>C	ns	ns
$\bar{x}$ Interval	ns	ns	ns	*	ns	*	ns	*	ns	ns
$\bar{x}$ Duration	ns	ns	ns	*	ns	*	ns	ns	ns	ns
# Chatters	N>C	ns	ns	*	ns	*	ns	ns	ns	ns
# Barks	N>C	ns	ns	*	ns	*	ns	C>N	ns	ns

ns - not significant, N>C - non-construction area greater than construction area, C>N - construction area greater than non-construction area, * - insufficient data for statistical analysis.

Table 19. Summary of results of Kruskal-Wallis (Chi-square Approximation) tests on time spent on grouped behavior categories by squirrels on the Non-construction and Construction Areas during 2-hour behavior observations.

SEASON	SPRING		SUMMER				AUTUMN			
HABITAT	TR	SF	TR		SF		TR		SF	
CONSTRUCTION ACTIVITY ?	Y	Y	Y	N	Y	N	Y	N	Y	N
FOODACT	ns	ns	ns	ns	ns	ns	ns	N>C	ns	ns
DEFACT	N>C	ns	ns	ns	ns	ns	ns	ns	ns	ns
PASSACT	ns	ns	ns	ns	ns	ns	ns	N>C	ns	ns
OOSACT	ns	ns	C>N	ns	ns	ns	ns	C>N	ns	ns

ns - not significant, N > C - non-construction area squirrels spent more time in this category than did construction area squirrels, C > N - construction area squirrels spent more time in this category than did non-construction area squirrels.

Table 20. Summary of results of Kruskal-Wallis (Chi^2 approximation) tests on time spent on individual behavior categories during 2-hour behavior observations.

SEASON	SPRING		SUMMER				AUTUMN			
HABITAT	TR	SF	TR		SF		TR		SF	
CONSTRUCTION ACTIVITY ?	Y	Y	Y	N	Y	N	Y	N	Y	N
FEEDING	ns	ns	N>C	ns	ns	ns	ns	N>C	ns	ns
FORAGING	ns	ns	N>C	ns	ns	ns	ns	N>C	ns	ns
CACHING	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TERRITORIAL a	ns	C>N	ns	ns	ns	ns	ns	ns	ns	ns
TERRITORIAL b	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
RESPOND TO HUMANS	ns	ns	ns	C>N	ns	ns	ns	C>N	ns	ns
RESPOND TO PREDATORS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ALERT	N>C	ns	ns	ns	ns	ns	ns	ns	ns	ns
BREEDING	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PLAYING	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
BASKING	ns	ns	N>C	N>C	N>C	ns	ns	N>C	ns	N>C
GROOMING	ns	ns	ns	ns	ns	ns	ns	N>C	ns	ns
IN-THE NEST	ns	ns	ns	ns	ns	ns	ns	N>C	ns	ns
OTHER MAINTENANCE	ns	ns	ns	ns	ns	ns	ns	N>C	ns	ns
UNUSUAL	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
MOVING	ns	ns	ns	N>C	ns	ns	ns	N>C	ns	ns
OTHER	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
OOSIM	ns	ns	ns	ns	ns	ns	ns	C>N	ns	ns

ns - not significant, N>C - Non-construction Area squirrels spent more time in this category than did Construction Area squirrels, C>N - Construction Area squirrels spent more time in this category than did Non-construction Area squirrels. Territorial a) against other red squirrels, b) against other species.

Table 21. Occurrence of cone caching during 2-hour behavior observations. Caching was observed at less than 1% of observations in Spring and Summer 1990.

Autumn 1990

	TRC	TRN	SFC	SFN
# Obs. with caching	18	17	36	32
# Obs. without caching	19	20	30	34

G=0.877, P=0.831

Spring 1991

	TRC	TRN	SFC	SFN
# Obs. with caching	4	3	13	11
# Obs. without caching	11	12	32	34

G=0.547, P=0.909

Summer 1991

	TRC	TRN	SFC	SFN
# Obs. with caching	4	6	34	27
# Obs. without caching	9	7	45	52

G=1.964, P=0.580

Autumn 1991

	TRC	TRN	SFC	SFN
# Obs. with caching	7	11	29	32
# Obs. without caching	15	11	50	47

G=1.831, P=0.608

Table 22. Cones cached per observation period by squirrels on the monitored areas during seasons when caching was observed. Observations without caching behavior have been excluded.

	Autumn 90		Spring 91		Summer 91		Autumn 91	
Area	n	median (range)	n	median (range)	n	median (range)	n	median (range)
TRC	18	10.5 (1-54)	4	1.5 (1-2)	4	1.5 (1-2)	7	1.0 (1-2)
		ns		*		ns		ns
TRN	17	9.0 (1-38)	3	5.0 (1-12)	6	2.0 (1-6)	12	2.0 (1-9)
SFC	37	17.0 (1-142)	13	11.0 (1-49)	34	4.5 (1-67)	29	2.0 (1-50)
		ns		ns		ns		ns
SFN	32	25.5 (1-139)	11	9.0 (1-62)	27	6.0 (1-52)	32	2.5 (1-55)

'*' - statistical significance ($\alpha < 0.05$) between construction and non-construction within habitat (Kruskal-Wallis tests).

MICROENVIRONMENT OF NEW FOREST EDGES AND MIDDENS

Introduction

In 1990, the Monitoring Program initiated a study to characterize changes in microenvironment that result from the creation of new forest edges due to the construction of MGIO. The main objective was to determine how some microenvironmental variables changed in response to the new forest edge, how far they extended into the forest area from the edge, and to evaluate changes that might result in a reduction in red squirrel habitat. The study was not intended to prove that an edge effect exists, but to describe the extent of the edge effect in terms of soil temperature and moisture.

This selection of soil temperature and soil moisture was based on variables that are most affected by the creation of new forest edges, such as increased wind flow, insolation, and temperature, and decreased moisture and relative humidity. All of these variables can change very rapidly and are not easily measured over a large area without extensive automated instrumentation. However, these variables all interact and influence soil temperature and moisture, which change much more slowly and over a narrower range.

The study was also designed to verify the extent of the edge effects predicted to directly influence the suitability of the forest to support red squirrel middens (Coronado National Forest 1988). The primary function of a midden is a storage site for cones; the accumulation of cone scales and debris provides a cool, moist environment conducive to long term storage of the cones, which open and lose their seeds as they dry out. Warming and drying of the microenvironment presumably could affect the storage ability of middens and, possibly, prevent the establishment of new middens near new forest edges. Therefore, temperature and moisture were selected as the most appropriate variables to measure, as they determine the quality of a midden as a storage facility.

Methods

The initial study used 30 transects along the newly cleared access road and two of the proposed telescope sites (Appendix Q). Beginning from the upper end of the access road, 20 transects were laid out perpendicular to the road at 100 meter intervals that alternated on either side of the road, so that one transect ran uphill and the next one downhill. At the switchbacks, the transects were oriented to extend outward from the apex of the turn. Most of the transects were 150 meters in length with marked recording points at 25 m intervals. Some transects were shorter because of terrain or physical features. Five transects were laid out at each telescope site and extended 100 m from the edge of the clearing in such a manner that the transects would not intersect each other or the access road. Transects at the Submillimeter Telescope (SMT) site extended to the N, NE, E, SE, and S, and transects at the Vatican Advanced Technology Telescope (VATT) site extended to the N, NW, W, SW, and S (Figure 6a).

In 1991, 32 additional transects were laid out at the four proposed sites for the Columbus Project telescope. These transects are 150 m in length and are laid out in the eight compass directions (N, NE, E, SE, S, SW, W, and NW) with recording points at 25 m intervals (Figure 6a). Some of these transects overlap with previously established transects and with each other due to the juxtaposition of the four proposed Columbus sites. Some transects are shorter than 150 m due to the terrain (Appendix Q).

Soil temperature and moisture at 15 cm depth were taken at each point along each transect at approximately two week intervals from June 1990 through October 1990 and from early July 1991 through October 1991. The depth for recording temperature and soil moisture was selected because the soil on the monitored areas is very thin; 15 cm was a depth that could be consistently attained at all microenvironment recording stations. Shallower depths are more susceptible to rapid changes in temperature and moisture, and deeper depths were unattainable in many locations. Soil temperature was recorded in degrees Celsius (°C) using a hand held digital thermocouple thermometer (Type T, Model 8528-20: Cole-Parmer Instrument Co., Chicago, IL). Soil moisture was recorded in centibars (cB) with a portable soil moisture tensiometer (Model 2900-F, Soil Moisture Equipment Corp., Santa Barbara, CA).

The average difference in the soil temperature and moisture between the edge station and each successive station was calculated and tested for differences by paired t-tests.

Data stations were established in 1990 at 20 midden sites. Five middens on each monitored area were selected based on the criteria that they had been continuously occupied by red squirrels since August of 1989. The rational was that these sites probably represented high quality midden sites. In 1991, 20 additional midden sites were chosen at random. The number selected on each area was stratified in proportion to the number of middens on each area at that time. Thus, the TRN area had a total of five stations, the TRC area had seven stations, the SFC area 12 stations, and the SFN area 16 (Figure 6b, Appendix Q). Each station was equipped with a minimum/maximum recording thermometer to record air temperature directly above the midden and soil temperature at 15 cm depth, and a rain gauge to record precipitation. The sensors were placed as close to the center of the midden as possible without being in the accumulated midden material and were protected from rodent damage by wire-screen cages. Records of minimum and maximum soil and air temperature, precipitation, and soil moisture were taken weekly at each station from the time the snow melted away from the stations until when the soil froze in autumn.

In 1991, we experimented with methods to directly assess evaporation rate at the forest floor. Because of the number of transects and the area encompassed by the project, a simple, accurate, and relatively inexpensive method was needed. A pilot study was conducted in June and July 1991 to test the potential of several custom designed "evaporometers". From those tests, one design was selected that showed promising results, and tests were continued for accuracy in Tucson during the winter and spring of 1991-1992. Although the results of these trails are not complete, the selected design appears to be successful and will be used during the 1992 field season in addition to measuring soil moisture and temperature.

Results

Two representative microenvironment transects were analyzed for this report. T13 runs uphill (north) from the access road and T16 runs downhill (south) from the access road (Figure 7). Both transects are on a steep, south facing slope on the western end of Emerald Peak and are in the SF habitat. The soil temperature at 25 m was 2.8°C cooler than the edge on T13 and 0.9°C on T16 and were not significantly warmer or cooler than the temperature at any other point except for the 150 m point on T16 ($P<0.05$)(Figure 7, Appendix R). Soil moisture on T13 was not significantly different from the edge, with the exception of the 75 m station. The soil moisture on all points on T16 were significantly more moist than the edge, but were not significantly different from one another (Figure 7, Appendix R). A cursory examination of remaining transects appears to follow the same trend.

At the midden sites, only the average 1990 and 1991 monthly values for precipitation, soil moisture, and minimum and maximum soil and air temperature are summarized (Appendix S).

Summer precipitation at midden sites were obtained from mid-June through early-November in 1990 and from June through October in 1991, however only months with complete data July through October, is presented for comparison (Appendix S). Freezing temperatures before and after these dates prevented the use of the plastic rain gauges, and most unrecorded precipitation fell as snow. Precipitation at the midden sites was highly variable, due mostly to differences in canopy closure at individual middens -- the denser the tree canopy, less precipitation reached the ground. The average monthly precipitation was generally greater at middens in SF habitat than at middens in TR habitat. July through October accumulated rainfall was correspondingly greater on the SF habitat and 1990 rainfall was approximately twice that of 1991 on both habitats (Figure 8).

Soil temperature at the midden sites was generally cool, rarely exceeding 10 or 11°C (Figure 9). Soil temperature in SF habitat was usually 1 to 2°C cooler than in TR habitat. Soil temperature in both habitats reached their highest maximum temperatures in summer, and were coldest in late-autumn -- no winter temperatures were recorded.

Air temperatures were more variable than soil temperature and there were no apparent differences in either average minimum or maximum air temperatures between habitats (Figure 9). There was a trend for air temperatures in SF habitat to be slightly cooler than in the TR habitat.

Some of the sensing instruments at the midden sites were covered by accumulating cone debris as the middens were expanded, and some suffered periodic damage from bears and other large animals, including vandalism. Damaged equipment was replaced as soon as possible after it was discovered.

Discussion

The preliminary analyses suggests that the edge effect on soil temperature occurs within the first 25 m and is at equilibrium beyond 25 m. Soil moisture shows a different pattern. On T13, there appears to be only a slight or no edge effect, and the entire transect is not significantly drier than the edge. On T16, the edge effect on soil moisture is restricted to the first 25 meters, but the edge is significantly drier than any point along the transect (Appendix R). A cursory examination of all transects supports these limited findings and suggests that whatever edge effect there is, it is within 25 meters of the access road, which is within the 3 tree length distance suggested in the Expanded Biological Assessment (Coronado National Forest 1988) (Figure 7).

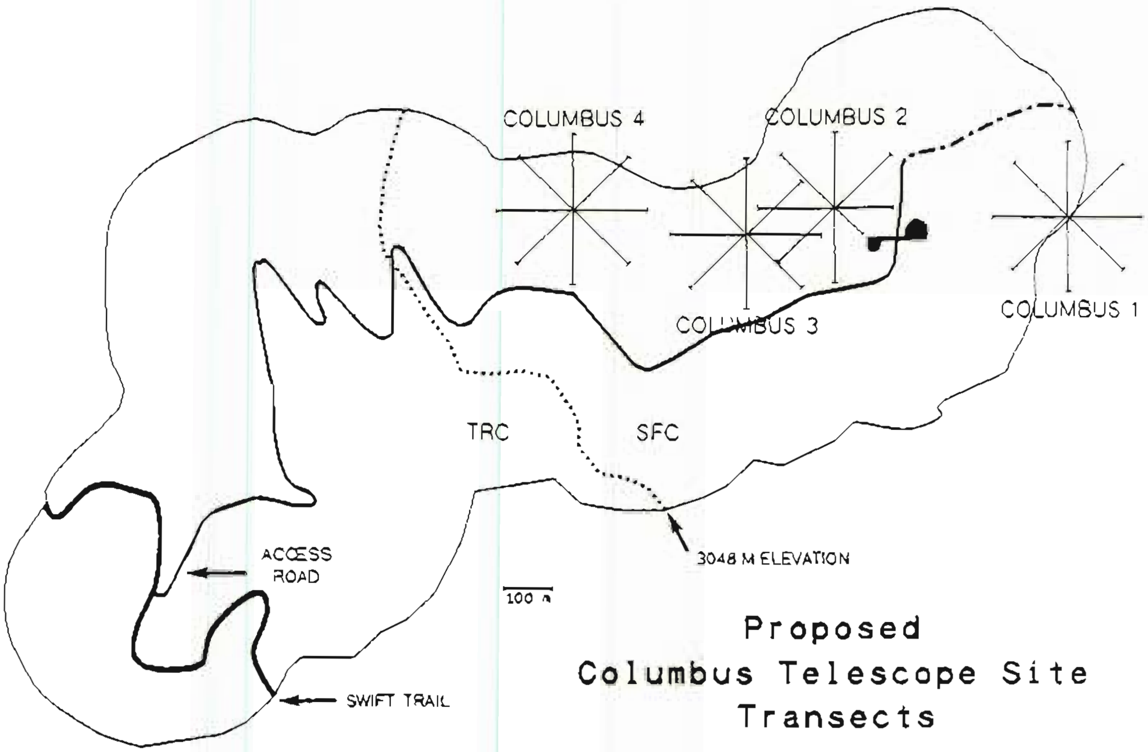
The average monthly soil moisture was also highly variable among different midden sites but apparently not different between habitats. However, there was a tendency for soil moisture to be lower at the middens in TR habitat than in the SF habitat (Figure 8). The soil was driest in spring, became progressively more moist during the summer rain season and dried again in autumn each year. The driest soils were recorded in spring/early summer 1990 following a winter with below normal snowfall and several years drought.

Recommendations

Further analysis of the microenvironment data will be used for the basis of revising the microenvironmental monitoring activities. The scope of the microenvironment study will be reduced and altered to improve data quality and concentrate on the transects in the most homogeneous habitat. Transects retained for the study will be shortened, and the recording points spaced closer together, (perhaps at 5 to 10 m intervals) to concentrate on the first 25 to 50 meters from the edge. The evaporometers designed in 1991 will be incorporated into the study. The number of potential Columbus telescope sites monitored will be reduced from four to the one or two most likely sites and the transects will be shortened with closer spacing between recording points. All of these changes will result it a more useful study specifically designed to provide information on microenvironment changes that could have a direct impact on the suitability of the habitat for red squirrels.

The preliminary microenvironment transect data will be submitted as a separate report.

Figure 6a. Map showing the location of microenvironment transects.



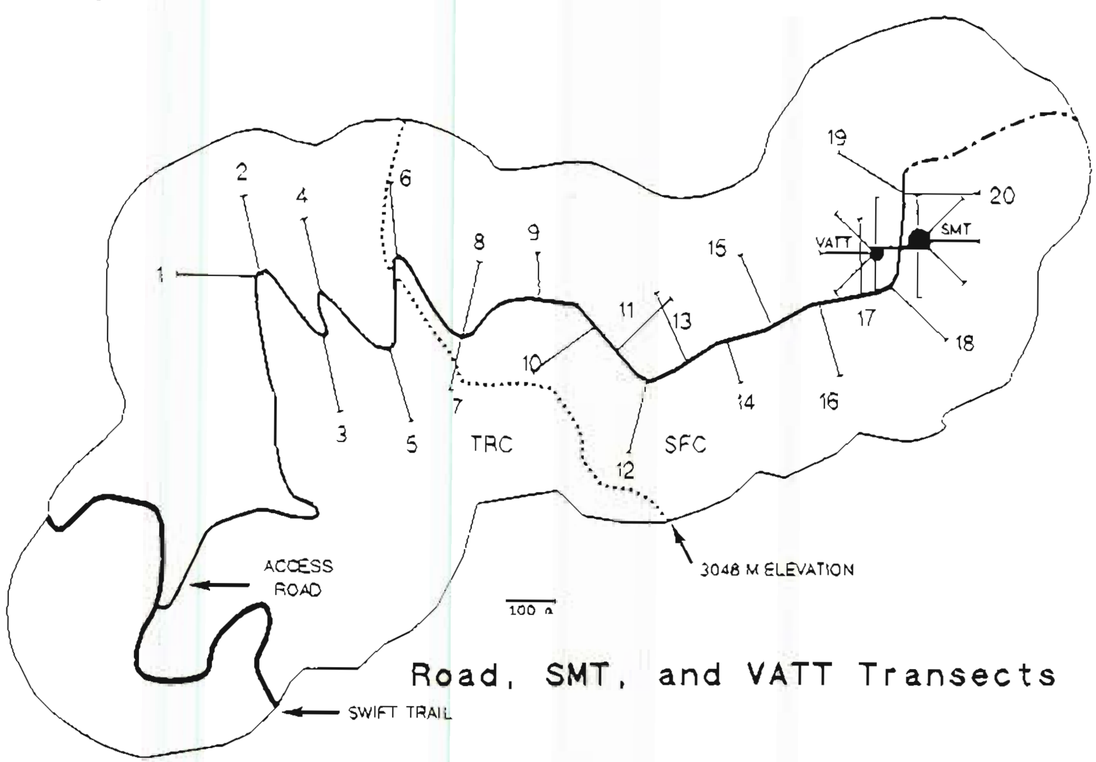


Figure 7. Plots of the average differences in soil moisture and soil temperature between the edge and points at 25 m intervals along two transects.

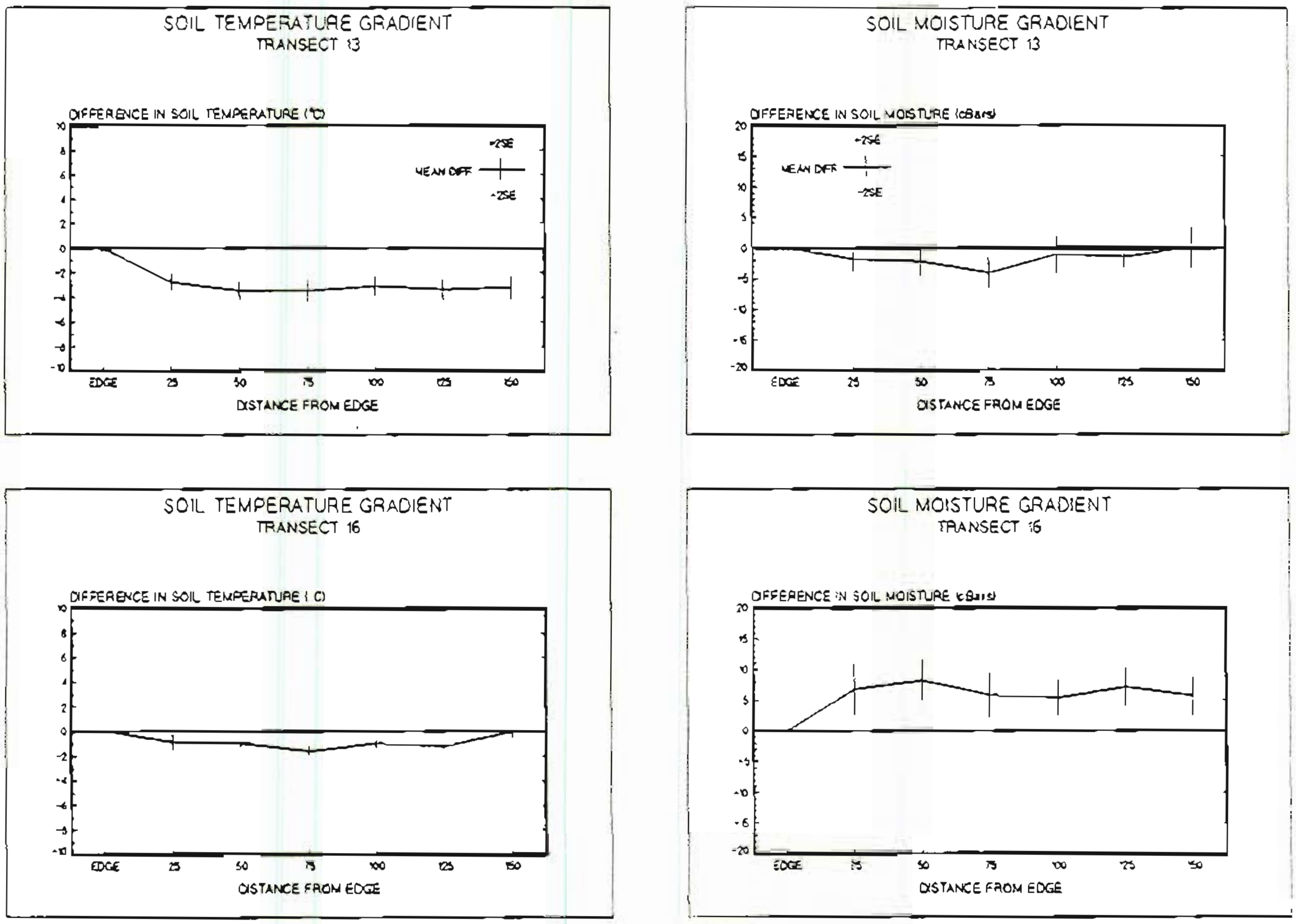
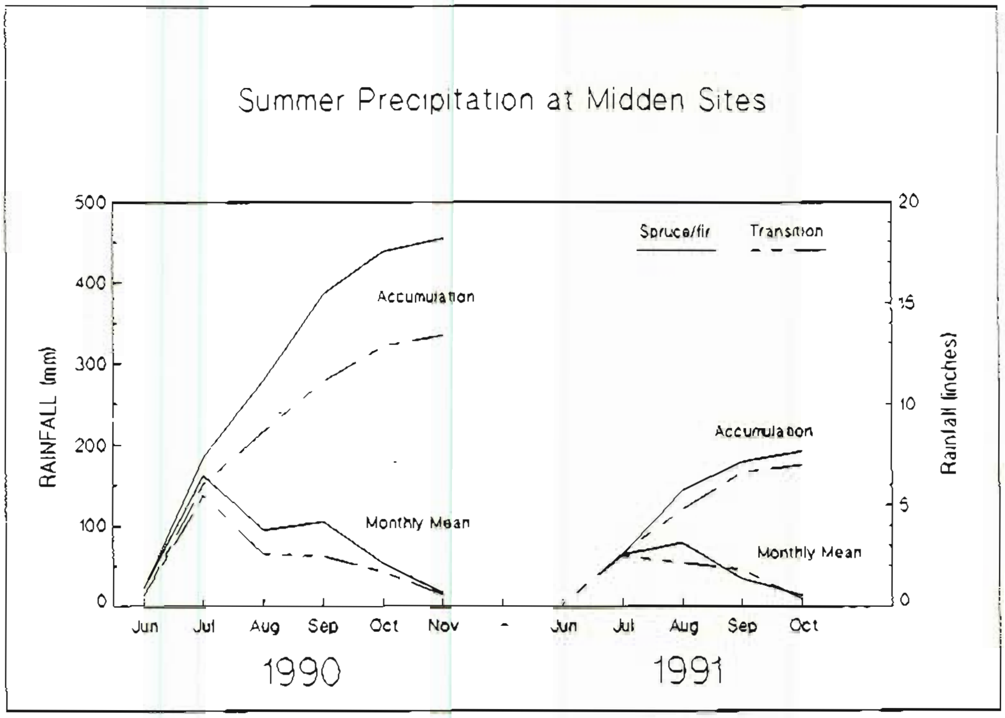


Figure 8. a)TOP: Mean monthly and total accumulated precipitation at red squirrel middens in different habitats.
b)BOTTOM: Mean monthly soil moisture at red squirrel middens in different habitats.



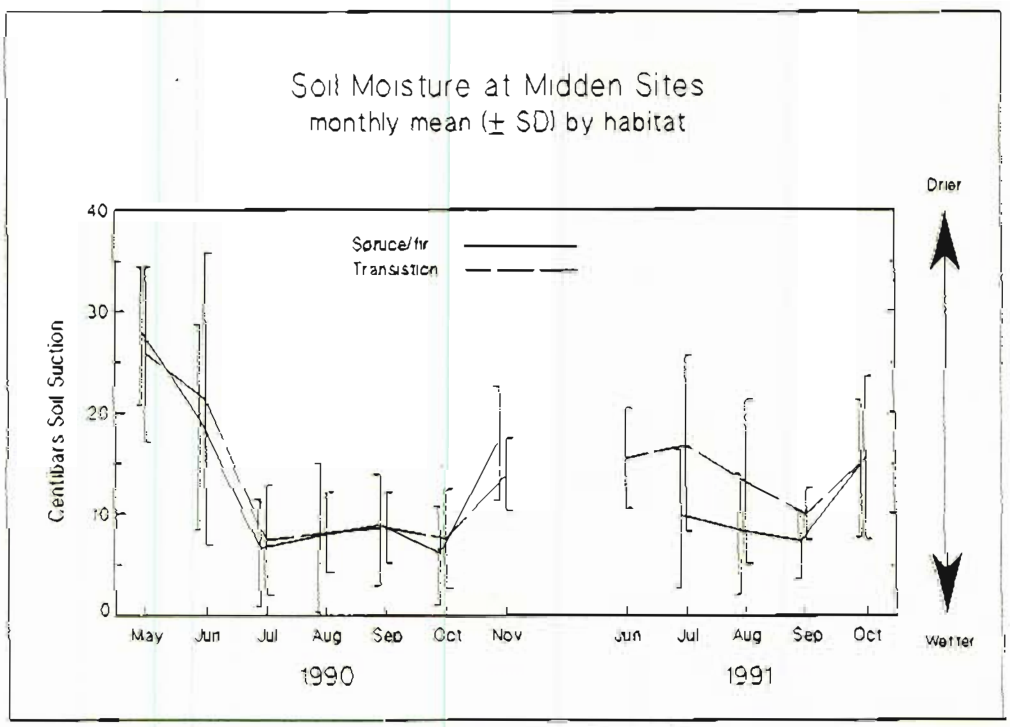
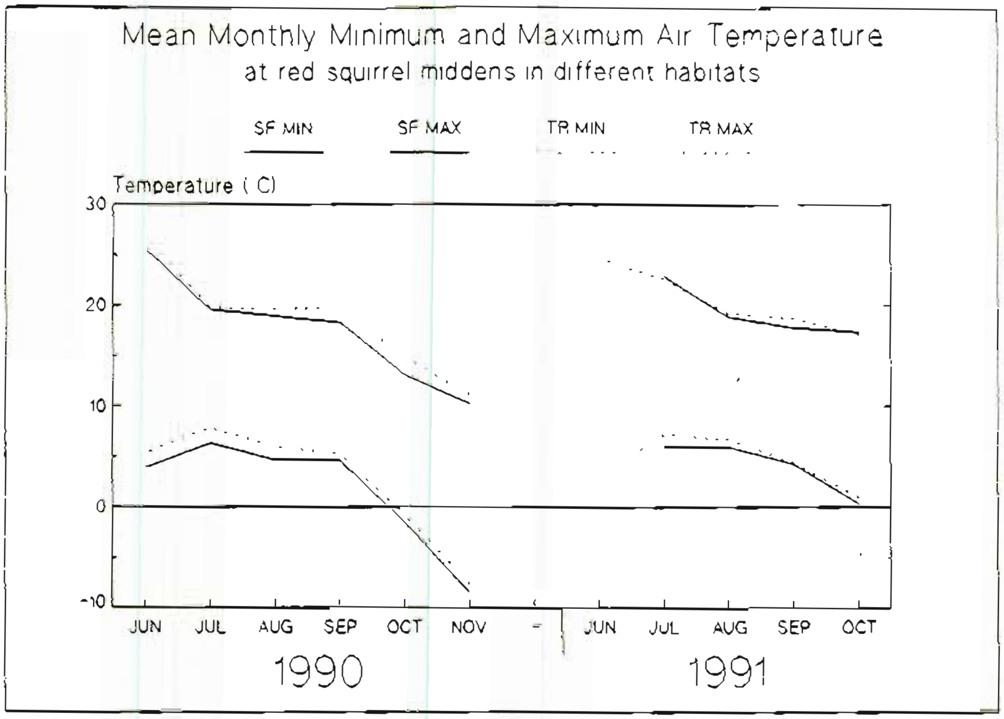
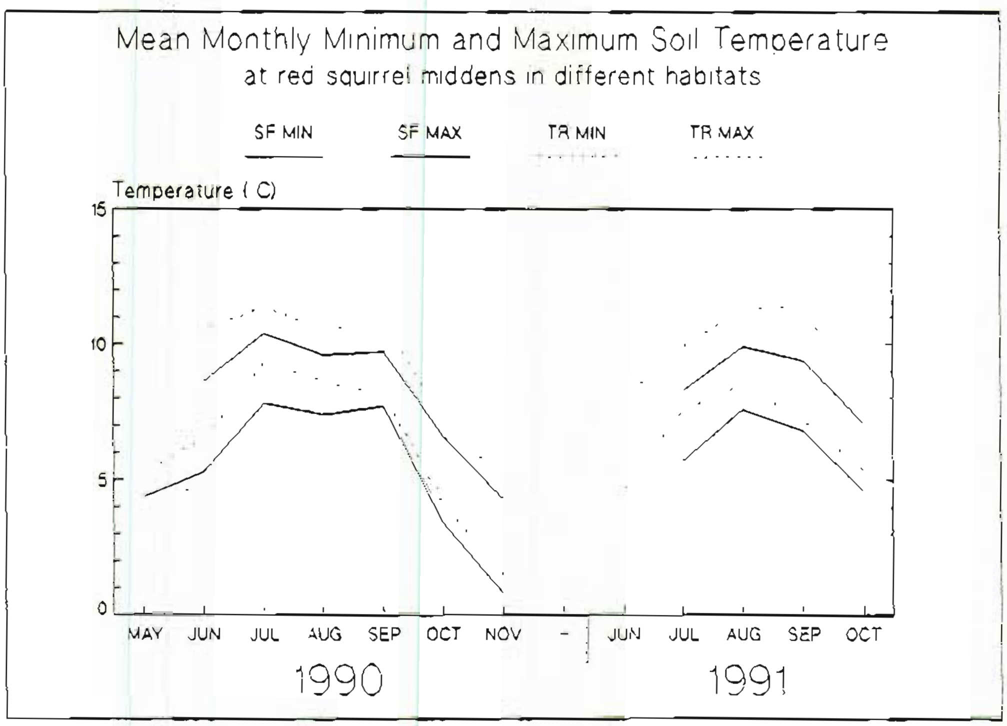


Figure 9. Mean monthly minimum and maximum air (top) and soil (bottom) temperatures, at red squirrel middens in different habitats.





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Appendix A. Midden maps for each month, August 1989 through November 1991.

Appendix B. Monthly squirrel census records, August 1989 - November 1991.

Table B1. Red squirrel populations on the monitored areas from August 1989 through December 1991. Numbers in table cells indicate the number of squirrels living independently. Cells with "##+##" indicate the number of squirrels living independently plus the numbers of juveniles living with their mothers.

DATE	Transition Habitat		Spruce/fir Habitat		Total
	TRC	TRN	SFC	SFN	
Aug 1989	11	-	6	12	29
Sep 1989	11	6	6	11	34
Oct 1989	17	8	5	10	40
Nov 1989	16	7	6	6	35
Dec 1989	-	-	-	-	-
Jan 1990	13	7	5	7	32
Feb 1990	13	7	3	-	32[1]
Mar 1990	10	7	7	9	33
Apr 1990	12	6	7	8	33
May 1990	10	7	6	8	31
Jun 1990	10	4 + 3	3	6	23 + 3
Jul 1990	6 + 5	5 + 6	3	6	20 + 11
Aug 1990	7 + 2	5 + 4	5	6	23 + 6
Sep 1990	9	8	6	15	38
Oct 1990	12	9	14	31	66
Nov 1990	16 + 3	14	17	42	89 + 3
Dec 1990	-	-	-	-	-
Jan 1991	8 + 1	8	11	36	63 + 1
Feb 1991	7	8	18	26	59
Mar 1991	-	-	-	-	-
Apr 1991	8	9	14	34	65
May 1991	12	8	18	35	73

DATE	Transition Habitat		Spruce/fir Habitat		Total
	TRC	TRN	SFC	SFN	
Jun 1991	15 + 8	10 + 4	19	36 + 3	80 + 15
Jul 1991	13 + 2	12	21	38 + 2	84 + 4
Aug 1991	18 + 1	12 + 2	22 + 8	41 + 3	93 + 14
Sep 1991	23	15	20 + 2	40 + 4	98 + 6
Oct 1991	33	16	25	41	115
Nov 1991	38	19	24	43	124

* Data missing; census not made owing to poor weather and snow conditions.

[1] Unable to census, assumes same population for UC as in Mar 1990.

Appendix C. Midden occupancy records.

Table C-1. -Occupancy records of middens on the monitored areas during 1989

KEY

For Midden Numbers:

###[89*] Midden Number['Year Found'] '*' following year indicates a newly established midden

For Monthly Occupancy cells:

N	Not Occupied
P	Possibly Occupied, red squirrel sign found but unsure of residency
Y	Occupied, Red Squirrel sign indicates resident
S	Occupied, Red Squirrel sighted
♀	Occupied, Adult female squirrel
♂	Occupied, Adult male squirrel
J	Occupied, juvenile squirrel sex unknown
A	Abert's Squirrel using area, no red squirrel present
+	Indicates the month in which the midden was found or established.
XXX	Remains of red squirrel found
*	Squirrel is tagged
-	Missing data
♀R	Adult female, reproductive
♀L	Adult female, lactating
♀+'#'	Adult female with "#" juveniles

Transition Habitat - Construction Area Midden Occupancy 1989												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101^{89}	-	-	-	-	♀	♀	-	S	♀	Y	S	-
102^{89}	-	-	-	-	P	Y	-	S	S	Y	S	-
103^{89}	-	-	-	-	P	♀*X	-	S	♀	Y	S	-
104^{89}	-	-	-	-	Y	Y	-	S	S	Y	S	-
105^{89}	-	-	-	-	Y	S	-	S	♀	Y	S	-
106^{89}	-	-	-	-	N	N	-	S	♂*	Y	S	-
107^{89}	-	-	-	-	-	S	-	S	♀*	Y	S	-
108^{89}	-	-	-	-	-	Y	-	S	♂	Y	S	-
109^{89}	-	-	-	-	-	S	-	S	S	Y	S	-
110^{89-}	New Midden (NE 109)									+S	S	-
111^{89}	-	-	-	-	S	♀*	♀+1	S	S	Y	S	-
112^{89-}	New Midden (NE 111)									+S	S	-
113^{89}	New Midden (ENE 112)									+Y	Y	-
114^{89}	New Midden (N 112)									+Y	N	-
115^{89}	New Midden (SE 101)									+P	P	-
116^{89-}	New Midden (S 104)									+P	N	-
117^{89}	New Midden (S 119)									+P	P	-
118^{89}	New Midden (E 111)									+S	S	-
119^{88}	-	-	-	-	P	P	-	S	S	Y	S	-
120^{89}	-	-	-	-	N	N	-	N	N	N	N	-
121^{89-}	New Midden (W 108)									+S	S	-
122^{89}	New Midden (ESE 108)									+N	N	-
# Mid.	-	-	-	-	12	12	12	12	12	22	22	-
# Occ.	-	-	-	-	4	9	1	11	11	17	16	-
% Occ.	-	-	-	-	33	75	8	92	92	81	73	-
# Sq.	-	-	-	-	4	9	1+1	11	11	17	16	-

Transition Habitat - Non-construction Area Midden Occupancy 1989												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
201[89]	New Midden (new area)								+S	Y	S	-
202[89]	New Midden (new area)								+S	Y	S	-
203[89]	New Midden (new area)								+S	Y	S	-
204[89]	New Midden (new area)								+S	S	S	-
205[89]	New Midden (new area)								+S	Y	S	-
206[89]	New Midden (new area)								+S	Y	S	-
207[89*]	New Midden (new area)									+S	S	-
208[89*]	New Midden (new area)									+Y	N	-
# Mid	-	-	-	-	-	-	-	-	6	8	8	-
# Occ.	-	-	-	-	-	-	-	-	6	8	7	-
% Occ.	-	-	-	-	-	-	-	-	100	100	88	-
# Sq.	-	-	-	-	-	-	-	-	6	8	7	-

Spruce/fir Habitat - Construction Area Midden Occupancy 1989												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
150[87]	-	-	-	-	N	N	-	N	N	N	N	-
151[87]	-	-	-	-	N	P	-	N	N	N	N	-
152[86]	-	-	-	-	N	N	-	N	N	N	N	-
153[87]	-	-	-	-	N	N	-	N	N	N	N	-
154[86]	-	-	-	-	P	Y	-	Y	S	S	S	-
155[86]	-	-	-	-	N	N	N	N				
156[86]	-	-	-	-	S	♀+2	-	S	S	Y	S	-
157[86]	-	-	-	-	N	N	-	N	N	N	N	-
158[87]	-	-	-	-	N	N	-	N	N	N	N	-
159[87]	-	-	-	-	N	Y	-	N	P	N	N	-
160[86]	-	-	-	-	P	P	-	P	S	Y	S	-
161[86]	-	-	-	-	N	P	-	P	N	N	N	-
162[86]	-	-	-	-	N	N	-	-	N	N	N	-
163[86]	-	-	-	-	N	N	-	N	N	N	N	-
164[86]	-	-	-	-	P	P	-	Y	P	N	N	-
165[86]	-	-	-	-	Y	♂?	-	S	S	S	S	-
166[86]	New Midden (E 167)							+N	N	N	-	-
167[87]	-	-	-	-	N	N	-	N	N	N	N	-
168[86]	-	-	-	-	N	Y	-	N	P	N	N	-
169[86]	-	-	-	-	N	N	-	N	N	N	N	-
170[86]	-	-	-	-	N	N	-	N	N	N	N	-
171[87]	-	-	-	-	P	-	-	-	P	N	N	-
172[89]	New Midden (E 171)									+N	N	-
173[87]	-	-	-	-	N	N	-	N	N	N	N	-
174[89]	-	-	-	-	S	J	-	S	S	S	S	-
175[86]	New Midden (WSW 176)									+N	N	-
176[86]	-	-	-	-	S	S	-	S	Y	P	Y	-
177[87]	-	-	-	-	P	Y	-	P	P	P	P	-

Spruce/fir Habitat - Construction Area Midden Occupancy 1989												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
# Mid.	-	-	-	-	25	25	-	26	25	27	27	-
# Occ.	-	-	-	-	4	8	-	6	6	5	6	-
% Occ.	-	-	-	-	16	32	-	23	24	19	22	-
# Sq.	-	-	-	-	4	8+2	-	6	6	5	6	-

Spruce/fir Habitat - Non-construction Area Midden Occupancy 1989												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
221[90]	-	-	-	-	P	-	-	P	P	P	P	-
222[86]	-	-	-	-	Y	-	-	S	S	Y	S	-
223[86]	-	-	-	-	P	-	-	S	S	Y	S	-
224[86]	-	-	-	-	N	-	-	N	N	N	N	-
225[87]	New Midden (SE 224)							+N	N	N	N	-
226[86]	-	-	-	-	N	-	-	N	N	N	N	-
227[86]	-	-	-	-	S	-	-	S	S	Y	S	-
228[86]	-	-	-	-	N	-	-	N	N	N	N	-
229[86]	-	-	-	-	S	-	-	S	S	S	S	-
230[86]	-	-	-	-	N	-	-	N	N	N	N	-
231[86]	-	-	-	-	P	-	-	N	P	N	P	-
232[86]	-	-	-	-	N	-	-	N	N	N	N	-
233[87]	New Midden (NE 231)										+N	-
235[86]	-	-	-	-	Y	-	-	Y	S	S	S	-
236[86]	-	-	-	-	Y	-	-	N	N	P	P	-
237[86]	-	-	-	-	N	-	-	N				
241[86]	-	-	-	-	N	-	-	N	N	N	N	-
242[86]	-	-	-	-	N	-	-	N				
243[86]	-	-	-	-	P	-	-	P	P	Y	-	-
244[86]	-	-	-	-	N	-	-	N	N	N	-	-
245[86]	-	-	-	-	P	-	-	N	-	N	-	-
246[86]	-	-	-	-	N	-	-	N	N	N	-	-
247[86]	-	-	-	-	Y	-	-	S	S	S	S	-
248[86]	-	-	-	-	N	-	-	N	N	N	-	-
249[86]	-	-	-	-	Y	-	-	N	-	N	-	-
250[86]	New Midden (SW 249)							+P	-	N	-	-
251[88]	-	-	-	-	P	-	-	P	P	N	N	-
252[86]	-	-	-	-	Y	-	-	P	Y	N	P	-

Spruce/fir Habitat - Non-construction Area Midden Occupancy 1989												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
253[86]	-	-	-	-	N	-	-	N	N	N	N	-
254[86]	-	-	-	-	P	-	-	N	-	P	N	-
255[86]	-	-	-	-	N	-	-	N	-	N	N	-
256[86]	-	-	-	-	N	-	-	N	P	P	N	-
257[86]	-	-	-	-	N	-	-	N	N	N	N	-
258[86]	-	-	-	-	N	-	-	N	-	N	N	-
259[86]	-	-	-	-	N	-	-	N	N	N	N	-
260[87]	-	-	-	-	P	-	-	N	-	N	N	-
266[87]	-	-	-	-	N	-	-	N	N	N	-	-
267[87]	-	-	-	-	P	-	-	S	Y	Y	-	-
268[87]	-	-	-	-	N	-	-	N	N	N	-	-
269[87]	-	-	-	-	P	-	-	P	S	N	P	-
270[87]	-	-	-	-	Y	-	-	Y	P	N	-	-
271[87]	-	-	-	-	P	-	-	P	P	N	-	-
272[87]	-	-	-	-	S	-	-	S	S	Y	-	-
273[87]	-	-	-	-	S	-	-	S	N	N	-	-
274[86]	-	-	-	-	Y	-	-	S	P	N	-	-
275[87]	-	-	-	-	P	-	-	-	N	N	-	-
276[87]	-	-	-	-	N	-	-	-				
281[86]	-	-	-	-	P	-	-	N	-	-	-	-
282[86]	-	-	-	-	N	-	-	N	-	N	-	-
283[86]	-	-	-	-	N	-	-	N	-	N	-	-
284[86]	-	-	-	-	S	-	-	S	S	Y	N	-
285[86]	-	-	-	-	N	-	-	N	N	N	N	-
286[86]	-	-	-	-	N	-	-	N	N	N	N	-
287[86]	-	-	-	-	N	-	-	N	N	N	N	-

Spruce/fir Habitat - Non-construction Area Midden Occupancy 1989												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
# Mid	-	-	-	-	51	-	-	53	50	50	51	-
# Occ	-	-	-	-	13	-	-	12	11	10	6	-
% Occ	-	-	-	-	25	-	-	23	22	20	12	-
# Sq	-	-	-	-	13	-	-	12	11	10	6	-

Table C-2. -Occupancy records of middens on the monitored areas during 1990

KEY

N - Not Occupied
Y - Occupied, Sex of squirrel unknown
P - Potentially Occupied, red squirrel sign found but no squirrel observed
♀ - Occupied, Adult female squirrel
♂ - Occupied, Adult male squirrel
J - Occupied, juvenile squirrel sex unknown
A - Abert's Squirrel using area, no red squirrel present

+	- before the letter or symbol indicates a midden that is newly located or newly added to the middens being monitored
XXX	- remains of red squirrel found
*	- squirrel is tagged
-	- missing data or midden unknown at that time
♀L	- Adult female, lactating
♀+'#'	- Adult female with "#" juveniles

Transition Habitat - Construction Area Midden Occupancy 1990												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101[89]	Y	Y	Y	Y	♀	♂	N	N	Y	Y	Y	-
102[89]	Y	Y	N	N	N	N	N	N	P	Y	Y	-
103[89]	Y	Y	Y	Y	♂	♂	♂	♂	♂	♂	Y	-
104[89]	P	N	Y	♀	♀	♀L	♀+3	♀	J	J	Y	-
105[89]	Y	Y	Y	♂	♂	♂	N	J	P	Y	Y	-
106[89]	♂*	♂*	♂*	♂*	♂*	♂*	♂*	♀	♀	♀	Y	-
107[89]	♀*	♀*	♀*	♀*	♀*	♀L*	♀*	N	N	N	Y	-
108[89]	Y	Y	Y	Y	N	Y	N	N	N	Y	Y	-
109[89]	Y	Y	Y	Y	♂	♂	N	N	N	N	N	-
110[89*]	Y	Y	N	Y	N	N	N	N	N	N	N	-
111[89]	Y	Y	Y	♂	♂	♂	♂	♂	N	N	N	-
112[89*]	Y	Y	N	♀	♀	♀	♀+2	♀+2	♀	♀	Y	-
113[89]	N	N	N	N	N	N	N	N	N	N	N	-
114[89]	N	N	N	N	N	N	N	N	N	N	N	-
115[89]	N	N	N	N	N	N	N	N	N	N	N	-
116[89*]	N	N	P	N	N	P	N	J	J	J	Y	-
117[89]	N	N	N	N	N	N	N	N	N	N	N	-
118[89]	Y	Y	Y	♂	♂	N	N	P	Y	Y	♀+3	-
119[88]	♂	♂	N	N	N	N	N	N	Y	Y	Y	-
120[89]	N	N	N	N	N	N	N	N	N	N	N	-
121[89*]	N	N	N	N	N	N	N	N	N	N	Y	-
122[89]	N	N	N	N	N	N	N	N	N	N	N	-
130[90]	New Midden (SE 111)										+Y	-
131[90*]	New Midden (W 111)								+Y	Y	Y	-
132[90*]	New Midden (SW 111)										+Y	-

Transition Habitat - Construction Area Midden Occupancy 1990												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
# Mid	22	22	22	22	22	22	22	22	23	23	25	-
# Occ	13	13	10	12	10	10	6	7	9	12	16	-
% Occ	59	59	45	55	45	45	27	32	39	52	64	-
# Sq	13	13	10	12	10	10	6+5	7+2	9	12	16+3	-

Transition Habitat - Non-construction Area Midden Occupancy 1990											
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
201[89]	Y	Y	Y	Y	♀	♀L	♀+3	♀+2	♀	♀	Y	-
202[89]	Y	Y	Y	Y	♀	N	N	N	J	J	Y	-
203[89]	Y	Y	Y	Y	♀	♀L	♀	♀	♀	♀	Y	-
204[89]	N	N	N	N	N	N	N	N	N	N	N	-
205[89]	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	-
206[89]	Y	Y	Y	♂	♂	♂	♂	Y	Y	Y	Y	-
207[89*]	Y	Y	Y	P	♀	N	N	N	N	N	N	-
208[89*]	Y	Y	Y	Y	♂	-	-	N	N	N	N	-
209[90]	New Midden(W203)			+♀	♀L	♀+3	♀+3	♀+2	♀	♀	Y	-
210[90]	New Midden (N 203)				+N	N	N	N	N	Y	Y	-
211[90*]	New Midden (SW 203)								+Y	Y	Y	-
212[90]	New Midden (W 210)								+N	N	Y	-
213[90]	New Midden (SE 201)								+Y	N	Y	-
214[90*]	New Midden (SE 213)									+Y	Y	-
215[90*]	New Midden (SE 201)										+Y	-
216[90*]	New Midden (NE 201)										+Y	-
217[90*]	New Midden (NE 202)										+Y	-
# Mid	8	8	8	9	10	10	10	10	13	14	17	-
# Occ	7	7	7	6	7	4	5	5	8	9	14	-
% Occ	88	88	88	67	70	40	50	50	62	64	82	-
# Sq	7	7	7	6	7	4+3	5+6	5+4	8	9	14	-

Spruce/fir Habitat - Construction Area Midden Occupancy 1990												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
150[87]	N	N	N	N	N	N	N	N	N	N	N	-
151[87]	N	N	N	N	N	N	N	N	N	N	N	-
152[86]	N	N	N	N	N	N	N	N	N	N	N	-
153[87]	N	N	N	N	N	N	N	N	N	N	Y	-
154[86] 155	Y	N	Y	Y	N	N	N	N	Y	Y	Y	-
156[86]	Y	P	Y	Y	Y	N	N	♀L	Y	♀	Y	-
157[86]	N	N	N	N	N	N	N	N	N	N	N	-
158[87]	N	N	N	N	N	N	N	N	N	N	N	-
159[87]	N	N	N	N	N	N	N	N	N	N	N	-
160[86]	Y	Y	Y	Y	♂	♂	♂	♂	♂	♂	Y	-
161[86]	N	N	N	N	N	N	N	N	N	N	P	-
162[86]	N	N	N	N	N	N	N	N	N	N	N	-
163[86]	N	N	N	N	N	N	N	N	N	N	N	-
164[86]	N	N	N	N	N	N	N	N	N	N	P	-
165[86]	Y	Y	Y	♀	♂	N	N	N	N	Y	Y	-
166[86]	N	N	N	N	N	N	N	N	N	Y	Y	-
167[87]	N	N	N	N	N	N	N	N	N	N	N	-
168[86]	P	P	Y	Y	♀	Y	Y	Y	♀	♀	Y	-
169[86]	N	N	N	N	N	N	N	N	N	P	Y	-
170[86]	N	N	N	N	N	N	N	N	N	N	N	-
171[87]	N	N	N	N	N	N	N	N	N	Y	Y	-
172[89]	N	N	N	N	N	N	N	N	N	N	Y	-
173[87]	N	N	N	N	N	N	N	N	N	N	N	-
174[89]	Y	Y	Y	♂	♂	♂	♂	♂	♂	♂	Y	-
175[86]	N	N	N	N	N	N	N	N	N	N	N	-
176[86]	P	P	Y	N	N	N	N	N	N	Y	Y	-
177[87]	P	P	N	Y	♂	N	N	♂	Y	Y	Y	-
178[90-]	New Midden (NE 153)									+Y	Y	-

Spruce/fir Habitat - Construction Area Midden Occupancy 1990												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
179[90*]	New Midden (NW 154)									+Y	Y	-
180[90*]	New Midden (NE 156)									+Y	Y	-
181[90*]	New Midden (NW 156)									+Y	Y	-
# Mid	27	27	27	27	27	27	27	27	27	31	31	-
# Occ	5	3	7	7	6	3	3	5	6	14	17	-
% Occ	19	11	26	26	22	11	11	19	22	45	55	-
# Sq	5	3	7	7	6	3	3	5	6	14	17	-

Spruce/fir Habitat - Non-construction Area Midden Occupancy 1990												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
220[90]	New Midden (SE 221)									+Y	Y	-
221[86]	N	-	N	N	N	N	N	N	N	N	Y	-
222[86]	Y	-	Y	Y	♂	♂	♂	♂	♂	♂	Y	-
223[86]	Y	-	Y	N	N	N	N	N	N	Y	Y	-
224[86]	N	-	N	N	N	N	N	N	N	N	N	-
225[87]	N	-	N	N	N	N	N	N	N	N	N	-
226[86]	N	-	N	N	N	N	N	N	N	N	N	-
227[86]	Y	-	Y	XXX	N	N	N	N	Y	Y	Y	-
228[86]	N	-	N	N	N	N	N	N	N	Y	Y	-
229[86]	Y	-	Y	Y	♂	♂	♂	♂	♂	♂	Y	-
230[86]	N	-	N	N	N	N	N	N	N	Y	Y	-
231[86]	N	-	N	N	N	N	N	N	N	Y	Y	-
232[86]	N	-	N	N	N	N	N	N	Y	J	Y	-
233[87]	N	-	N	N	N	N	N	N	N	N	P	-
234[86]	+N	-	N	N	N	N	N	N	N	N	N	-
235[86]	Y	-	Y	Y	♀	♀	♀	Y	Y	Y	Y	-
236[86] 237	N	-	N	N	N	N	N	N	N	Y	Y	-
238[90*]	New Midden (NE 235)										+Y	-
239[90*]	New Midden (SW 229)										+Y	-
241[86] 242	N	-	N	N	N	N	N	N	N	Y	Y	-
243[86]	N	-	N	N	N	N	N	N	N	Y	Y	-
244[86]	N	-	N	Y	Y	N	N	N	N	Y	Y	-
245[86]	N	-	P	N	N	N	N	N	N	Y	Y	-
246[86]	N	-	N	N	N	N	N	N	N	N	N	-
247[86]	Y	-	Y	Y	♂	♂	♂	♂	♂	Y	Y	-
248[86]	N	-	N	N	N	N	N	N	N	N	N	-
249[86]	N	-	P	N	N	N	N	N	N	N	N	-

Spruce/fir Habitat - Non-construction Area Midden Occupancy 1990												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
250^{86}	N	-	N	N	N	N	N	N	N	Y	Y	-
251^{88}	N	-	N	N	N	N	N	N	N	N	N	-
252^{86}	P	-	Y	Y	♀	N	N	N	N	Y	Y	-
253^{86}	N	-	N	N	N	N	N	N	N	N	N	-
254^{86}	N	-	N	N	N	N	N	N	N	N	Y	-
255^{86}	N	-	N	N	N	N	N	N	N	N	N	-
256^{86}	N	-	N	N	N	N	N	N	N	N	N	-
257^{86}	N	-	N	N	N	N	N	N	N	N	N	-
258^{86}	N	-	N	N	N	N	N	N	N	N	N	-
259^{86}	N	-	N	N	N	N	N	N	N	N	N	-
260^{87}	N	-	N	N	N	N	N	N	J♀	Y	Y	-
262^{90}	FS Midden MT-13 (S 257)								+N	Y	Y	-
263^{90}	FS Midden MT-12 (SSW 257)								+Y	Y	Y	-
264^{90}	New Midden (W 271)								+Y	Y	Y	-
265^{90*}	New Midden (NW 266)								+Y	Y	Y	-
266^{87}	N	-	N	N	N	N	N	N	N	P	Y	-
267^{87}	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	-
268^{87}	N	-	N	N	N	N	N	N	N	N	N	-
269^{87}	N	-	N	N	N	N	N	P	Y	Y	Y	-
270^{87}	N	-	N	N	N	N	N	P	Y	Y	Y	-
271^{87}	N	-	N	N	N	N	N	N	N	N	Y	-
272^{87}	P	-	Y	Y	Y	Y	Y	Y	Y	♂	Y	-
273^{87}	N	-	N	N	N	N	N	N	Y	J	Y	-
274^{86}	N	-	N	N	N	N	N	N	N	Y	Y	-
275^{87} 276	N	-	N	N	N	N	N	N	N	Y	Y	-
277^{87}	FS Midden BS-20 (W 274)									+Y	Y	-
278^{90*}	New Midden (NW 267)										+Y	-
279^{90*}	New Midden (W 267)										+Y	-

Spruce/fir Habitat - Non-construction Area Midden Occupancy 1990												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
280^{90-}	New Midden (NW 220)										+Y	-
281^{86}	N	-	N	N	N	N	N	N	N	N	N	-
282^{86}	N	-	N	N	N	N	N	N	N	N	N	-
283^{86}	N	-	N	N	N	N	N	N	N	N	N	-
284^{86}	N	-	N	N	N	N	N	N	N	N	Y	-
285^{86}	N	-	N	N	N	N	N	N	N	N	N	-
286^{86}	N	-	N	N	N	N	N	N	N	N	Y	-
287^{86}	N	-	N	N	N	N	N	N	N	N	N	-
# Mid	52	-	52	52	52	52	52	52	56	58	63	-
# Occ	7	-	9	8	8	6	6	6	15	31	42	-
% Occ	13	-	17	15	15	12	12	12	27	53	67	-
# Sq	7	-	9	8	8	6	6	6	15	31	42	-

Table C-3. Occupancy records of middens on the monitored areas during 1991

KEY

For Midden Numbers:

###$^{89-}$ Midden Number$^{\text{'Year Found'+*'}}$ following year indicates a newly established midden.

Middens found prior to 1989 were located by USFS and AGFD surveys.

For Monthly Occupancy cells:

N	Not Occupied
P	Possibly Occupied, red squirrel sign found but unsure of residency
Y	Occupied, Red Squirrel sign indicates resident
S	Occupied, Red Squirrel sighted
♀	Occupied, Adult female squirrel
♂	Occupied, Adult male squirrel
J	Occupied, juvenile squirrel sex unknown
A	Abert's Squirrel using area, no red squirrel present
+	Indicates the month in which the midden was found or established.
XXX	Remains of red squirrel found
*	Squirrel is tagged
-	Missing data
♀R	Adult female, reproductive
♀L	Adult female, lactating
♀+'#'	Adult female with "#" juveniles

Transition Habitat - Construction Area Midden Occupancy 1991												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
101^{89}	S	P	-	S	♂	♂	♂	♂	♂	♂	♂	-
102^{89}	Y	S	-	N	♀	♀R	♀L	♀	♀	♀	♀	-
103^{89}	J	J	-	S	♂	♂	♂	♂	♂	♂	♂	-
104^{89}	Y	♂	-	N	♀L	♀L+2	♀L	♀+1	♀	♂J	♀	-
105^{89}	P	N	-	S	N	N	N	N	N	N	N	-
106^{89}	P	P	-	S	N	♂	P	♂	♂	♂	♂	-
107^{89}	P	N	-	N	N	N	N	♂	♂	♂	♀	-
108^{89}	P	N	-	N	N	N	N	♀	♀	♀	♀	-
109^{89}	N	N	-	N	N	N	N	P	♀	♀J	♀	-
110^{89*}	N	N	-	N	N	N	N	N	♀	♀	♀	-
111^{89}	N	N	-	N	N	N	N	N	N	N	N	-
112^{89*}	N	P	-	N	♀L	♀L+4	♀+2	♂	♂	♂	♂	-
113^{89}	N	N	-	N	N	N	N	S	♀	♀	♀	-
114^{89}	N	N	-	N	N	N	N	N	S	P	N	-
115^{89}	N	N	-	N	N	N	N	N	♀J	♀J	S	-
116^{89*}	P	Y	-	♂	S	♂	Y	♂	♂	♂	♂	-
117^{89}	N	N	-	N	A	A	N	N	N	N	N	-
118^{89}	♀+1	J	-	P	♀	♀L	♀	♀	♀	♀	♀	-
119^{88}	Y	N	-	Y	♀	♀	♀	♀	♀	♀	S	-
120^{89}	N	N	-	N	N	♂	N	N	N	N	♀	-
121^{89*}	P	P	-	N	A	♀L+2	♀	S	♀	♀	♀	-
122^{89}	N	N	-	N	N	N	N	N	N	N	N	-
130^{90}	Y	S	-	S	♀L	♀L	♀	♀	♀	♀	♀	-
131^{90*}	Y	Y	-	N	♂	♂	♂	♂	S	♂	♂	-
132^{90*}	N	N	-	Y	♂	♂	♂	♂	♂	♂	♂	-
134^{91*}	Site near camp				+♀L	♀L	♀L	♀L	♀	P	N	-
135^{91*}	New Midden (SSE 105)							+♀	♀L/♂	♂	♂	-
136^{91*}	New Midden (NE 109)									+♂J	♂	-
137^{91*}	New Midden (E 106)									+♀	♀	-
138^{91*}	New Midden (NW 106)									+♀	♂	-
139^{91*}	New Midden (SW 122)									+♂	♂	-
140^{91*}	New Midden (SE 122)									+♂	♂	-
141^{91*}	New Midden (S 140)									+♂	♂	-
142^{91*}	New Midden (E 120)									+♀	♀	-
143^{91*}	New Midden (SW 120)									+♀	♀	-

Transition Habitat - Construction Area Midden Occupancy 1991												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
144^{91*}	New Midden (NE 115)									+♂	S	-
145^{91*}	New Midden (N 114)									+S	♂	-
146^{91*}	New Midden (E 114)								+S[1]	S	♂	-
147^{91*}	New Midden (NE 114)									+♂J	♂	-
148^{91*}	New Midden (NNE 120)									+S	♀	-
149^{91*}	New Midden (NE 118)										+♂	-
300^{91*}	New Midden (W 112)										+♂	-
301^{91*}	New Midden (ENE 113)										+S	-
302^{91*}	New Midden (SE 110)										+S	-
# Mid	25	25	-	25	26	26	26	27	28	40	44	-
# Occ	8	7	-	8	12	15	13	18	23	33	38	-
% Occ	32	28	-	32	46	58	50	67	82	83	86	-
# Sq	8+1	7	-	8	12	15+8	13+2	18+1	23	33	38	-

[1] This midden was found on 21 September and was omitted in error from Quarterly Report 3. The population numbers for September are correct and should replace those in QR-3.

Transition Habitat - Non-construction Area Midden Occupancy 1991												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
201[89]	N	Y	-	S	N	♂	♂	♂	♂	♂	♂	-
202[89]	N	N	-	♀	♀L	♀L+1	♀	♀	♀	♀	♀	-
203[89]	S	S	-	S	♀L	♀	♀	♀	♀	♀	♀	-
204[89]	N	N	-	N	N	N	P	P	J	♀	♀	-
205[89]	Y	♀	-	♂	♀	♂	♂	♂	♂	♀	♀	-
206[89]	S	S	-	♂	♂	♂	♂	♂	♂	♂	♂	-
207[89*]	N	N	-	A	N	N	N	N	N	♂J	♂J	-
208[89*]	N	N	-	N	N	N	N	N	N	N	♀	-
209[90]	N	Y	-	♂	♂	♂	♂	♂	♂	♂	♂	-
210[90]	Y	Y	-	♂	♂	♂	♂	♂	♂	♂	♂	-
211[90*]	Y	Y	-	S	♀L	♀L+3	♀	♀+2	2J	♀	♀	-
212[90]	P	N	-	N	N	N	N	P	♀	P	N	-
213[90]	Y	A	-	N	N	N	A	A	N	N	N	-
214[90*]	N	A	-	N	N	N	♂	Y	♂	♂	♂	-
215[90*]	Y	Y	-	N	N	N	♂	♂	♂	♂	♂	-
216[90*]	N	N	-	N	N	N	N	Y	♂	♂	N	-
217[90*]	Y	P	-	♂	♀L	♀	♀	P	P	P	N	-
218[91*]	New Midden (S 210)					+♀L	♀	♀	♀	♀	♂	-
219[91*]	New Midden (NE 205)									+S	♀J	-
400[91*]	New Midden (SW 204)									+♀	♀J	-
401[91*]	New Midden (SE 206)										+♀	-
402[91*]	New Midden (W 201)										+♂	-
403[91*]	New Midden (W 212)										+♀	-
# Mid	17	17	-	17	17	18	18	18	18	20	23	-
# Occ	8	8	-	9	8	10	12	12	14	16	19	-
% Occ	47	47	-	53	47	56	67	67	78	80	83	-
# Sq	8	8	-	9	8	10+4	12	12+2	15	16	19	-

Spruce/fir Habitat - Construction Area Midden Occupancy 1991												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
150^{87}	N	A	-	N	N	A	N	N	N	N	N	-
151^{87}	P	N	-	-	N	N	N	N	N	N	N	-
152^{86}	P	N	-	N	N	P	N	N	N	N	N	-
153^{87}	S	♀	-	♀	♀	♀L	♀L	♀+2	♀	♀	♀	-
154^{86}	S	♀	-	♂	♂	♂	♂	♂	♂	♂	♂	-
156^{86}	S	♂	-	P	♀	♀L	♀L	♀+2	♀	♀	♀	-
157^{86}	N	N	-	N	N	N	N	N	N	N	N	-
158^{87}	N	P	-	N	P	P	P	♀+1	N	N	N	-
159^{87}	N	N	-	N	N	N	N	N	N	N	N	-
160^{86}	S	P	-	S	♂	♂	♂	♂	♂	♂*	♂*	-
161^{86}	P	P	-	N	♂	♂	♂	♂	♂	♂	♂	-
162^{86}	N	N	-	N	N	N	N	N	N	♀	♀	-
163^{86}	N	N	-	N	N	N	N	N	N	♀*	♀*	-
164^{86}	N	N	-	N	N	N	N	N	N	♀	P	-
165^{86}	S	♀	-	♂	♂	♂	♂	♂	♂	♂*	♂*	-
166^{86}	Y	♂	-	♂	Y	♂	♂	♂	♂	♂	Y	-
167^{87}	P	N	-	A	A	N	N	N	P	P	N	-
168^{86}	Y	♀	-	♀	♀	♀L	♂	♂	♂*	♂*	♂*	-
169^{86}	P	Y	-	N	♂	♂	♂	♂	♂	♂*	♂*	-
170^{86}	N	N	-	N	N	N	N	N	N	N	N	-
171^{87}	P	♂	-	♂	♂	♂	♂	♂	♂	♂	♂	-
172^{89}	P	Y	-	N	N	Y	♂	♂	♂	♂	Y	-
173^{87}	P	P	-	N	A	N	N	N	N	N	N	-
174^{89}	Y	S	-	♂	♂	♂	♂	♂	♂	♂	♂	-
175^{86}	P	Y	-	N	A	P	N	N	N	P	N	-
176^{86}	N	♀	-	♀	♀R	♀L	♀L	♀+3	♀+1	♀	♀	-
177^{87}	N	♀	-	S	P	♀R	♀L	♀L	♀	♀	♀	-
178^{90*}	Y	♂	-	Y	♀	♀	♀L	♀L	♀+1	♀	♀	-
179^{90*}	N	S	-	Y	♀	♂	♂	♂	♂	♂	♂	-
180^{90*}	Y	P	-	N	♀	♀L	♀	♀	♀	♀	♀	-
181^{90*}	Y	♂	-	Y	♂	♂	♂	♂	♂	♂	♂	-
182^{90*}	+P	Y	-	N	N	N	♂	P	P	♀*	♀*	-
183^{90*}	-	+S	-	S	♂	P	N	N	N	N	N	-
184^{91*}	New Midden (SW 158)				+ ♂	S	N	♀	N	N	N	-
185^{91*}	Split off 168						+♀	♀	♀*	♀*	♀*	-

Spruce/fir Habitat - Construction Area Midden Occupancy 1991												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
186[91*]	New Midden (below 160)						+♀	♀	♀	♀	♀	-
187[91*]	New Midden (E 172)									+♀	♀	-
#Mid	32	33	-	33	34	34	36	36	36	37	37	-
#Occ	11	18	-	14	18	19	21	22	20	25	24	-
%Occ	34	55	-	42	53	56	58	61	56	68	65	-
#Sq	11	18	-	14	18	19	21	22+8	20+2	25	24	-

Spruce/fir Habitat Non-construction Area Midden Occupancy 1991												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
220[90]	P	♀	-	♂	Y	♀L	♀	♀	♂	♂	♂	-
221[86]	P	P	-	N	N	N	P	P	S	P	N	-
222[86]	Y	P	-	Y	♂	♂	♂	♂	♂	♂	♂	-
223[86]	Y	♀	-	♀	♀	♀	♀	♀	♀	♀	Y	-
224[86]	P	P	-	N	N	N	N	N	N	N	N	-
225[87]	N	N	-	N	N	N	N	N	N	P	N	-
226[86]	P	P	-	N	N	N	N	N	N	N	N	-
227[86]	Y	♂	-	♂	♂	♂	S	♂	♂	♂	♂	-
228[86]	P	N	-	♀	♀L	♀L	♀	♀	♀	♀	♀	-
229[86]	Y	P	-	♂	♂	♂	♂	♂	♂	♂*	♂*	-
230[86]	Y	♀	-	N	P	N	N	N	N	N	N	-
231[86]	P	P	-	♂	S	♂	♂	♂	♂	♂	♂	-
232[86]	Y	♀	-	♀	S	♀L	♀L	♀+1	♀+1	♀	♀	-
233[87]	N	P	-	N	P	N	N	N	N	N	N	-
234[86]	N	N	-	N	N	♀L	♀	P	P	N	N	-
235[86]	S	Y	-	♀	♂	♂	S	♂	♂	♂*	♂*	-
236[86]	P	Y	-	♂	♂	♂	♂	♂	♂	♂*	♂*	-
238[90*]	S	Y	-	♂	S	♂	♂	♂	♂	♂	S	-
239[90*]	-	Y	-	N	N	♀L	♀+2	♀+1	P	N	N	-
240[91]	+N	-	-	-	N	P	N	N	N	N	N	-
241[86]	Y	-	-	♂	Y	P	♂	♂	♂	♂	♂	-
243[86]	Y	-	-	-	♀	♀R	♀	♀	♀	♀	♀	-
244[86]	S	Y	-	♀	♀	♀L	XXX/♂	♂	♂	♂	♂	-
245[86]	Y	♂	-	♀	♀	♂	♂	♂	♂	♂	♂	-
246[86]	N	A	-	♀	N	N	N	N	N	N	N	-
247[86]	Y	S	-	♀L	♀L	♀L+3	S	♀+1	♀	♀	♀	-
248[86]	-	-	-	-	-	-	-	-	N	-	-	-
249[86]	Y	P	-	N	N	P	N	N	N	N	P	-
250[86]	Y	P	-	N	N	N	P	♂	♂	♂	Y	-
251[88]	N	N	-	N	N	N	N	N	N	N	N	-
252[86]	Y	S	-	♀	♀	♀L	♂/♀	♂	♂	Y	♂	-
253[86]	N	N	-	N	N	N	N	N	N	N	N	-
254[86]	Y	P	-	Y	♀	♀	Y	Y	Y	♀	♀	-
255[86]	N	N	-	N	N	N	N	N	N	N	N	-

Spruce/fir Habitat Non-construction Area Midden Occupancy 1991												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
256^{86}	N	A	-	N	N	N	N	N	N	N	N	-
257^{86}	N	N	-	N	N	N	N	N	N	N	N	-
258^{86}	S	N	-	N	N	N	N	N	N	N	N	-
259^{86}	N	N	-	N	N	N	N	N	N	N	N	-
260^{87}	Y	Y	-	♂	Y	♀L	♂	♂	♂	♂	♂	-
261^{91}	New Midden (NW 241)					+♀L	♀L	S	♀	♀*	♀*	-
262^{90}	S	S	-	♀	Y	♂	♂	S	♂	S	♂	-
263^{90}	Y	♂	-	♀	Y	♂	♂	♂	♂	♂	♂	-
264^{90}	S	♀	-	♀	♀	♀L	♀	♀	♀+1	♀	♀	-
265^{90*}	Y	♂	-	♂	♂	♂	♂	♂	♂	♂	♂	-
266^{87}	Y	P	-	S	♀	♀L	S	♂/♀	♀	S	Y	-
267^{87}	Y	P	-	♀	♀	♂	♂	♂	♂	♂	♂	-
268^{87}	N	N	-	N	N	N	N	N	N	N	N	-
269^{87}	Y	S	-	Y	Y	♀	S	♀	♀	♀	♂	-
270^{87}	Y	P	-	Y	♂	♂	♂	♂	♂	♂	♂	-
271^{87}	Y	N	-	♂	P	N	N	S	♀	♀	Y	-
272^{87}	Y	Y	-	♂	♂	♂	♂	♂	♂	♂	Y	-
273^{87}	Y	P	-	N	♂	♂	♂	♂	♂	♂	♂	-
274^{86}	Y	P	-	N	N	N	♂	♂	♂	♂	Y	-
275^{87}	Y	♀	-	N	♀	♀	P	♀	♀	♀	♀	-
277^{87}	-	♀	-	♀R	♀L	♀	♀	♀	♀	♀	S	-
278^{90*}	Y	P	-	♀	Y	♀R	♀	♀	♀	♀	♀J	-
279^{90*}	Y	S	-	N	N	N	N	N	N	N	N	-
280^{90*}	-	♀	-	N	P	N	N	N	N	N	N	-
281^{86}	N	N	-	N	N	N	N	N	N	P	S	-
282^{86}	N	N	-	N	N	N	N	N	N	N	N	-
283^{86}	N	N	-	N	N	N	N	N	N	N	N	-
284^{86}	Y	♀	-	♀	Y	♀L	♀	♀	♀+2	♀	♀	-
285^{86}	N	N	-	♂	N	N	N	N	N	N	N	-
286^{86}	Y	S	-	N	P	P	N	N	N	N	N	-
287^{86}	-	N	-	N	Y	N	N	N	N	N	N	-
288^{91*}	New Midden (NW 284)					+♂	♂	♂	♂	♂	♂	-
289^{91*}	New Midden (SW 281)				+P	P	♀	♀	♀	♀	♀	-
290^{91*}	New Midden (NW228)			+♀	♂	P	P	♀	P	N	N	-
291^{91*}	New Midden (NW 272)									+♀J	Y	-

Spruce/fir Habitat Non-construction Area Midden Occupancy 1991												
Midden	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
292[91*]	New Midden (SW 285)									+♂	♂	-
293[91*]	New Midden (SE 236)									+P	P	-
294[91*]	New Midden (SE 227)										+S	-
#Mid	64	64	-	65	66	68	68	68	68	71	72	-
#Occ	36	26	-	34	35	36	38	41	40	41	43	-
%Occ	56	41	-	52	53	53	56	60	59	58	60	-
#Sq	36	26	-	34	35	36+3	38+2	41+3	40+4	41	43	-

Appendix D. Measures of Spatial Distribution

Table D-1. Crude densities a) squirrels, b) middens

Table D-2. Local Densities and Nearest Neighbor Distances

Table D-3. Index of Aggregation

Table D-1a. Crude Density of red squirrels (including juveniles) in each of the areas under study by the Monitoring Program. The size of each area is given in hectares (ha); densities are given in squirrels per hectare (sq/ha).

DATE	Lower Study Area 91 ha	Lower Control Area 25 ha	Upper Study Area 89 ha	Upper Control Area 122 ha
Aug 1989	0.12	-	0.07	0.10
Sep 1989	0.12	0.24	0.07	0.09
Oct 1989	0.19	0.32	0.06	0.08
Nov 1989	0.18	0.28	0.07	0.05
Dec 1989	-	-	-	-
Jan 1990	0.14	0.28	0.06	0.06
Feb 1990	0.14	0.28	0.03	0.07[1]
Mar 1990	0.11	0.28	0.08	0.07
Apr 1990	0.13	0.24	0.08	0.07
May 1990	0.11	0.28	0.07	0.07
Jun 1990	0.11	0.28	0.03	0.05
Jul 1990	0.12	0.44	0.03	0.05
Aug 1990	0.10	0.36	0.06	0.05
Sep 1990	0.10	0.32	0.07	0.12
Oct 1990	0.13	0.36	0.16	0.25
Nov 1990	0.21	0.56	0.19	0.34
Dec 1990	-	-	-	-
Jan 1991	0.10	0.32	0.12	0.30
Feb 1991	0.08	0.32	0.20	0.21
Mar 1991	-	-	-	-
Apr 1991	0.09	0.36	0.16	0.28
May 1991	0.13	0.32	0.20	0.29
Jun 1991	0.25	0.56	0.21	0.32
Jul 1991	0.16	0.48	0.24	0.33
Aug 1991	0.21	0.56	0.34	0.36

DATE	Lower Study Area 91 ha	Lower Control Area 25 ha	Upper Study Area 89 ha	Upper Control Area 122 ha
Sep 1991	0.25	0.60	0.25	0.36
Oct 1991	0.36	0.64	0.28	0.34
Nov 1991	0.42	0.76	0.27	0.35
Dec 1991	-	-	-	-

\- Data missing; census not made owing to poor weather and snow conditions.

1 Unable to census, assumes same population for UC as in Mar 1990.

Table D-1b. Crude Density of red squirrel middens in each of the areas under study by the Monitoring Program. The size of each area is given in hectares (ha); densities are given in middens per hectare (mid/ha).

DATE	Lower Study Area 91 ha	Lower Control Area 25 ha	Upper Study Area 89 ha	Upper Control Area 122 ha
Aug 1989	0.13	-	0.29	0.43
Sep 1989	0.13	0.24	0.28	0.41
Oct 1989	0.24	0.32	0.30	0.42
Nov 1989	0.24	0.32	0.30	0.42
Dec 1989	-	-	-	-
Jan 1990	0.24	0.32	0.30	0.43
Feb 1990	0.24	0.32	0.30	0.43
Mar 1990	0.24	0.32	0.30	0.43
Apr 1990	0.24	0.36	0.30	0.43
May 1990	0.24	0.40	0.30	0.43
Jun 1990	0.24	0.40	0.30	0.43
Jul 1990	0.24	0.40	0.30	0.43
Aug 1990	0.24	0.40	0.30	0.43
Sep 1990	0.25	0.52	0.30	0.46
Oct 1990	0.25	0.56	0.35	0.48
Nov 1990	0.27	0.68	0.35	0.52
Dec 1990	-	-	-	-
Jan 1991	0.27	0.68	0.36	0.52
Feb 1991	0.27	0.68	0.37	0.52
Mar 1991	-	-	-	-
Apr 1991	0.27	0.68	0.37	0.53
May 1991	0.29	0.68	0.38	0.54
Jun 1991	0.29	0.72	0.38	0.56
Jul 1991	0.29	0.72	0.40	0.56
Aug 1991	0.30	0.72	0.40	0.56

DATE	Lower Study Area 91 ha	Lower Control Area 25 ha	Upper Study Area 89 ha	Upper Control Area 122 ha
Sep 1991	0.31	0.72	0.40	0.56
Oct 1991	0.44	0.80	0.42	0.58
Nov 1991	0.48	0.92	0.42	0.59
Dec 1991	-	-	-	-

\- Data missing; census not made owing to poor weather and snow conditions.

Table D-2. Local Density of middens and squirrels

Transition Habitat - Construction Area (TRC)									
		Middens				Squirrels			
Month	# Mid	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean
Aug 89	12	1.7	0.36	143.9	54.15	1.5	0.34	152.2	60.03
Sep 89	12	1.7	0.36	143.9	54.15	1.5	0.34	152.2	60.03
Oct 89	22	1.9	0.34	88.7	8.73	1.4	0.26	101.2	20.03
Nov 89	22	1.9	0.34	88.7	8.73	1.5	0.26	97.2	83.56
Dec 89	-	-	-	-	-	-	-	-	-
Jan 90[1]	22	2.0	0.33	84.8	7.86	0.9	0.21	103.3	25.61
Feb 90	22	2.0	0.33	84.8	7.86	0.9	0.21	103.3	25.61
Mar 90	22	2.0	0.33	84.8	7.86	1.2	0.39	83.5	9.11
Apr 90	22	2.0	0.33	84.8	7.86	1.2	0.32	83.2	7.76
May 90	22	2.0	0.33	84.8	7.86	1.0	0.39	91.8	8.88
Jun 90	22	2.0	0.33	84.8	7.86	1.2	0.39	88.9	12.04
Jul 90	22	2.0	0.33	84.8	7.86	1.0	0.37	92.8	17.16
Aug 90	22	2.0	0.33	84.8	7.86	2.3	0.64	78.5	17.31
Sep 90	23	2.0	0.31	80.2	7.95	1.1	0.46	134.0	44.93
Oct 90	23	2.2	0.32	79.0	8.16	1.9	0.51	111.3	30.86
Nov 90	25	2.2	0.30	79.2	8.16	2.2	0.40	90.6	23.63
Dec 90	-	-	-	-	-	-	-	-	-
Jan 91	25	2.2	0.30	79.2	8.16	0.9	0.40	147.8	50.78
Feb 91	25	2.2	0.30	79.2	8.16	1.3	0.42	80.7	15.55
Mar 91	-	-	-	-	-	-	-	-	-
Apr 91	25	2.2	0.30	79.2	8.16	1.0	0.42	143.6	42.06
May 91	26	2.1	0.30	83.6	9.02	1.0	0.30	104.1	21.98
Jun 91	26	2.1	0.30	83.6	9.02	1.3	0.32	97.4	17.43
Jul 91	26	2.1	0.30	83.6	9.02	1.4	0.37	97.1	20.34
Aug 91	27	2.2	0.33	81.4	8.90	1.8	0.34	88.7	14.56
Sep 91	28	2.2	0.31	78.3	8.78	1.7	0.28	86.1	11.89
Oct 91	40	4.0	0.38	61.6	6.59	3.3	0.33	63.0	9.10
Nov 91	44	3.8	0.37	58.4	5.43	3.3	0.33	58.5	7.75
Dec 91	-	-	-	-	-	-	-	-	-

1 Off-Area middens within 100m of monitored middens are now included in the analysis.

Transition Habitat - Non-construction Area (TRN)									
		Middens				Squirrels			
Month	# Mid	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean
Aug 89	-	-	-	-	-	-	-	-	-
Sep 89	6	1.3	0.21	73.0	7.25	1.3	0.21	73.0	7.25
Oct 89	8	1.5	0.38	83.2	9.94	1.5	0.38	83.2	9.94
Nov 89	8	1.5	0.38	83.2	9.94	1.7	0.36	75.1	6.67
Dec 89	-	-	-	-	-	-	-	-	-
Jan 90	8	1.5	0.38	83.2	9.94	1.1	0.26	82.3	11.30
Feb 90	8	1.5	0.38	83.2	9.94	1.1	0.26	82.3	11.30
Mar 90	9	1.6	0.34	83.9	8.79	1.1	0.26	82.3	11.30
Apr 90	9	1.6	0.34	83.9	8.79	1.0	0.37	88.9	15.38
May 90	10	1.4	0.34	88.9	9.34	1.1	0.26	84.5	11.43
Jun 90	10	1.4	0.34	88.9	9.34	0.5	0.29	107.2	10.60
Jul 90	10	1.4	0.34	88.9	9.34	0.8	0.20	93.5	7.58
Aug 90	10	1.4	0.34	88.9	9.34	0.8	0.20	93.5	7.58
Sep 90	13	1.6	0.35	85.0	8.00	1.8	0.41	70.5	7.03
Oct 90	14	1.9	0.36	79.4	8.42	1.9	0.39	70.1	9.93
Nov 90	17	2.7	0.40	67.2	7.56	2.9	0.44	61.7	8.52
Dec 90	-	-	-	-	-	-	-	-	-
Jan 91	17	2.7	0.40	67.2	7.56	1.1	0.30	82.7	15.52
Feb 91	17	2.7	0.40	67.2	7.56	1.3	0.25	79.8	8.92
Mar 91	-	-	-	-	-	-	-	-	-
Apr 91	17	2.7	0.40	67.2	7.56	2.4	0.53	67.0	10.82
May 91	17	2.7	0.40	67.2	7.56	2.3	0.53	68.9	12.07
Jun 91	18	2.8	0.38	62.2	6.06	2.8	0.42	57.3	5.91
Jul 91	18	2.8	0.38	62.2	6.06	2.8	0.37	56.7	5.43
Aug 91	18	2.8	0.38	62.2	6.06	2.6	0.26	55.6	5.87
Sep 91	18	2.8	0.38	62.2	6.06	2.4	0.31	61.9	6.61
Oct 91	20	2.8	0.35	55.4	5.10	2.6	0.28	52.7	4.67
Nov 91	23	3.0	0.36	51.2	3.99	2.5	0.31	60.9	4.84
Dec 91	-	-	-	-	-	-	-	-	-

Spruce/Fir Habitat - Construction Area (SFC)									
		Middens				Squirrels			
Month	# Mid	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean
Aug 89	26	1.2	0.19	95.2	11.23	0.3	0.20	175.4	34.17
Sep 89	25[2]	1.0	0.18	98.9	11.16	0.0	0.0	262.6	24.17
Oct 89	27	1.4	0.24	95.5	10.59	0.0	0.0	332.7	43.60
Nov 89	27	1.4	0.24	95.5	10.59	0.0	0.0	262.6	24.17
Dec 89	-	-	-	-	-	-	-	-	-
Jan 90	27	1.4	0.25	95.5	10.59	0.0	0.0	332.7	43.60
Feb 90	27	1.4	0.25	95.5	10.59	0.0	0.0	386.0	52.77
Mar 90	27	1.4	0.25	95.5	10.59	0.0	0.0	262.8	20.41
Apr 90	27	1.4	0.25	95.5	10.59	0.0	0.0	246.1	29.52
May 90	27	1.4	0.25	95.5	10.59	0.0	0.0	250.1	35.52
Jun 90	27	1.4	0.25	95.5	10.59	0.0	0.0	329.5	66.05
Jul 90	27	1.4	0.25	95.5	10.59	0.0	0.0	329.5	66.05
Aug 90	27	1.4	0.25	95.5	10.59	0.0	0.0	258.0	57.42
Sep 90	27	1.4	0.25	95.5	10.59	0.0	0.0	252.0	46.62
Oct 90	31	1.7	0.22	85.5	9.05	1.0	0.24	111.8	22.40
Nov 90	31	1.7	0.22	85.5	9.05	1.3	0.19	92.8	18.55
Dec 90	-	-	-	-	-	-	-	-	-
Jan 91	32	1.7	0.21	81.0	8.36	0.9	0.12	138.0	30.63
Feb 91	33	1.6	0.21	82.5	8.08	1.3	0.24	87.5	12.12
Mar 91	-	-	-	-	-	-	-	-	-
Apr 91	33	1.6	0.21	82.5	8.08	0.9	0.24	123.5	21.03
May 91	34	1.6	0.21	83.1	7.55	1.1	0.16	86.9	12.52
Jun 91	34	1.6	0.21	83.1	7.55	1.3	0.16	89.1	16.82
Jul 91	36	1.7	0.22	80.3	7.33	1.3	0.17	77.8	11.15
Aug 91	36	1.7	0.22	80.3	7.22	1.3	0.17	81.0	11.09
Sep 91	36	1.7	0.22	80.3	7.22	1.4	0.18	73.8	10.89
Oct 91	37	1.8	0.25	77.9	7.25	1.6	0.18	69.9	8.58
Nov 91	37	1.8	0.25	77.9	7.25	1.5	0.18	72.7	8.58
Dec 91	-	-	-	-	-	-	-	-	-

2 Middens 154 and 155 are merged and now counted as one midden.

Spruce/fir Habitat - Non-construction Area (SFN)									
		Middens				Squirrels			
Month	# Mid	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean
Aug 89	53	1.4	0.12	72.6	4.89	0.3	0.14	194.8	48.76
Sep 89	50[3]	1.3	0.13	82.5	4.98	0.2	0.12	239.8	55.33
Oct 89	50	1.3	0.13	82.5	4.98	0.2	0.06	235.3	50.75
Nov 89	51	1.3	0.13	82.1	4.77	0.3	0.20	185.2	54.30
Dec 89	-	-	-	-	-	-	-	-	-
Jan 90	52	1.4	0.14	80.7	4.74	0.3	0.19	209.2	51.78
Feb 90	-[4]	-	-	-	-	-	-	-	-
Mar 90	52	1.4	0.14	80.7	4.74	0.2	0.13	242.6	47.67
Apr 90	52	1.4	0.14	80.7	4.74	0.0	0.0	281.8	39.99
May 90	52	1.4	0.14	80.7	4.74	0.0	0.0	281.8	39.99
Jun 90	52	1.4	0.14	80.7	4.74	0.0	0.0	291.9	49.36
Jul 90	52	1.4	0.14	80.7	4.74	0.0	0.0	291.9	49.36
Aug 90	52	1.4	0.14	80.7	4.74	0.0	0.0	291.9	49.36
Sep 90	56	1.4	0.13	79.5	4.32	0.3	0.13	151.1	24.37
Oct 90	58	1.3	0.13	81.1	4.32	0.6	0.13	108.8	10.42
Nov 90	63	1.6	0.14	76.6	3.97	1.1	0.17	93.4	6.73
Dec 90	-	-	-	-	-	-	-	-	-
Jan 91	64	1.6	0.14	76.7	3.91	1.0	0.18	101.2	7.40
Feb 91	64	1.6	0.14	76.7	3.91	0.4	0.14	132.3	15.79
Mar 91	-	-	-	-	-	-	-	-	-
Apr 91	65	1.6	0.14	76.5	3.82	0.9	0.17	98.9	5.92
May 91	66	1.6	0.14	75.5	3.68	0.8	0.15	105.6	7.67
Jun 91	68	1.7	0.12	74.1	3.25	1.0	0.17	99.9	6.55
Jul 91	68	1.7	0.12	74.1	3.25	1.0	0.16	96.3	5.21
Aug 91	68	1.7	0.12	74.1	3.25	1.1	0.16	94.7	4.94
Sep 91	68	1.7	0.12	74.1	3.25	1.0	0.14	97.4	5.12
Oct 91	71	1.8	0.13	72.0	3.14	1.0	0.14	93.4	5.47
Nov 91	72	1.8	0.13	71.0	3.06	1.1	0.14	88.1	4.90
Dec 91	-	-	-	-	-	-	-	-	-

3 The following midden pairs are merged: 236-237, 241-242 and 275-276
4 No census of Upper Control Area in February 1990.

All Areas Combined									
		Middens				Squirrels			
Month	# Mid	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean	Mean Number w/i 100m	Std. Error of the Mean	Mean Nearest Neighbor Dist (M)	Std. Error of the Mean
Aug 89	91	1.3	0.10	88.5	8.46	0.8	0.18	174.6	30.50
Sep 89	93	1.3	0.10	94.2	8.12	0.8	0.16	186.0	28.56
Oct 89	107	1.5	0.11	87.1	4.02	1.0	0.17	160.1	21.13
Nov 89	108	1.5	0.11	86.9	3.96	1.1	0.18	136.3	17.71
Dec 89	-	-	-	-	-	-	-	-	-
Jan 90	116[1]	1.5	0.11	84.7	3.73	0.7	0.12	153.5	20.99
Feb 90	-[4]	-	-	-	-	-	-	-	-
Mar 90	117	1.5	0.11	84.7	3.69	0.7	0.14	157.7	18.05
Apr 90	117	1.5	0.11	84.7	3.69	0.6	0.14	162.4	17.97
May 90	118	1.5	0.11	85.2	3.69	0.6	0.15	158.6	18.31
Jun 90	118	1.5	0.11	85.2	3.69	0.6	0.18	165.9	23.33
Jul 90	118	1.5	0.11	85.2	3.69	0.5	0.13	174.4	25.58
Aug 90	118	1.5	0.11	85.2	3.69	0.8	0.25	165.9	23.57
Sep 90	129	1.6	0.10	82.1	3.39	0.8	0.15	133.8	15.74
Oct 90	137	1.7	0.10	80.0	3.21	1.1	0.13	101.6	8.12
Nov 90	147	1.8	0.11	76.7	3.07	1.6	0.14	86.1	5.96
Dec 90	-	-	-	-	-	-	-	-	-
Jan 91	149	1.8	0.11	75.9	2.96	1.0	0.12	109.7	8.67
Feb 91	150	1.8	0.11	76.2	2.94	0.9	0.11	106.2	8.14
Mar 91	-	-	-	-	-	-	-	-	-
Apr 91	151	1.8	0.10	76.1	2.92	1.1	0.14	106.7	7.60
May 91	154	1.8	0.10	76.7	2.91	1.0	0.12	98.4	6.14
Jun 91	157	1.9	0.10	75.4	2.77	1.3	0.13	91.2	5.69
Jul 91	159	1.9	0.10	74.8	2.72	1.4	0.12	86.1	4.75
Aug 91	160	1.9	0.10	74.5	2.73	1.4	0.11	84.4	4.33
Sep 91	161	1.9	0.10	74.0	2.73	1.5	0.11	83.0	4.07
Oct 91	180	2.4	0.14	68.0	2.57	2.5	0.14	72.7	3.74
Nov 91	188	2.5	0.13	66.0	2.39	2.1	0.14	70.5	3.36
Dec 91	-	-	-	-	-	-	-	-	-

Table D-3. Index of aggregation of middens and squirrels. Index ranges from 0 (most aggregated) to 2.15 (most uniform), a value of 1 is not different from random. 'Z' values < -2.4 or > 2.4 are significant (P < 0.05).

Month	Area	Middens		Squirrels	
		Index	Corrected Z	Index	Corrected Z
Aug 1989	TRC	1.4356	1.4804	1.4529	1.4512
	TRN	-	-	-	-
	SFC	1.0404	-0.4248	0.9205	-1.0212
	SFN	0.8876	-2.1156	1.1332	-0.0624
Sep 1989	TRC	1.4356	1.4804	1.4529	1.4512
	TRN	1.4610	0.5369	1.4610	0.5369
	SFC	1.0596	-0.2799	1.3784	0.5310
	SFN	0.9987	-0.7704	1.3614	1.0193
Oct 1989	TRC	1.1513	0.3497	1.1550	0.2190
	TRN	1.1737	-0.1048	1.1737	-0.1048
	SFC	1.0634	-0.2272	1.5938	1.0451
	SFN	0.9987	-0.7704	1.2739	0.5161
Nov 1989	TRC	1.1513	0.3497	1.0762	-0.2956
	TRN	1.1737	-0.1048	0.9913	-0.8275
	SFC	1.0634	-0.2272	1.3784	0.5310
	SFN	1.0042	-0.7075	0.7767	-1.5085
Jan 1990	TRC	1.1010	-0.0200	1.0309	-0.5926
	TRN	1.1737	-0.1048	1.0852	-0.4833
	SFC	1.0634	-0.2272	1.5938	1.0451
	SFN	0.9962	-0.8010	0.9474	-0.9470
Feb 1990	TRC	1.1010	-0.0200	1.0309	-0.5926
	TRN	1.1737	-0.1048	1.0852	-0.4833
	SFC	1.0634	-0.2272	1.4323	0.1902
	SFN	-	-	-	-
Mar 1990	TRC	1.1010	-0.0200	0.7303	-2.0023
	TRN	1.1641	-0.1122	1.0072	-0.7833
	SFC	1.0634	-0.2272	1.4895	1.0727
	SFN	0.9962	-0.8010	1.2460	0.3173
Apr 1990	TRC	1.1010	-0.0200	0.7976	-1.8002
	TRN	1.1641	-0.1122	1.0074	-0.7851
	SFC	1.0634	-0.2272	1.3948	0.7200
	SFN	0.9962	-0.8010	1.3644	0.7219

Month	Area	Middens		Squirrels	
		Index	Corrected Z	Index	Corrected Z
May 1990	TRC	1.1010	-0.0200	0.8033	-1.6658
	TRN	1.1115	-0.2637	0.8840	-1.2034
	SFC	1.0634	-0.2272	1.3124	0.3073
	SFN	0.9962	-0.8010	1.3644	0.7219
Jun 1990	TRC	1.1010	-0.0200	0.7781	-1.7822
	TRN	1.1115	-0.2637	0.8477	-1.1751
	SFC	1.0634	-0.2272	1.2226	-0.2702
	SFN	0.9962	-0.8010	1.2240	0.0075
Jul 1990	TRC	1.1010	-0.0200	0.6290	-2.0135
	TRN	1.1115	-0.2637	0.8263	-1.2971
	SFC	1.0634	-0.2272	1.2226	-0.2702
	SFN	0.9962	-0.8010	1.2240	0.0075
Aug 1990	TRC	1.1010	-0.0200	0.5750	-2.3379
	TRN	1.1115	-0.2637	0.8263	-1.2971
	SFC	1.0634	-0.2272	1.2359	-0.0386
	SFN	0.9962	-0.8010	1.2240	0.0075
Sep 1990	TRC	1.0285	-0.5436	1.0748	-0.4325
	TRN	1.1908	0.2440	0.7740	-1.6821
	SFC	1.0634	-0.2272	1.3223	0.3409
	SFN	1.0188	-0.5216	1.0016	-0.7413
Oct 1990	TRC	1.0131	-0.6595	1.0314	-0.5949
	TRN	1.1537	0.0823	0.8165	-1.5666
	SFC	1.0201	-0.5724	0.8965	-1.3350
	SFN	1.0572	-0.0276	1.0370	-0.4215
Nov 1990	TRC	0.9903	-0.8434	0.9060	-1.3371
	TRN	1.0762	-0.3010	0.8979	-1.3509
	SFC	1.0201	-0.5724	0.8197	-1.8925
	SFN	1.0407	-0.2146	1.0365	-0.3661
Jan 1991	TRC	0.9903	-0.8434	1.0455	-0.5809
	TRN	1.0762	-0.3010	0.9084	-1.1446
	SFC	0.9815	-0.9213	0.9806	-0.8450
	SFN	1.0508	-0.0732	1.0815	0.0773
Feb 1991	TRC	0.9903	-0.8434	0.5342	-2.4910
	TRN	1.0762	-0.3010	0.8768	-1.2711
	SFC	1.0153	-0.6110	0.7952	-2.0915
	SFN	1.0508	-0.0732	1.1981	0.9215

Month	Area	Middens		Squirrels	
		Index	Corrected Z	Index	Corrected Z
Apr 1991	TRC	0.9903	-0.8434	1.0157	-0.7007
	TRN	1.0762	-0.3010	0.7806	-1.7209
	SFC	1.0153	-0.6110	0.9901	-0.8062
	SFN	1.0555	-0.0035	1.0017	-0.7369
May 1991	TRC	1.0667	-0.2283	0.9020	-1.2675
	TRN	1.0762	-0.3010	0.7569	-1.7508
	SFC	1.0376	-0.3980	0.7902	-2.1245
	SFN	1.0507	-0.0636	1.0695	-0.0864
Jun 1991	TRC	1.0667	-0.2283	0.9433	-1.0970
	TRN	1.0243	-0.6219	0.7031	-2.1383
	SFC	1.0376	-0.3980	0.8323	-1.8843
	SFN	1.0457	-0.1214	1.0264	-0.4961
Jul 1991	TRC	1.0667	-0.2283	0.8760	-1.4320
	TRN	1.0243	-0.6219	0.7629	-1.9904
	SFC	1.0321	-0.4404	0.7643	-2.4394
	SFN	1.0457	-0.1214	1.0160	-0.5932
Aug 1991	TRC	1.0585	-0.2842	0.9412	-1.1485
	TRN	1.0243	-0.6219	0.7479	-2.0672
	SFC	1.0321	-0.4404	0.8143	-2.1175
	SFN	1.0457	-0.1214	1.0380	-0.3552
Sep 1991	TRC	1.0369	-0.4567	1.0325	-0.5215
	TRN	1.0243	-0.6219	0.8994	-1.3424
	SFC	1.0321	-0.4404	0.7066	-2.7935
	SFN	1.0457	-0.1214	1.0543	-0.1927
Oct 1991	TRC	0.9740	-1.0371	0.9048	-1.6488
	TRN	0.9617	-1.0448	0.8187	-1.8786
	SFC	1.0157	-0.5982	0.7484	-2.7444
	SFN	1.0388	-0.2046	1.0241	-0.5018
Nov 1991	TRC	0.9204	-1.6300	0.8574	-2.1934
	TRN	0.9311	-1.3024	1.0063	-0.7429
	SFC	1.0157	-0.5982	0.7626	-2.5880
	SFN	1.0313	-0.3081	0.9893	-0.8695

Appendix P. Resolving power of statistics used in analysis of behavior.

The following letter and supporting materials were sent to Mr. Rich Kvale in October 1991, upon his request for information concerning the resolving power of the data and statistical tests used in the behavior section of the 1990 Annual Report. It is reproduced here in response to the continuing request by the Forest Service biologists for information on the resolving power of the 1991 data and statistical tests. The same "rule of thumb" which applied to the 1990 data, and indeed applies to any data set, can be applied to the 1991 data; the accuracy of the estimates of central tendency (the mean in most cases) of a data set can be gauged by multiplying the Standard Error of the Mean (SE) times 2 (or 1.96 to be precise). It is for this reason that a measure of the variance of a data set is presented with the measure of central tendency; ie. $\bar{x}$±SE, $\bar{x}$±SD, median and range. For the same reason, standard error bars are usually placed on figures representing the means of different data sets. Statistical significance can not be detected if the standard error bars of one the means overlaps the other mean. For a more detailed, expert explanation refer to any statistical text book.

We have appended two similar examples from the 1991 data; in general the resolving power of the 1991 data is similar or better than for the 1991 data.

05 October 1991

Mr. Richard Kvale
District Ranger
Safford Ranger District
Coronado National Forest
P.O. Box 709
Safford, AZ 85548-0709

Dear Rich:

This letter, and attachments, are the result of the meeting we held at the Columbine Work Center on 2 October 1991, where we discussed the possibility of changing the protocols for the Red Squirrel Monitoring Program.

At the meeting held in Tucson last January, the possibility of stopping the 2 hour behavior observations was discussed. It was my perception that the consensus of the attenders of that meeting was that they could be stopped this autumn, at the time of year where we already have two years data collected. The analyses of the 1989 and 1990 data has been presented to the Forest Service in either the Quarterly reports, or in the 1990 Annual Report.

In response to some of the questions that you and Tom Newman had concerning the resolving power of the statistical tests performed on the behavior data, I have calculated the resolving power of some examples from that analysis. I have also calculated the required sample size necessary to obtain resolving powers of different magnitude, given the large variability in the behavior of individual squirrels.

The formula for calculating sample size is as follows:

$$n=\frac{\sigma^2 z^2{}_{\alpha/2}}{D^2}$$

Where:

- n = sample size
- σ = standard deviation (= St. Error of the Mean * $\sqrt{n}$)
- $z_{\alpha/2}$ = critical value of the cumulative normal variable (z) at the $\alpha/2$ level of significance (I have assumed α=0.05 is acceptable to the Forest Service)
- D = maximum acceptable difference between the sample mean and the "true" mean (resolving power)

This equation is normally used to determine the sample size necessary to collect data where the sample mean is within a specified limited difference of the true (population) mean (Martin and Bateson, 1986). I have used the equation in this manner to show the power curve that describes the sample size needed to collect data of different levels of resolving power. I have also solved the equation for 'D' in a few examples, using the 1990 data, to show the resolving power of the statistics applied to the behavior data. As a "rule of thumb" one can multiply the Standard Error of the Mean by 2 to arrive at the resolving power of the statistical tests that were used in the 1990 analysis.

I think the examples I have enclosed will illustrate the points we discussed at the meeting concerning the variance in the behavior data, and the exceptionally large sample sizes needed to improve the resolving power of the statistics used to analyzed it.

I have often expressed, to Forest Service personnel and others, my belief that the behavior data is of very little real value for determining whether or not the construction activities on Emerald Peak are having any effect on the red squirrel population. I would stress that this belief is not a result of collecting poor data, rather it stems from the large variability in the behavior of individual squirrels, and the interpretive nature of any analysis of behavior data.

There is no good basis for determining how large a difference in the behavior of squirrels on the Study and Control Areas must be to be considered an "impact". For example; Does a difference of 1 chatter per hour constitute a biologically significant difference in the rate of vocalization? Is a difference of 15 minutes spent in the midden area during a 2 hour period of biological significance? What magnitude of difference is required to show a potential effect from construction?

Example 1 (below) shows that a difference of 17.7 minutes (approx. 15% of an observation period) in the amount of time a squirrel spent at the midden site during construction periods in 1990 would have been statistically significant. Compare this to the average difference between squirrels on the Study and Control Area (2.98 minutes). In order to detect a statistically significant difference in this variable as small as 5 minutes would require a sample size of 585 paired observations; over 700 pairs if you consider that approximately 20% of the observations do not have squirrels present at both middens and must be discarded. To obtain a resolving power of 3 minutes would require thousands of paired observations over the same 28 days as our sample of 38 was collected. I have a difficult time imagining what effect hundreds of biologists, tramping through the forest, and watching virtually every red squirrel, continuously, every day, in order to get this resolution, might have on the behavior of the squirrels.

I also believe that any subtle changes in the behavior of squirrels (that we could not statistically detect without enormous sample sizes) that might affect their survival or reproductive success are also better addressed by looking for the results of such changes rather than for the changes themselves. For example, I have had Forest Service personnel tell me that they believe it is important to collect behavior data for such reasons as;

> If a squirrel near construction is disturbed by the noise and activity, it may not forage for food as much an undisturbed squirrel farther away from construction. In this way the disturbance of construction could affect the survival of the squirrel, or reduce its reproductive success.

I believe that such a scenario is possible and plausible, but, I have also maintained that it is much easier and more efficient to measure the effect (ie. the squirrel dies or moves away, or is able to raise fewer young) than it is to measure the cause (a change in foraging time or foraging pattern). Now that we have uniquely marked squirrels on the monitored areas our ability to measure these types of effects are greatly enhanced, reducing the utility of the behavior data even further. I believe that the efforts of the Monitoring Program would be better spent on collecting a greater amount and more detailed data on the numbers and distribution of the red squirrels on the monitored areas.

With marked squirrels we will now be able to determine the rate of turnover of squirrels at middens, record reproductive success of marked females from year to year, and record daily movements of individual squirrels, as well as begin collecting data on the dispersal of juveniles. These aspects of population biology should form the foundation of the Monitoring Program, as they allow us to test simple hypothesis based on assumptions of what effect the construction and operation of the observatory might have on the red squirrel population, such as:

1) Middens nearest to the observatory would have a greater turnover of occupying squirrels than would middens farther from the site. These middens might also be expected to have a lower rate of occupancy than middens farther form the site.

2) Female squirrels nearest to the observatory site would have lower reproductive success than those farther from the site.

3) Squirrels would not disperse into the area closest to the observatory, either to occupy established middens, or to establish new ones.

4) Squirrels at the middens nearest to the observatory would be expected to avoid the site (and vicinity) while foraging

I hope the information in this letter, and my abbreviated logic for preferring population biology data over behavior data will help convince you that a change in the Monitoring Program Protocols is justified. I will be happy to meet with you or any other Forest Service representatives to further discuss this matter, at your earliest convenience. I hope that we can move quickly on this matter so that I will be able to shift the emphasis of the Monitoring Program in time to take advantage of what little time we have this autumn to trap and tag as many squirrels on the monitored areas as we can.

Sincerely,

Paul J. Young
Supervisor
U of A, Mt. Graham Red Squirrel Monitoring Program

cc: Buddy Powell
Dr. M. Cusanovich

Example 1: Time spent in midden area by squirrels on Upper Study and Control Areas during construction. (Table 17b in AR-90)

N (number of paired observations) = 38
mean difference = -2.98 (US squirrels spent 2.98 minutes less at midden)
Standard Error = 9.06
T = -0.37
P>|T| = 0.7138

D = 17.7 (Difference would have to be ≥ 17.7 min. to be statistically significant)

Sample Size	Resolving Power
20 pairs	25 minutes
30 pairs	20 minutes
38 pairs *	17.7 minutes
53 pairs	15 minutes
120 pairs	10 minutes
585 pairs	5 minutes

* sample size for analysis in AR-90, only 38 paired observations had squirrels present at both middens during the observation.

The resolving power of this test was such that a difference in the amount of time spent at the midden of approximately 15% of the total observation period would have been statistically significant.

Figure 1. Graph showing the relationship between sample size and resolving power of statistical analysis, using the data from Example 1.

Example 2: Number of visits to the midden area by squirrels on Upper Study and Control Areas during construction. (Table 17b in AR-90)

N (number of paired observations) = 38
mean difference = -0.39 (US squirrels made 0.39 fewer visits to midden)
Standard Error = 0.72
T = -0.55
$P>|T| = 0.5884$

D = 1.4 (Difference would have to be ≥ 1.4 visits per 2 hours to be statistically significant)

Sample Size	Resolving Power
3 pairs	5.0 visits/2 hr.
19 pairs	2.0 visits/2 hr.
38 pairs *	1.4 visits/2 hr.
75 pairs	1.0 visits/2 hr.
303 pairs	0.5 visits/2 hr.
7556 pairs	0.1 visits/2 hr.

* sample size for analysis in AR-90, only 38 paired observations had squirrels present at both middens during the observation.

The resolving power of this test was such that a difference in the number of visits to the midden of less than 1 visit per hour of the total observation period would have been statistically significant.

Figure 2. Graph showing the relationship between sample size and resolving power of statistical analysis, using the data from Example 2.

Example 3: Time spent in midden area by squirrels on Upper Study and Control Areas during non-construction. (Table 16b in AR-90)

n = 15
mean = 0.04 (US squirrels spent 0.04 minutes more at midden)
St. Error = 15.92
T = 0.00
P>|T| = 0.9978

D = 31.2 (Difference would have to be ≥ 31.2 min. to be statistically significant)

Sample Size	Resolving Power
15 pairs *	31.2 minutes
24 pairs	25 minutes
37 pairs	20 minutes
65 pairs	15 minutes
147 pairs	10 minutes
585 pairs	5 minutes

* sample size for analysis in AR-90, only 15 paired observations had squirrels present at both middens during the observation.

The resolving power of this test was such that a difference in the amount of time spent at the midden of 26% of the total observation period would have been statistically significant.

Figure 3. Graph showing the relationship between sample size and resolving power of statistical analysis, using the data from Example 3.

Example 4: Number of visits to the midden area by squirrels on Upper Study and Control Areas during non-construction. (Table 17b in AR-90)

N (number of paired observations) = 15
mean difference = -0.53 (US squirrels made 0.39 fewer visits to midden)
Standard Error = 0.53
T = -1.00
P>|T| = 0.3343

D = 1.04 (Difference would have to be ≥ 1.04 visits per 2 hours to be statistically significant)

Sample Size	Resolving Power
10 pairs	1.27 visits/2 hr.
15 pairs *	1.04 visits/2 hr.
20 pairs	0.90 visits/2 hr.
30 pairs	0.73 visits/2 hr.
40 pairs	0.63 visits/2 hr.
100 pairs	0.40 visits/2 hr.

* sample size for analysis in AR-90, only 15 paired observations had squirrels present at both middens during the observation.

The resolving power of this test was such that a difference in the number of visits to the midden of less than 1 visit per hour of the total observation period would have been statistically significant.

Figure 4. Graph showing the relationship between sample size and resolving power of statistical analysis, using the data from Example 4.

Example 5. Number of visits to the midden area by squirrels on SFC and SFN Areas during construction in Autumn. (Appendix K) in AR-91)

N (number of paired observations) = 66
mean difference = 0.17 (US squirrels made 0.17 fewer visits to midden)
Standard Error = 0.29
T = 0.58
P>|T| = 0.5666

D = 0.57 (Difference would have to be ≥ 0.57 visits per 2 hours to be statistically significant)

Sample Size	Resolving Power
10 pairs	1.45 visits/2 hr.
20 pairs	1.03 visits/2 hr.
30 pairs	0.84 visits/2 hr.
40 pairs	0.72 visits/2 hr.
66 pairs *	0.57 visits/2 hr.
100 pairs	0.46 visits/2 hr.

* sample size for analysis in AR-91, only 66 paired observations had squirrels present at both middens during the observation.

The resolving power of this test was such that a difference in the number of visits to the midden of 0.29 visit per hour of the total observation period would have been statistically significant.

Figure 5. Graph showing relationship between sample size and resolving power of statistical analysis, using data from Example 5.

Example 6. Time spent at midden site by squirrels on TRC and TRN Areas during non-construction in Autumn. (Appendix K) in AR-91)

N (number of paired observations) = 11
mean difference = 58.55 (TRC squirrels spent 58.55 minutes more at midden than TRN squirrels on average)
Standard Error = 11.69
T = 5.01
P>|T| = 0.0005

D = 3.68 (Difference would have to be ≥ 3.68 minutes per 2 hours to be statistically significant)

Sample Size	Resolving Power
10 pairs	3.86
11 pairs *	3.68
20 pairs	2.73
30 pairs	2.22
40 pairs	1.93
100 pairs	1.22

* sample size for analysis in AR-91, only 11 paired observations had squirrels present at both middens during the observation.

The resolving power of this test was such that a difference in the amount of time spent at the midden of more than 1.84 minutes per hour of the total observation period would have been statistically significant.

Appendix Q. Location of microenvironment transects and recording stations.

Table Q-1. List of microenvironment transects, location and orientation.

Transect	Location	Orientation	Length (m)	
T1	SwBk 2	270°	150	7
T2	SwBk 2	360°	150	7
T3	SwBk 3	172°	150	7
T4	SwBk 4	350°	150	7
T5	SwBk 5	158°	150	7
T6	SwBk 6	352°	150	7
T7	SwBk 7	210°	100	5
T8	SwBk 8	344°	150	7
T9	2050 m	354°	75	4
T10	2150 m	230°	150	7
T11	2250 m	56°	150	7
T12	2350 m	196°	150	7
T13	2450 m	337°	150	7
T14	2550 m	180°	100	5
T15	2650 m	320°	150	7
T16	2750 m	174°	150	7
T17	2850 m	300°	150	7
T18	2925 m	126°	150	7
T19	3100 m	320°	150	7
T20	3100 m	104°	150	7
SMT1	SMT	360°	50	3
SMT2	SMT	45°	100	5
SMT3	SMT	90°	100	5
SMT4	SMT	135°	100	5
SMT5	SMT	180°	100	5
VATT1	VATT	360°	100	5
VATT2	VATT	315°	100	5
VATT3	VATT	270°	100	5
VATT4	VATT	225°	100	5
VATT5	VATT	180°	75	4
COL1-1	COL 1	360°	150	7
COL1-2	COL 1	45°	150	7
COL1-3	COL 1	90°	150	7
COL1-4	COL 1	135°	150	7
COL1-5	COL 1	180°	150	7

Transect	Location	Orientation	Length (m)	
COL1-6	COL 1	225°	150	7
COL1-7	COL 1	270°	150	7
COL1-8	COL 1	315°	150	7
COL2-1	COL 2	360°	150	7
COL2-2	COL 2	45°	150	7
COL2-3	COL 2	90°	100	5
COL2-4	COL 2	135°	75	4
COL2-5	COL 2	180°	150	7
COL2-6	COL 2	225°	150	7
COL2-7	COL 2	270°	150	7
COL2-8	COL 2	315°	150	7
COL3-1	COL 3	360°	125	6
COL3-2	COL 3	45°	150	7
COL3-3	COL 3	90°	150	7
COL3-4	COL 3	135°	150	7
COL3-5	COL 3	180°	150	7
COL3-6	COL 3	225°	150	7
COL3-7	COL 3	270°	150	7
COL3-8	COL 3	315°	100	5
COL4-1	COL 4	360°	75	4
COL4-2	COL 4	45°	100	5
COL4-3	COL 4	90°	150	7
COL4-4	COL 4	135°	150	7
COL4-5	COL 4	180°	150	7
COL4-6	COL 4	225°	150	7
COL4-7	COL 4	270°	150	7
COL4-8	COL 4	315°	125	6

Table Q-2. List of microenvironment recording stations location and year established.

Area	Midden	Year Established
TRN	201	1990
	202	1990
	204	1990
	206	1990
	209	1990
TRC	101	1990
	118	1990
	103	1990
	105	1990
	107	1990
	117	1991
	130	1991
SFN	222	1990
	229	1990
	247	1990
	252	1990
	272	1990
	232	1991
	236	1991
	241	1991
	243	1991
	245	1991
	255	1991
	258	1991
	260	1991
	267	1991
	270	1991
	277	1991
	289	1991
	288	1991
	290	1991
SFC (cont.)	156	1990
	160	1990
	165	1990
	168	1990
	177	1990
	150	1991

Area	Midden	Year Established
	159	1991
	166	1991
	173	1991

Appendix R. Results of paired t-tests on the difference in soil temperature and soil moisture between the edge station and stations at 25-m intervals along microenvironment transects 13 and 16.

TRAN=13

N Obi	Variable	Mean	Std Error	T	Prob>|T|
17	T0	0.0	0.0	.	.
	T25	-2.8	0.4	-7.9	0.0001
	T50	-3.5	0.4	-8.4	0.0001
	T75	-3.5	0.5	-7.6	0.0001
	T100	-3.1	0.4	-7.5	0.0001
	T125	-3.4	0.4	-8.8	0.0001
	T150	-3.2	0.5	-7.1	0.0001
	M0	0.0	0.0	.	.
	M25	-1.7	1.2	-1.4	0.1815
	M50	-2.2	1.2	-1.8	0.0947
	M75	-4.1	1.3	-3.1	0.0070
	M100	-1.0	1.6	-0.6	0.5366
	M125	-1.4	1.0	-1.4	0.1756
	M150	0.1	1.8	0.1	0.9481

TRAN=16

N Obi	Variable	Mean	Std Error	T	Prob>|T|
17	T0	0.0	0.0	.	.
	T25	-0.9	0.3	-2.9	0.0115
	T50	-1.0	0.2	-6.3	0.0001
	T75	-1.6	0.2	-7.6	0.0001
	T100	-1.0	0.2	-5.1	0.0001
	T125	-1.2	0.2	-6.7	0.0001
	T150	-0.1	0.3	-0.3	0.7373
	M0	0.0	0.0	.	.
	M25	6.8	2.2	3.2	0.0060
	M50	8.2	1.7	4.7	0.0002
	M75	5.8	1.9	3.1	0.0069
	M100	5.4	1.5	3.6	0.0026
	M125	7.1	1.6	4.4	0.0004
	M150	5.7	1.6	3.6	0.0026

Appendix S. Precipitation and temperatures at midden microenvironment stations.

Table S1. Mean monthly precipitation (mm rain) at red squirrel middens.

	1990				1991			
Month	7	8	9	10	7	8	9	10
TR Habitat	138.4	64.9	62.1	42.7	63.1	54.1	46.0	8.6
SF Habitat	162.8	94.6	105.8	53.0	64.5	79.7	34.9	13.7

Table S2. Mean monthly minimum and maximum soil and air temperatures (°C) at red squirrel middens. Soil temperatures (T_{soil}) are at 15 cm depth, air temperatures (T_{air}) are at 20 cm height. Maximum air temperatures at some middens are influenced by direct solar radiation on the thermometer, and this skews the mean for this variable toward higher temperatures.

	Spruce-fir				Transition			
	T_{soil}		T_{air}		T_{soil}		T_{air}	
1990	$\bar{x}$ min	$\bar{x}$ max	$\bar{x}$ min	$\bar{x}$ max	$\bar{x}$ min	$\bar{x}$ max	$\bar{x}$ min	$\bar{x}$ max
May	4.4	-	13.2	-	5.3	-	13.4	-
Jun	5.3	8.6	3.9	25.6	6.5	10.5	5.4	26.7
Jul	7.8	10.4	6.3	19.5	11.4	11.4	7.8	19.7
Aug	7.4	9.6	4.6	18.9	8.6	10.5	5.9	19.6
Sep	7.7	9.7	4.6	18.2	8.1	10.8	5.3	19.7
Oct	3.4	6.6	-1.5	13.1	4.1	7.1	-0.8	14.7
Nov	0.8	4.3	-8.5	10.3	1.5	5.1	-7.6	11.2
1991								
Jun	-	-	-	-	4.6	8.0	3.1	24.6
Jul	5.7	11.2	6.0	22.9	7.6	9.9	7.2	22.6
Aug	7.6	9.9	6.0	18.9	8.5	11.3	6.8	19.2
Sep	6.8	9.4	4.3	17.8	7.2	11.4	4.4	18.7
Oct	4.6	7.1	0.4	17.3	5.4	7.8	1.0	17.1