DALL'S SHEEP OF THE KILLERMUN LAKE REGION: ECOLOGICAL AND BEHAVIOURAL DATA IN RELATION TO MINERAL EXPLORATION

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Yukon Fish & Wildlife and Archer Cathro & Associates LTD

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ABSTRACT

Ecological and behavioural data in relation to mineral exploration was collected for Dall's sheep (*Ovis dalli dalli)* occupying the mountain west of Killermun Lake, in a roadless area of the Ruby Mountains, Southwest Yukon, during 1995. Fieldwork was limited to 21 days during lambing (when sheep were undisturbed) and 10 days during early summer (when mineral exploration was occurring); thus, most conclusions are preliminary. A minimum of 165 sheep -- almost exclusively adult females and juveniles (including 42 lambs) -- used the study area. The lambing range was on the southeast slopes, and the summer range was on the ridge tops and west and north slopes. Mineral licks near the north end of the lambing range were heavily used -- primarily after 10 AM. These licks were near the exploration camp and drill, and consequently sheep using them were susceptible to helicopter disturbance. Because pre-disturbance data during summer has yet to be collected, I cannot properly evaluate the impact of mineral exploration on use of the summer range. Nonetheless, areas used heavily during summer were identified. All sheep groups reacted to helicopters by either running away or by becoming vigilant when the helicopter was at a mean ± SD distance of 2.20 ±0.83 km. In 75 % of the records helicopter disturbance displaced sheep from their pre-disturbance location, and the mean ± SD escape distance was at least 0.65 ± 0.35 km. Models based on similar data for woodland caribou (*Rangifer tarandus caribou*) predict that these artificial energetic costs, if frequently repeated, could result in reduced reproductive success (Bradshaw 1994). Whether sheep decided to escape or to just stand vigilant was not dependent on distances to the helicopter, but was strongly dependent on group size. Limited data suggest that, when exposed to more than one helicopter flight during a short period of time, responses by some sheep are stronger during the first flight than during subsequent flights. A helicopter route which minimizes impact was determined. Trenching by an excavator greatly disturbed sheep that were 200 m away, but caused only mild disturbance and no overt disturbance to sheep that were, respectively, 2.0 and 2.8 km away. Drilling occurred where it likely had the least impact, but data are lacking to test this. In addition to the above results, data on vigilance and suckling variables were collected during lambing (in the absence of disturbance), and some vigilance data of undisturbed sheep was collected during summer. Although vigilance and suckling data have yet to be analyzed, they are available (along with the population data) as a baseline for monitoring the effects of long term disturbance. My recommendations for minimizing and monitoring impact of mining activities are as follows:

1) To allow for late lambing seasons resulting from delayed plant phenology, mining activity (and related helicopter flights) should not take place before the third week of June, and should be avoided as much as possible before July.

2) Use the helicopter route I suggested. If helicopters must fly over the Killermun Lake valley, these flights should occur before 8 AM to avoid disturbing sheep at mineral licks. When in direct line of sight, helicopters should try to stay at least 3 km away from areas known to be heavily used by sheep. If a large number of flights must take place within a short time, it might be better to concentrate these flights in a single day, rather than spreading the disturbance over several days. Simultaneously using two helicopters to half disturbance time might reduce the impact. Data testing these approaches are badly needed.

3) To adequately measure the effects of disturbance on use of summer range, study the latter while disturbance is absent, and compare it with data obtained during disturbance.

4) Until more data are collected, trenching or other high impact activities should not take place within 2.5 km of the boundary of block B8 (the most used block during summer).
5) To evaluate impacts on foraging efficiency, vigilance by individuals (and if possible heart rates, using heart rate radio-telemetry) should be compared between disturbed and undisturbed sheep.
6) To test whether long-term disturbance indirectly affects milk production of mothers -- by affecting their foraging efficiency and increasing energetic costs, thereby deteriorating their condition -- suckling data (controlled for plant phenology) should be collected during lambing periods following disturbance seasons, and be compared to pre-disturbance data.
7) To assess whether effects of disturbance are having population consequences, long term data on population productivity and mortality of different age-sex classes should be collected. A definitive study of general application would assess the relationships between disturbance, vigilance and energetic costs, condition, milk production, and reproductive success and mortality. Ideally, this task would be accomplished by studying marked individuals over several seasons under various conditions of disturbance.

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INTRODUCTION

The mountain located west of Killermun Lake, in a roadless area of the Ruby Mountains of the southwest Yukon, is a very important lambing and summer range for Dall's sheep (*Ovis dalli dalli*). A minimum of 165 sheep -- including 42 lambs -- used this mountain during the spring and early summer of 1995. These sheep consisted almost exclusively of adult females (≥ 3 years old) and juveniles (males and females ≤ 2 years old), but at least seven rams of horn class II - IV (*sensu* Geist 1971) occasionally used the area.

The pilot study presented in this report was triggered by concern for the impact of mining activities on this sheep population. During June and July of 1994 and the summer of 1995, Archer Cathro & Associates LTD conducted mineral exploration on the mountain located west of Killermun Lake. (At the time of writing, exploration was still occurring). During 1994, machinery-related exploration was limited to some trenching by an excavator, and to the helicopter flights necessary for operating the camp and excavator. During 1995, exploration became more machinery intensive, and included a greater frequency of helicopter flights, more extensive trenching, and drilling at the north end of the study site.

I had three major goals for this study. The first was to collect ecological and behavioural data that would provide a baseline for monitoring the long term impacts of mining activities. The second goal was to record and, as much as possible, quantify the short term impacts of mining activities on sheep. The latter mainly involved collecting data on responses by sheep to helicopters and the excavator. The third goal was to provide recommendations that would help reduce impact on the sheep population, and suggest future research for determining the behavioural and population consequences of disturbance.

Although all of these goals were met, fieldwork was limited to 21 days during the lambing period (while sheep were undisturbed) and 10 days during early summer (while disturbance was occurring). Thus, most results are preliminary.

STUDY SITE AND METHODS

Study Site and Seasons

The study site is located in a roadless area of the Ruby Mountains, southwest Yukon, west of Killermun Lake (ca. 61° 8' - 61° 11' N, 137° 40' - 137° 46' W). The southeast slopes of the mountain are the lambing and primary spring range (Fig. 1a). These slopes are a mosaic of large cliffs, small bluffs, extensive areas covered by tall/dense vegetation cover (willow, poplar and scattered spruces), and open slopes without cliffs nor tall/dense vegetation cover. The primary summer range is located on the ridge tops and west and north slopes of the mountain (Fig. 1a). The latter consists mainly of open slopes or meadows located far (>1 km) from cliffs, and lacks tall/dense vegetation cover. Important mineral licks are found in the lambing range (Fig. 1a), but I did not locate any in the summer range.

Data was collected on the lambing range from 15 May to 5 June 1995. During this period, there was no mineral exploration and disturbance by helicopters was minimal. Data was collected on the lambing and summer ranges during 1-9 July 1995, when mineral exploration was occurring. Unfortunately, heavy rains and fog hampered data collection on several days of this period. For brevity, I will refer to the first field trip as the lambing study, and to the second field trip as the summer study.

Population Characteristics

During the lambing study, data on population characteristics was obtained through 18 censuses of the southeast slopes of the study area. These censuses were done from five vantage points along the valley of Killermun and Shutdunmun Lakes (Fig. 1a). Travel between vantage points was done via mountain bike, foot, and canoe. Censuses (including travel time) took 4 to 5 hours to complete. Movements by sheep can be affected by time of day; thus, once the logistics of travel and vantage points were sorted out, censuses (14 out of 18) took place between 0600 and 1100.

During the summer study, the entire study area was censused on four occasions (4, 6, 8 and 9 July). This was done by having one observer census the lambing range as described above, while a second observer semi-simultaneously censused the summer range while traveling it by foot (Fig. 1). These censuses were done in the morning (start 0530 - 0600, end 1100 - 1400).

During the lambing and summer studies, I collected data on total population size and the number of lambs. Data on structure of the non-lamb component of the population (adults, two-year olds, and yearlings), however, was collected during the lambing study only.

During all censuses, measurement error caused by re-counting sheep that made large movements was unlikely. Counting and traveling was done at a fast, steady pace, and observers were always aware of the sheeps' movements.

Some measurement error, however, likely occurred in three ways. First, some blind spots were unavoidable. Second, observers may have missed some lambs which were laying behind their bedded mother. Also, censuses during the lambing study were affected when sheep moved between the lambing range and the rest of the study area. However, repeated censuses can be seen as 22 attempts at estimating the number of nonlambs, 18 attempts at estimating structure of the non-lamb component of the population, about seven attempts at estimating the number of lambs near the end of the lambing period, and four attempts at estimating the number of lambs during early summer. Given the multiple censuses, I believe that my highest counts provide good estimates of population characteristics.

Sheep in areas adjacent to the study area were recorded during the censuses of the summer period. These data are meant to provide only a general idea of the *minimum* number of sheep using these areas.

Use of Space

To quantify use of space, the location of each sheep group encountered during censuses was marked on a 1:50,000 topographic map. I then divided the study site into blocks, and calculated the proportion of animals found within each block. These data were pooled for each week of the lambing study, and for the week of the summer censuses. Because locations were recorded as actual points on the map, the data is suitable for very fine grained analysis of habitat use which could be done in the future.

"F" blocks (Fig. 1a) represent the lambing and primary spring range, and are of similar sizes. They differ in their distances from the areas of mineral exploration and concentrated helicopter activity, with F4 being closest and F1 being farthest. Also, important concentrations of mineral licks are found on blocks F3 and F4, but appear to be absent in blocks F1 and F2 (Fig. 1a).

The "B" blocks (Fig. 1a) represent the summer range. Their boundaries were created *a posteriori* so that they could reflect the very clumped distribution of sheep and the potential effects of mineral exploration during the summer study. Potential effects of the mining camp were concentrated in B1, potential effects of drilling were concentrated in B2, and potential effects of the excavator were concentrated in B4.

Use of Mineral Licks

Use of mineral licks was recorded only opportunistically during the lambing study. During the summer study, however, a systematic effort was made to quantify the time sheep spent at the licks between 0600 and 2200, using sheep hours (number of hours multiplied by the number of sheep at the lick) as a measure. Most of these data (1-7 July) were collected by recording all of the time sheep spent at the mineral licks. This task was quite feasible because the mineral licks were directly observable from a base camp at the south end of Killermun Lake. During 8 and 9 July however, use of mineral licks was recorded through instantaneous scan samples (Martin & Bateson 1993) every 30 min.

Defining Vigilance, Juveniles, and Female-like Sheep

Throughout the report, I will refer several times to vigilance behaviour. Vigilance is defined as interrupting other activities, such as foraging, to stand with head above shoulder height and scan the surroundings. Although vigilance can be related to social and other factors, it is largely an anti-predator behaviour (review in Elgar 1989). Vigilance is discussed in greater detail in a subsequent section.

For brevity I will refer to lambs + yearlings + two-year olds as "juveniles". Also, I will refer to adult females + yearlings + two-year olds as "female-like sheep".

Responses to Helicopter Disturbance

I attempted to record -- while observing from the ground -- all interactions between sheep and helicopters. Analysis criteria (see below), however, limited the number of observations analyzed. The most detailed data was recorded when we had advanced warning that a helicopter was enroute. In that situation, I selected one or two focal groups, and recorded their group size, number of lambs, activity, and other data prior and after disturbance. The actual response of sheep to the helicopter was recorded by one observer into a tape recorder, while a second observer recorded distances between the helicopter and the sheep. When helicopters appeared unexpectedly and/or only one observer was available, not all variables could be recorded. Thus, sample sizes varied between variables.

I quantified the response of sheep to helicopters with the following measures. *First reaction distance* is the distance from the helicopter at which the sheep first reacted, regardless of whether this first reaction was to be vigilant or to escape. *Least distance* is the smallest distance between sheep and the helicopter, which may or may not be smaller than the first reaction distance. *Helicopter time* is the time the helicopter was audible to observers, and provides an index of how long the helicopter was in the area. *Escape* is a binomial variable, being positive when the disturbed sheep moved from their pre-disturbance location to a new area. This movement was usually done by an initial run which was followed by walking; some nervous feeding sometimes occurred during the walk. *Escape distance* is the distance which sheep escaped until they either bedded at a new location or settled into feeding without traveling. Escape distance was analyzed only for cases in which sheep were not traveling prior to being disturbed. *Response duration* is the time between the first reaction (either vigilance or immediate escape) and when sheep settled into either feeding without traveling or bedding. When a group had three or more sheep (excluding lambs) and the above measures differed between individuals, the measure that corresponded to > 50 % of the group was recorded. All distances were estimated from a 1:50,000 topographic map.

I hypothesized that when multiple helicopter flights occur during the same day, the sheeps' responses during the first flight may be much strong than during subsequent flights. (This likely differs between individuals.) Thus, I considered observations to be independent only when data were collected during the first helicopter flight of separate days. (There was one exception in which I considered two helicopter flights that occurred 10.75 hours apart to be independent.) I used only independent samples to analyze the factors that affect first reaction distance, escape, escape distance, and response duration. These data were collected during both the lambing and the summer study.

To gain insights into whether sheep habituate to repeated helicopter flights occurring during the same day, I compared first reaction distance, escape distance, and response duration within the two groups which I observed during the first and several subsequent helicopter flights of a given day. Intervals between helicopter flights were of < 40 min.

All analyses were of groups of adult females and juveniles. The only record that involved a male group was excluded from analyses because in polygynous ungulates males tend to take greater risks than females (review in Main & Coblentz 1990). One group of females was excluded from analyses because the line of sight (and likely sound) between the helicopter and sheep was blocked by a large ridge.

Responses to the Excavator

To document potential disturbance from trenching, I first located a group that was in direct line of sight (and likely sound) from the excavator. (I could hear the excavator from as far as 4 km away, and the largest distance between sheep and the excavator in these records was 2.8 km.). Prior to when the excavator began working for the day, I recorded the group size and activity of sheep. Then, when the excavator began working, I recorded the response of the sheep. These data were collected only for groups of adult females and juveniles.

Undisturbed ungulates would be expected to be less vigilant than disturbed ones (Berger et. al 1983; Stockwell et al. 1991). To try to quantify potential disturbance, I recorded the percent time spent vigilant by sheep (if possible of the same individuals) that were feeding within 1 h prior to and 0.5 h after the excavator began working. These data were collected only for mothers with lambs. I compared pre-disturbance and disturbance vigilance using a non-parametric paired - sample test (Zar 1984). Sample sizes were adequate for analyzing only one group. Because vigilance is affected by distance to cliffs and group size (Frid 1994), and likely by distance to the excavator, I did not pool data collected for different groups. Methods used for collecting vigilance data were similar to those described in detail in Frid (1994).

RESULTS AND DISCUSSION

Population Characteristics

According to the highest count obtained during a census (4 July; see Figs 2a, 2c), the study site was occupied during the late spring and early summer by approximately 158 adult females and juveniles. Based on the highest counts obtained on a given day for each age-sex class, the structure of this component of the population consisted of approximately 70 adult females ($\geq$ 3 years old), 9 two-year old females (*sensu* Hoefs and Cowan 1979), 14 yearlings, 42 lambs, and 23 female-like sheep which I could not classify.

In addition to adult females and juveniles, up to seven rams of horn class II - IV were sometimes seen during censuses (Figs. 2a, 2c), making 165 the minimum number of sheep that used the study area. I do not know where most rams spent the spring and summer.

Lambing (including the isolation period that follows birth [*sensu* Lent 1974]) appears to have occurred until at least sometime between 29 May and 2 June. This estimate is based on the ratio of lambs to female-like sheep, which appears to have peaked between these dates. A more precise estimate is not possible because the increase to a plateau of these ratios, which is expected when lambing is ongoing, is masked by scatter in the data (Fig. 2b). This scatter was likely caused by movements of mother - lamb pairs between the lambing and summer ranges (see Fig. 2a), and by some measurement error caused by observers missing lambs laying behind their bedded mothers. (Recall that the summer range was not censused during the lambing study.)

I estimate that near the end of the lambing period, on 29 May, the ratios of lambs to adult females and of lambs to female-like sheep were, respectively 0.62 and 0.39. Although a few births likely occurred after 29 May, I consider these to be reasonable estimates for the following reasons. First, they were obtained during a census in which only one adult female was of questionable reproductive status. Second, only 13 female-like sheep could not be classified during that census. And third, the number of female-like sheep counted that day equaled 87.3 % of the highest count. (The ratio of lambs to female-like sheep reached 0.41 on 30 May and 0.42 on 2 June, but only 69.6 % and 70.9 % of the highest count of female-like sheep, respectively, were observed on those days. Thus, these higher ratios may be an artifact of smaller samples [Figs. 2a, b]).

I estimate that during early July the ratio of lambs to female-like sheep was 0.36. This estimate is based on the 4 July census, when the highest count of female-like sheep and lambs was obtained for the study area (see Figs. 2a, c). The drop from 0.39 on 29 May to 0.36 on 4 July might reflect some early summer mortality, but could also be an artifact of a smaller sample during 29 May. (At least one lamb was killed by a coyote [*Canis latrans*] in early July, and golden eagles [*Aquila chrysaetos*] attempted to take lambs on at least five occasions. See subsequent sections.)

Use of Space during the Lambing Period

During censuses undertaken in the lambing study (except 20 May), most of the population (except rams) was found on the lambing range. The number of sheep observed during these censuses, however, fluctuated between 74 and 145 (Fig. 2a), reflecting frequent movements between the lambing and summer range.

While in the lambing range between 16 May and 4 June, sheep tended to be evenly distributed in the southern and northern halves of the range (respectively, blocks F1 + F2 and blocks F3 + F4: Fig. 1a), but a slightly higher proportion of animals used the southern half between 23 and 29 May (Fig 3a). Although the proportion of lambs tended to be highest in the southern half of the lambing range, a large proportion (18.19% - 40.47%, depending on the week) was also found in the northern half (Fig 3b).

Block F4 is of particular interest because it is the part of the lambing range nearest to where mining disturbance was concentrated during summer (Fig. 1a). A substantial proportion of the observed sheep (34.65 %), including lambs (24 %) were found in that block during the first week of the lambing study. Although the proportion of sheep using that block later decreased, 9.64 % of the observed sheep, including 4.76% of the lambs were still using the area during late May -early June (Fig. 3). Thus, mining-related activities occurring before July could have an impact on sheep using that block.

All of the above data are based on morning censuses which do not reflect the true importance to sheep and sensitivity to helicopter disturbance of block F4 and of the north end of block F3. Heavily used mineral licks are found in these blocks, but mineral licks tended to be used in the afternoons, after censuses had finished. Use of mineral licks is discussed in a subsequent section.

Use of Space During the Summer Study

An obvious problem of the summer study is that fieldwork began at the same time as mineral exploration. Recall that an excavator was digging trenches in block B4 (and, to a lesser extent on B3). Drilling was taking place at the north end of block B2. The mining exploration camp was in block B1. Helicopter activity was concentrated over blocks B1, B2, F3 and F4 (Fig. 1a). Thus, it is no possible to properly discern disturbed from undisturbed patterns of use of space during summer.

During the summer study, most of the sheep (including mother-lamb pairs) were concentrated on the summer range, specifically on blocks B8, B9 and B10 (Figs. 1a, 4). The only exception is July 3, when 67.6 % of the non-ram population (107 adult females and juveniles, including 17 lambs) was on the lambing range. (The summer range was not surveyed on that day.) Almost all of these sheep, however, escaped into the summer range (likely the southern end of it) in the late morning, when multiple helicopter flights began.

The most heavily used part of the summer range was block B8 (Figs. 1a, 4). (In addition to data obtained during full censuses, 55 sheep --34.8 % of the highest count of adult females + juveniles -- were seen on this block during a partial census on 7 July). Most of the sheep in this block were approximately 2.8 km in direct line of sight from the southwest-most point where the excavator was trenching, but some sheep were as close as 2 km to this point. Although sheep seemed to be little affected by the excavator from these distances (see subsequent section), the high concentration of sheep makes block B8 a potentially sensitive area if mining activity -- helicopter flights in particular -- was to intensify in its vicinity.

The second most heavily used part of the summer range was block B9 (Figs 1a,4). This block is less sensitive to disturbance than B8 because it is farther from the mineral exploration activities, and a ridge separates it from where disturbance is concentrated.

Only a very small proportion of sheep counted during censuses used blocks B1 and B4. and sheep appear to have not used block B2 (Figs. 1a, 4). (In addition to data obtained during full censuses, during partial censuses, three mother-lamb pairs plus a female, and three mother-lamb pairs used blocks B4 on, respectively, 5 July and 7 July.) This low use may be -- at least partially -- an effect of disturbance. The latter is suggested by observations of Archer Cathro's field staff, who saw approximately 30 sheep regularly using blocks B1 and B4 between 7 June and mid-July of 1994. Mineral exploration at that time was not machinery intensive, and consisted primarily of lower impact activities, such as soil sampling (Archer Cathro LTD field staff, pers. comm.).

Sheep were not observed using Blocks B3 and B5. It is difficult to tell whether this lack of use was due to disturbance. Block B7 was used by some sheep, but not during morning censuses. Block B11 was likely used (I once saw 55 sheep move into it), but the lack of a good vantage point prevented me from censusing it (see Fig. 1a).

Although very few sheep were counted during morning censuses on the lambing range, the mineral licks of blocks F3 and F4 (Fig. 1a) were heavily used in the afternoons. Use of these licks is discussed in the next section.

Sheep were present in areas adjacent to the study area, but in apparently low numbers. During five censuses in early July, the number of sheep at block O1 (Fig. 1a) fluctuated between 14 and 22. Most of these animals were female-like sheep, but a group of seven to nine rams (class II - IV) used the area on four of the censuses. I saw no lambs on this block. Also during early July, sheep used block O2 (Fig. 1a) during four censuses. The highest of these counts was 19 sheep (16 female-like sheep and 3 rams). However, six mothers with lambs not seen during the highest count were seen on a previous day, indicating that at least 31 sheep used block O2 during early July. Because of the large distance between my observation points and these blocks, and the many blind spots on the latter, these numbers are underestimates. In addition, at least one lamb was born on the mountain east of Shutdunmun (see Fig. 1a) during May.

Use of Mineral Licks

As mentioned earlier, heavily used mineral licks were found in blocks F3 and F4 (Fig. 1a), but appeared to be absent elsewhere in the study site. When sheep were at the licks, they spent much of their time licking, but also spent time feeding, bedding, and engaged in intense social behaviour. Only adult females and juveniles (including mother-lamb pairs) used the mineral licks.

During the lambing study, I did not begin to record use of mineral licks until 23 May (sheep did use the licks prior to that date), and then only opportunistically. Thus, my records reflect only the minimum amount of time that sheep spent at the licks. Mineral Lick Area 1 (Fig. 1a) was used by 4 mothers with lambs on 3 June, 7 female-like sheep on 4 June, 2 females on 23 May, 2 females on 1 June, 24 sheep (including 5 lambs) on 3 June, and 2 females on 4 June. During a 3 h 50 min period in 4 June, Mineral Lick Area 2 (Fig. 1a) was used by 19 sheep (including 2 lambs), and for an additional 50 min by 4-10 sheep. Unfortunately, I did not keep records of Mineral Lick Area 3 (Fig. 1a) during the lambing study; sheep however, were in its general area during 9 of the 18 censuses done during lambing.

While observations during lambing were anecdotal, the summer data provided a quantitative measure of the importance of the mineral licks and their sensitivity to helicopter disturbance. Mineral licks (Areas 1 and 2 pooled, Fig. 1a) were used every day of the summer study in which they were monitored, for a daily mean ± SD of 38.23 ± 22.36 sheep hours. (Recall that sheep hours equal number of sheep at the mineral lick multiplied by the time sheep spent there.) The only day that mineral licks were not used was 1 July, when helicopter flights throughout the day prevented sheep from approaching them. Both Mineral Lick Area 1 and 2 were used on most days, for up to 50.02 and 55.28 sheep hours, respectively. Much of the use was by mothers with lambs (Fig. 5). While Mineral Lick Area 3 appears to have been important during the lambing period, it was not used during the summer study.

Use of the mineral licks was primarily in the late morning or afternoons. On six out of seven days of observation, the sheep did not arrive before 1000 (Fig. 6).

Recall that the mineral licks are in the vicinity of the exploration camp and drill, where helicopter activity is concentrated (Fig 1a.). On three out of seven days of observation (42.85 %), the sheep were forced to leave the mineral licks when disturbed by a helicopter. (In addition, there was one day in which sheep had just left the lick when a helicopter forced them out of the area.) Thus, my data are underestimates of how much time sheep spend at the mineral licks when undisturbed.

Responses to Helicopter Disturbance: Independent Events

It is well known that "mountain sheep respond dramatically to helicopter disturbance" (Bleich et al. 1994:1). During the summer study, helicopter activity related to mineral exploration severely disturbed sheep on several occasions. The most extreme case, as mentioned earlier, was on 3 July when repeated helicopter flights displaced most of the 107 sheep which were using the lambing range. Many other instances of disturbance by helicopter occurred, particularly at the mineral licks (see previous section). (At the end of the summer study, however, data on use of space was used to mitigate helicopter impacts. See Conclusions and Recommendations.) To a much lesser degree, helicopter disturbance (both related and unrelated to my fieldwork) also occurred during the lambing study.

My impression is that impact of helicopters on sheep depends on multiple factors, including group size, distances between sheep and the helicopter, time the helicopter spends in the area, number of helicopter flights in a day, and other factors. Also, the responses of sheep probably vary between individuals. My goal in this section is, under the constraints of small sample sizes and lack of marked individuals, to present some preliminary insights into these multiple factors. Given adequate sample sizes to be achieved in the future, these data could help answer basic question such as, under a given set of circumstances, how close can a helicopter get to sheep without disturbing them? (Recall that all analyses are for groups of adult females plus juveniles).

During independent records of sheep-helicopter interactions, the mean ± SD first reaction distance was 2.20 ± 0.83 km (n = 9). (See Methods for definitions of independent records, first reaction distance, least distance, helicopter time, escape, escape distance, and response duration.) In 66.7 % of these records, first reaction distance equaled 2.0-2.5 km . There was no difference in the first reaction distance of the groups in which sheep escaped (n = 6) and in which they did not (n = 3) (Table 1: Mann-Whitney U test: U= 11, P > 1.0). Sheep that did not escape reacted primarily by becoming vigilant.

Helicopter disturbance caused a substantial energetic cost to sheep. Sheep escaped from helicopters on 75 % of the independent records (n=13), and the mean ± SD escape distance was at least 0.65 ± 0.35 km (n = 6) (Table 1). (The latter is underestimated because sheep ran out of sight over a ridge top during two records.) Woodland caribou (*Rangifer tarandus caribou*) displaced by noise from petroleum exploration have been found to suffer an increase in daily energy expenditure of 16-39 %, which could cause a deterioration of condition and a reduction in reproductive success (Bradshaw 1994). Sheep forced to frequently escape from helicopters could suffer similar consequences.

Helicopter disturbance also disrupted the activity patterns of some sheep. In the three records in which sheep were bedded prior to disturbance, sheep fed, rather than re-bedding, once their response was over.

The mean ± SD response duration was 10.54 ± 10.37 min for sheep that escaped (n = 4: Table 1). In the two records for sheep that did not escape, when the response consisted of becoming vigilant, response duration equaled 0.08 and 6.0 min. My limited observations suggest that response duration (and -- by correlation -- escape distance) might be positively related to helicopter time (Table 1).

In a preliminary effort to assess what affects the decision to escape from a helicopter, I analyzed the effects of group size and least distance. Least distance did not differ between those groups that escaped (n = 7) and those that did not (n = 4) (Table 1; Mann-Whitney U test: U = 18.5, two-tailed P > 0.10). Thus, it appears that if sheep are going to escape, they will do so at a far threshold distance, and not necessarily when the helicopter is very close to them.

The effect of group size on whether sheep escaped or not was striking. Groups that escaped (n = 8) had more than five sheep (or more than three female-like sheep when lambs are excluded from group size) while groups that did not escape (n = 4) had smaller group sizes (Table 1, Fig. 7; Mann-Whitney U test: U'=31, P = 0.005 for total group size; U' = 32, P = 0.0025 for when lambs are excluded from group size). I suggest that increasing group size might cause the "stampede effect". In other words, a "cool" individual that is holding her ground might be startled by associates which decide to panic. When startled by associates, the formerly "cool" individual is stimulated to, like the proverbial sheep, join the panic. The probability of having "panicky" individuals causing the stampede effect likely increases with group size.

Because of limited sample sizes, I analyzed the effects of least distance and group size on whether sheep escaped using non-parametric two-sample tests (Zar 1984). Given adequate sample sizes, these analyses would likely be suitable for logistic regression (Analytical Software 1992). Also, future work should try to quantify not only the first reaction distance, but also the distance to the helicopter at which sheep begin to escape.

Another potential impact of helicopter disturbance is that it could artificially enhance the success of golden eagle predation on lambs. There is at least one record for the Yukon in which a helicopter caused a mother to escape, and a golden eagle took the opportunity to seize the lamb which had lagged behind (Nette et. al 1984; P. Merchant, pers. comm.). I once saw group of 27 sheep (including 10 lambs) increase its group spread (the greatest distance between two group members) from 50 m prior to disturbance to 180 m when escaping from a helicopter, and lambs lagged behind their mothers during the escape. Had a golden eagle been in the vicinity, it would have likely seized the opportunity to take a stray lamb.

Responses to Helicopter Disturbance: Repeated Events

My limited data suggest that some individuals can -- to some degree -- habituate to helicopter disturbance. A group of 16 sheep (including six lambs) escaped during the first helicopter flight, but did not escape during the three flights that occurred during the following 1.5 hours. Also, first reaction distance decreased from 4 km during the first flight to 2 km during the second. This distance, however, increased during the fourth flight (Fig. 8a). Finally, response duration decreased from 26 min (which were spent mostly escaping) during the first flight to < 5 min (which were spent vigilant) during the second and third flights (Fig. 8b). In a group of three sheep (including one lamb) -- which did not escape and who responded only by being vigilant or pacing in circles -- first reaction distance and response duration also decreased between the first and subsequent helicopter flights. Furthermore, the latter group showed no reaction at all during the second to sixth flight, and during the eighth flight (Fig. 9).

Although the above data suggest some habituation by some individuals, partial records (sheep were not observed during the first flight, but were observed during subsequent flights) indicate that some sheep still respond strongly during repeated disturbance. (All of these observations occurred on separate days and within 40 min of the previous flight). During a second flight of the day, three mothers with lambs had a first reaction distance of 1.5, and escaped out of sight into a gully. Also during a second flight, 12 sheep had a first reaction distance of 3 km, and escaped for 300 m before going out of sight over a ridge. During an eighth flight, 12 sheep (including five lambs) had a first reaction distance of 2.5 km, and an escape distance of 1 km. The latter sheep, which had not escape during the previous flight, reacted so strongly likely because the helicopter stayed in the area for 22 min.

In addition to overt effects, helicopter disturbance could elicit costs at a physiological level (MacArthur et. al 1982). Thus, the lack of an overt behavioural response does not indicate that there are no consequences to disturbance. Being repeatedly scared (and most sheep certainly are scared of helicopters) can lead -- over the long term -- to deterioration of health, as it has been documented in Africa for cheetahs (*Acinonyx jubatus*) without territories, who are constantly under attack by territory holders (Caro 1994).

Responses to Excavator Activity

The response of sheep to trenching was recorded on three days, when sheep were in direct line of sight from the excavator. (Recall that I was able to hear the excavator from up to 4 km away. Thus, sheep in these samples, which had a maximum distance of 2.8 km from the trenching site, likely could hear it too.) My limited observations do not allow quantitative analysis, but do suggest that the sheeps' response to trenching depended on distance from the excavator. (The effects of distance from the excavator, however, might be confounded by group size effects.)

On the one occasion when sheep were near the excavator, sheep responded strongly to disturbance. The sheep -- a group of four adult females and three lambs -- had arrived to the vicinity of the excavator early in the morning, one hour prior to the excavator beginning to work. They were bedded 200 m from the excavator when the operator arrived, and the sheep responded by first standing vigilant, and then feeding. When the excavator was turned on, the sheep immediately ran. Two mother-lamb pairs left the area, but the remaining sheep stayed within 300 m of the excavator for 1.5 min before leaving the area. The sheep did not regroup and settle into feeding for 47 min, until they were 1.5 km away from where they were originally bedded. Similar to the effects of helicopter disturbance (see above), this disturbance disrupted the activity pattern, caused energetic costs, and likely caused the physiological stress associated with fear.

On the one occasion when sheep were 2 km from the excavator, disturbance was more subtle. The sheep -- a group of 18 (including four lambs) -- were bedded prior to the excavator beginning to work. Forty five seconds after the excavator began to idle, two sheep stood vigilant. All but three sheep were up and feeding 2 min later. By the time 44 min had elapsed since the excavator began to idle (and 35 min since it began trenching), the entire group had moved -- by walking slowly as they fed -- 300 m to the opposite side of a ridge which blocked the line of sight between them and the excavator. The sheep re-bedded at the new location for several hours. A nearby group of 15 sheep (including two lambs) which were feeding nearby also walked over the ridgetop and bedded with the first group. When I returned to the area eight hours later, while the excavator was still working (and had been working all this time), the 33 sheep (plus 9 others) had moved back to their pre-disturbance location. My interpretation of this event is that sheep may have been somewhat disturbed by the excavator at first, but within a few hours the threat that they may have originally perceived diminished.

In my one record when trenching occurred 2.8 km from sheep, I detected no overt responses. Most members (61) of a group of 91 sheep (including 25 lambs) were bedded prior to and for $\geq$ 10 min after the excavator started working. When I returned to the area seven hours later, while the excavator was still working (and had been working all this time), most (77) of the sheep were still there. The limited data on vigilance also suggests that, when at 2.8 km from the sheep, the excavator caused no overt disturbance. Mothers with lambs were not significantly less vigilant while feeding prior to, than during the excavator working (Wilcoxon two-sample test: $n = 4$, $T- = 4$, one-tailed $P > 0.25$. Percent time spent vigilant equaled 8.60, 5.83, 2.77, and 3.55 within 1 hour prior to excavator activity, and 13.06, 4.16, 1.39, and 0 within the first 0.5 hour.) Also, sheep faced towards the excavator in only two out of eight vigilance bouts, suggesting that the sheep were not too concerned by it.

Potential Disturbance by Drilling and the Mineral Exploration Camp

Recall that drilling took place in block B2, and the mining camp was in block B1 (Fig 1a). Sheep rarely used these areas during the lambing study. Because drilling began at the same time as my summer study, I cannot properly evaluate its impact. My guess is that the drill was located where it caused the least disturbance. In the absence of helicopter activity, the mineral exploration camp appeared not to keep sheep from traveling in its vicinity enroute to the licks.

Sheep - Golden Eagle Interactions

Golden eagles were seen during most days of the study. These raptors are known to successfully hunt Dall's sheep lambs (Nette et. al 1984). We recorded eight interactions between golden eagles and mothers with lambs, including five unsuccessful attacks on lambs. In four of these attacks the primary defense response was to stand with all group members clustered tightly together and with lambs between the mothers legs. Only once, in an attack involving two eagles, did the sheep respond primarily by running. My impression is that eagles tried to make the sheep scatter, so that lambs that lagged behind could be targeted. Lambs appeared to be safe, as long as they remained between their mothers legs.

Terrestrial Predators

At least four species of terrestrial carnivores known to prey on sheep (with different degrees of success) were found in the study site (see Hoefs & Cowan 1979; Burles & Hoefs 1984; Hoefs et al. 1986). In this section I briefly summarize our observations, but more precise records are available.

At the valley bottom during the lambing study, we once saw a grizzly bear (*Ursus arctos*), and twice found fresh grizzly bear tracks. Fresh tracks were found also at the valley bottom once during the summer study. We did not see bears in any of the areas used by sheep.

During the lambing study, we saw a wolf (*Canis lupus*) get as close as 200 m from a group of seven sheep, but the wolf did not attempt a kill. During early July, I found fresh tracks of one wolf on a snow patch of the summer range, and Archer Cathro's staff heard two wolves howling from the north end of Killermun Lake.

Coyotes were not seen during the lambing study, but I found numerous scats. During the summer study, Sally Wright (my field assistant) saw a coyote kill a lamb at Mineral Lick Area 1.

During the lambing study we saw a wolverine (*Gulo gulo*) attack a group of three sheep. The attack was unsuccessful.

Vigilance and Suckling Data

Two data types collected during the lambing period -- vigilance while feeding by adult females (including mothers), and frequency and duration of suckling bouts by lambs -- could not be analyzed and interpreted within the short-term nature of this project. I also collected (but have yet to analyze) data on vigilance while feeding of mothers in undisturbed conditions during summer (at the opposite end of the summer range from where mineral exploration was occurring). However, the data are available to describe the behaviour of an undisturbed sheep population. These data are important because they provide a baseline for detecting long term impacts of disturbance.

Long term impacts of mining activities on individual behaviour, which has population consequences (see below), would likely be detected by comparing the pre-disturbance data with disturbance data. For this comparison to be valid, however, the vigilance data, must be controlled for several key factors (see Frid 1994), and the suckling data must be controlled for plant phenology (e.g. Rachlow & Bowyer 1994). (I also collected baseline phenology data.) Given the potential importance of these data to management, below I describe in further detail their theoretical basis and application.

Optimality theory predicts that natural selection will favour individuals that balance conflicting needs (Krebs & Kacelnik 1994). For example, foraging and vigilance tend to be mutually exclusive for ungulates (Illius & FitzGibbon 1994). Though vigilance can be related to social and other factors, it is largely aimed at looking for predators. The latter is supported by empirical data which found that a less vigilant individual is more likely to be taken by a predator (e.g., FitzGibbon 1989). Though safer from predation, however, an animal that is too vigilant will miss foraging opportunities. Thus, deciding how much time should be invested in the simple act of "looking around" has been a major evolutionary force shaping the behaviour of prey (review in Lima & Dill 1990). Reproductive success will be greatest for those animals which -- for each set of conditions -- find an optimal level of vigilance. This optimal level is sensitive to a multitude of predation risk factors, as well as to factors related to sociality, food distribution and other conditions (reviews in Elgar 1989; Lima & Dill 1990). Furthermore, factors sometimes have interactive (multiplicative) rather than independent (additive) effects on vigilance (Frid 1994). In spite of the overwhelming complexity of the system, a substantial amount of the variation in vigilance has been explained by empirical studies of several taxa (review in Elgar 1989). For Dall's sheep, in particular, I have accomplished the latter by using a few key factors in multiple regression models with interactive terms (Frid 1994).

How does the above relate to management and conservation? Vigilance can be thought of as a *measurable* variable reflecting predation risk plus disturbance by industrial activities. At least to an unhabituated animal, the latter is perceived as another form of predation risk. Indeed, ungulates of disturbed populations have been found to be more vigilant than ungulates of undisturbed populations (Berger et. al 1983). The implications of increased vigilance is that individuals will be less efficient foragers (Berger et. al 1983) and consequently their condition might deteriorate (see FitzGibbon & Lazarus 1994). (Another measurable variable that is sensitive to predation risk and disturbance -- more so than vigilance -- is heart rate. While collecting vigilance data is inexpensive, however, heart rate radio-telemetry is financially very costly [MacArthur et. al 1982].)

How might the above affect population productivity? Milk production -- which is reflected in the suckling frequency and duration of lambs (White & Luick 1984, cited in Rachlow & Bowyer 1994) -- is largely a function of the mother's condition. The latter is a function of the availability of nutritious forage (Loudon 1985, cited in Rachlow & Bowyer 1994) (which is largely a function of plant phenology [e.g. Rachlow & Bowyer 1994]), probably the mother's foraging efficiency, and other factors. Thus, a potential scenario is that disturbed mothers -- which have increased vigilance and are less efficient foragers -- might have lower milk production, which in turn would result in young being in poorer condition (e.g. White et. al 1981, cited in Rachlow & Bowyer 1994) and probably having higher mortality rates. Although data testing this hypothesis are badly needed, mathematical models already predict that woodland caribou that are repeatedly displaced by industrial noise will suffer extreme weight losses and reduced reproductive success (Bradshaw 1994).

The idea that individual behaviour has population consequences is gaining a growing understanding (e.g. FitzGibbon & Lazarus 1994). Thus, a manager's goal of maintaining a healthy population of ungulates can be greatly aided by understanding factors affecting the behaviour of individuals. A study on the effects of disturbance on vigilance, energetic, and suckling variables, and the relationship of these variables to population productivity, would be of general application. A study of this sort could provide a model for monitoring impacts of disturbance not only from industrial activities, but also from roads and wildlife viewing.

CONCLUSIONS AND RECOMMENDATIONS

The mountain block located west of Killermun Lake is an important lambing and summer range which was used by a minimum of 165 sheep during the late spring and early summer of 1995. Long term mining activities in the area would undoubtedly have certain impacts for this population. Below I make recommendations on how to reduce and measure this impact.

Avoiding Impacts During the Lambing Period

Blocks F1, F2, F3 and F4 (Fig. 1a) are the principal lambing area for the population, and lambing occurred until at least sometime between 29 May and 2 June (perhaps later). Late lambing periods might occur in response to delayed plant phenology (Rachlow & Bowyer 1991). Thus, I suggest that mining activity (and related helicopter flights) should not take place before the third week of June, and should be avoided as much as possible before July.

Reducing Impact of Helicopter Flights

The most immediate application of my study was to provide -- based on the use of space and mineral lick data -- a helicopter route for accessing the mining camp and drill site that minimizes disturbance on sheep (Figs. 1a, b). This route avoids all areas known to be heavily used during the lambing and summer studies. Also, the route likely affects only a small number of sheep on the mountain east of Killermun Lake, but more data are required to confirm this. I strongly recommend that this route be used as much as possible. (With the cooperation of Archer Cathro, this helicopter route began to be implemented on 9 July.)

If helicopters must access the Mining Camp and drill by flying over the Killermun Lake valley, these flights should occur in the early morning, before 0800. This recommendation is based on the observation that sheep were seen using the mineral licks mostly after 1000, but once as early as 0825.

In general, I recommend that, when in direct line of sight, helicopters should try to stay at least 3 km away from areas heavily used by sheep, such as blocks F1, F2, F3 and F4 during May and June (and likely earlier in the year), and blocks F3, F4, B8, B9 and B10 during summer (Fig. 1a). This recommendation is based on results showing that the mean $\pm$ SD distance from a helicopter at which sheep showed a reaction (the first reaction distance) was 2.30 ± 0.82 km, and most of these responses resulted in substantial energetic costs to the sheep. Groups with more than 5 sheep were more likely to escape from helicopters than smaller groups, so large groups in particular should be avoided. The helicopter route I recommended comes within 3 km from blocks F3 and F4, but the route is acceptable because sheep in these blocks are not in direct line of sight, and likely can hear very little (or not at all) a helicopter using the route. The latter is supported by the following observations. Once while I stood just above Mineral Lick Area 1 (Fig. 1a), I barely heard a helicopter that came into the mineral exploration camp following this route. Also, when a helicopter and a group of seven sheep were separated by a ridge, the sheep showed no response when the helicopter got as close as 2.5 km. Thus, though more data are needed to corroborate these two observations, it appears that sheep can tolerate a helicopter at < 3 km when a topographic feature breaks the line of sight and sound between sheep and the helicopter.

If a large number of flights must take place within a short time frame, it is probably better to concentrate those flights in a single day, rather than spreading the disturbance over several days. Also, based on an observation made 3 July, my impression is that having two helicopters flying at the same time does not double the disturbance. Thus, I suggest using two helicopters to half disturbance time. Data testing whether these are the best approaches are badly needed.

Reducing Impacts On Sheep Using The Summer Range.

As mentioned earlier, data on use of the summer range in the absence of disturbance is still badly needed. Only by comparing that data with disturbance data will we be able to evaluate whether mining activities are displacing sheep from important areas.

However, the summer data does indicate that block B8 (Fig. 1a), which is in the vicinity of an area where trenching took place, was heavily used. Sheep using this block showed no overt response when trenching took place 2.8 km away, but showed a relatively weak response when the excavator was 2 km away. The response when sheep were 200 m from the excavator (in block B4) was very strong. Until more data is collected on how sheep can tolerate the excavator, I suggest that trenching or other machinery-oriented activities should not take place closer than 2.5 km of the boundary of B8. Sheep might tolerate the excavator at smaller distances, but without available data, uncertainty should be treated with caution.

Fortunately, the drill appears to be in an area of little importance to sheep. Thus, the drill might already be working where its impact is least. This impression, however, needs to be corroborated by future data.

Measuring Impacts on Individual Behaviour and Population Productivity

To evaluate impacts on foraging efficiency, data on vigilance while feeding by individuals should be collected shortly before and during disturbance from helicopters, excavator, or other machinery. These data can then be compared with paired-sample tests. The specific prediction is that sheep will be more vigilant after/during disturbance. Given an adequate sample size, the lack of a disturbance effect on vigilance would suggest that sheep are not affected by mining activities, but data on cardiac responses might indicate that an impact is still occurring (MacArthur et. al 1982). The experimental design described above could also be used for a heart rate telemetry study. The data I already have on vigilance by undisturbed sheep could also be compared -- as long as several factors are controlled for -- to data collected during disturbance.

To test whether long-term disturbance indirectly affects milk production of mothers -- by affecting their foraging efficiency and increasing energetic costs, and consequently deteriorating their condition -- suckling data should be collected during lambing periods following disturbance seasons. The prediction is that if mothers deteriorate in condition, suckling bouts will be shorter and less frequent, and a greater proportion of suckling bouts will be terminated by the mother. These data should be controlled for plant phenology (e.g. Rachlow & Bowyer 1994) and age of the lamb (D. M. Shackleton, pers. comm.).

To assess whether effects of disturbance are having population consequences, long term data on population productivity and mortality of different age-sex classes should be collected. A definitive study of general application would assess the relationships between disturbance, vigilance and energetic costs, condition, milk production, and reproductive success and mortality. Ideally, this task would be accomplished by studying marked individuals over several seasons under various conditions of disturbance.

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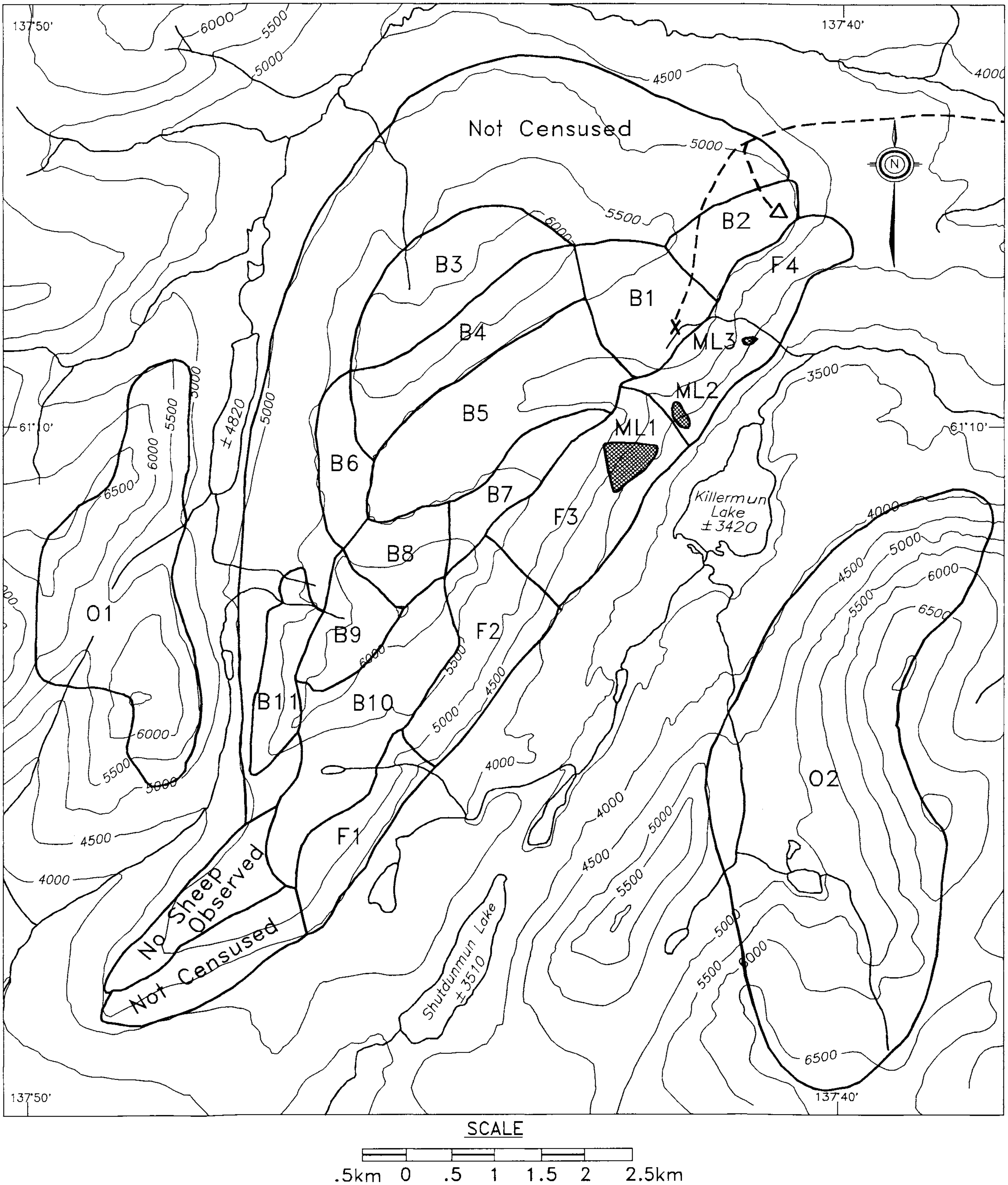
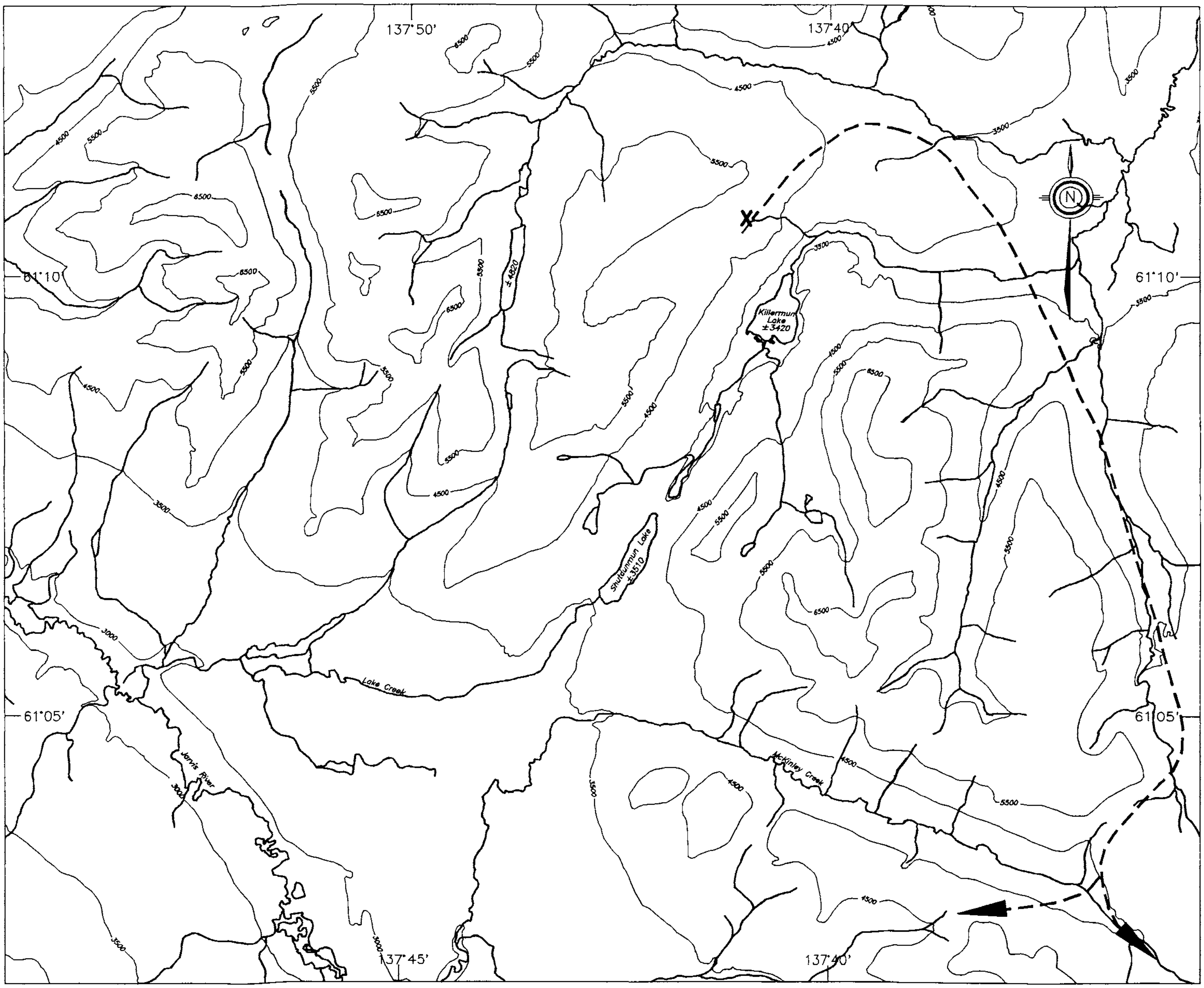
Fig. 1) Locations of (a) census blocks [letter + number], Mineral Lick Areas 1, 2 and 3 [ML shaded areas], drill [open triangle], mineral exploration camp [X], and (a, b) recommended helicopter route [broken line]. (Mineral Lick Area 1 is a cluster of four small mineral licks.)

1a.


137°50'
137°40'
Not Censused
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
F1
F2
F3
F4
ML1
ML2
ML3
O1
O2
No Sheep Observed
Not Censused
Killermun Lake ±3420
Shutdunmun Lake ±3510
±4820
61°10'
SCALE
.5km 0 .5 1 1.5 2 2.5km

1b.

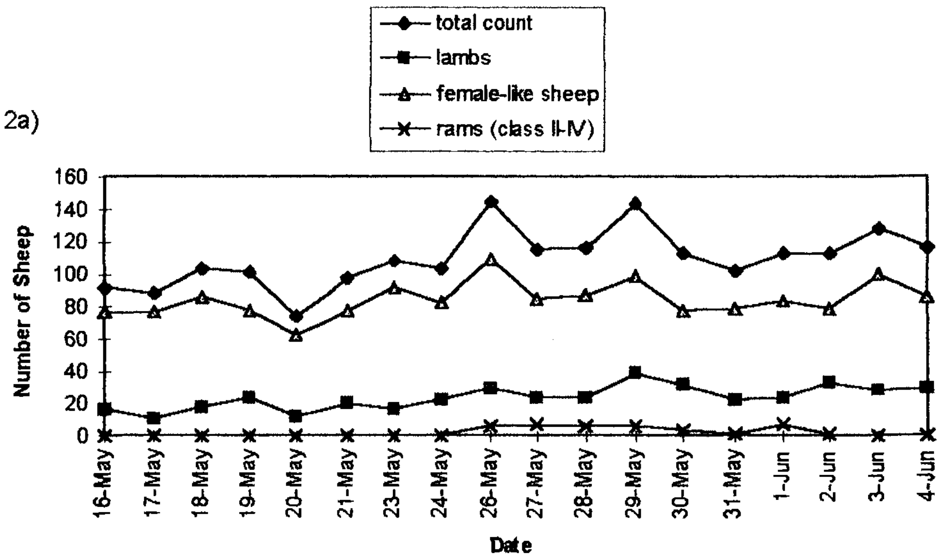


SCALE

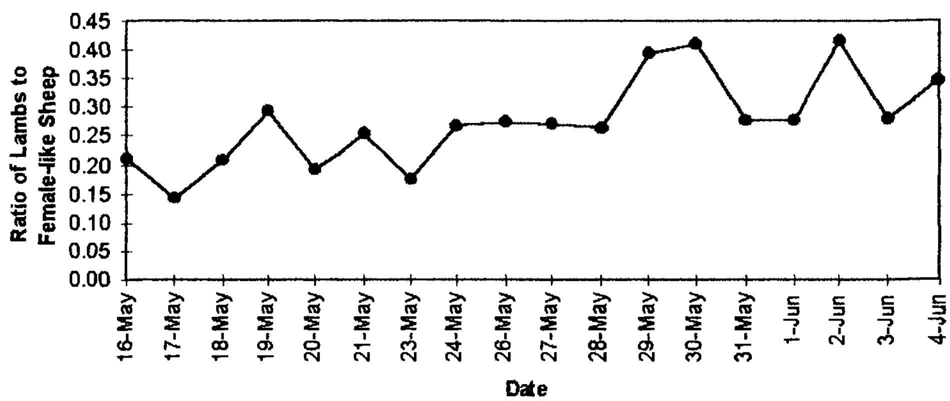
1km 0 1 2 3 4 5km

Fig. 2) Population data collected during censuses for (a, b) the lambing range during the lambing study, and (c) the lambing and summer ranges during the summer study. Fluctuations in Figs. 2a and the lack of an increase to a plateau in Fig. 2b are due primarily to sheep moving in and out of the lambing range. Fluctuations in Fig. 2c are due to observers missing sheep in blind spots. Female-like sheep are adult females, yearlings and two year olds of both sexes pooled.

2a)


total count
lambs
female-like sheep
rams (class II-IV)
Number of Sheep
0
20
40
60
80
100
120
140
160
16-May
17-May
18-May
19-May
20-May
21-May
23-May
24-May
26-May
27-May
28-May
29-May
30-May
31-May
1-Jun
2-Jun
3-Jun
4-Jun
Date

2b)


Ratio of Lambs to Female-like Sheep
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
16-May
17-May
18-May
19-May
20-May
21-May
23-May
24-May
26-May
27-May
28-May
29-May
30-May
31-May
1-Jun
2-Jun
3-Jun
4-Jun
Date

2c)

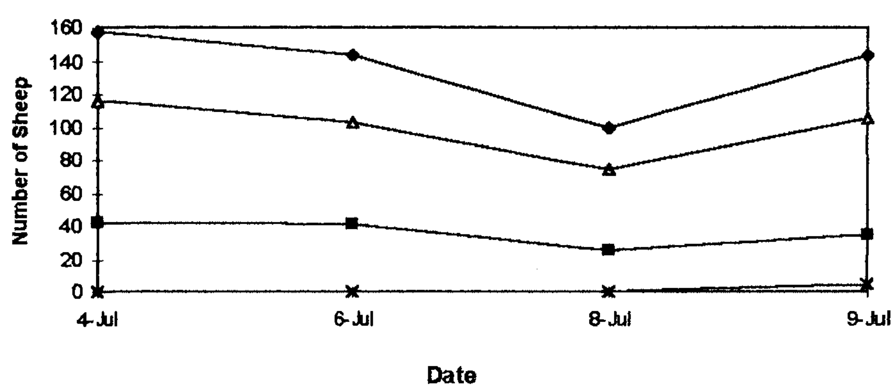

Number of Sheep
0
20
40
60
80
100
120
140
160
4-Jul
6-Jul
8-Jul
9-Jul
Date

Fig. 3) Proportions of sheep occupying different blocks during morning censuses at the lambing range during the lambing study. Data are pooled for the weeks of 16-22 May, 23-29 May, and 30 - 4 June (respectively, weeks 1, 2 and 3). There were six censuses during each week. Fig. 3a represents all age-sex classes pooled, and Fig. 3b represents lambs only. See Fig. 1a for block locations.

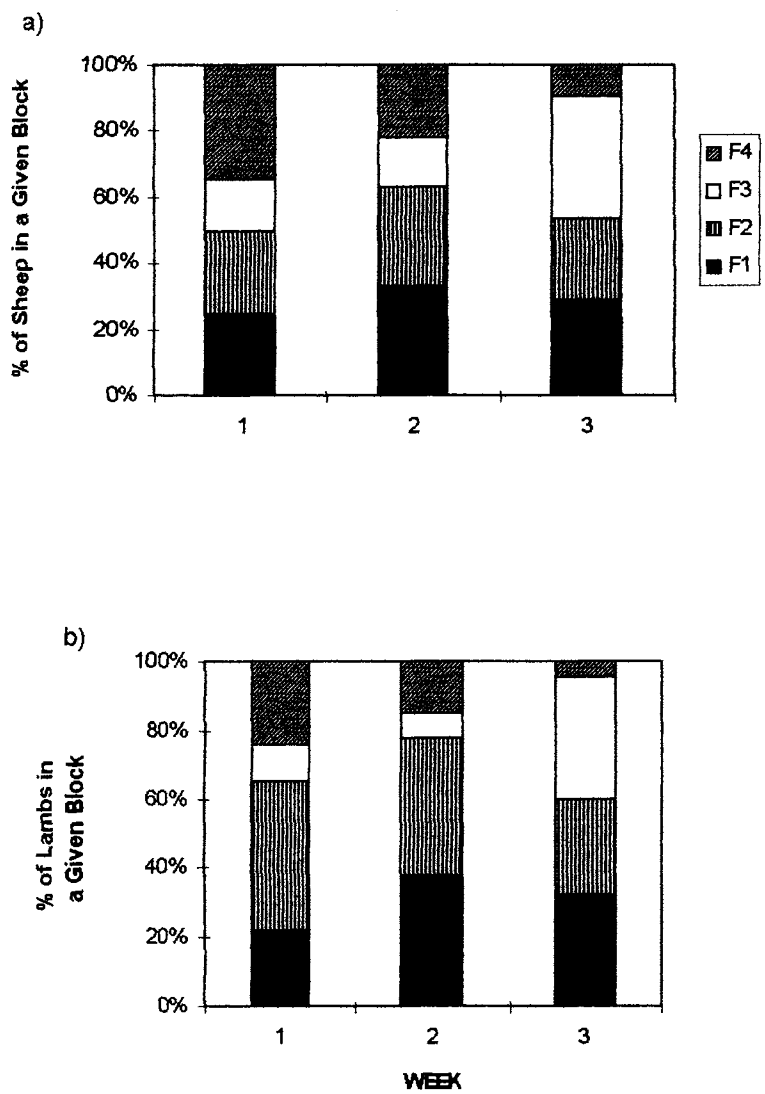


Fig. 4) Proportion of sheep occupying different blocks during morning censuses during the summer study. Data are pooled for 4, 6, 8, and 9 July. See Fig. 1a for the location of each block.

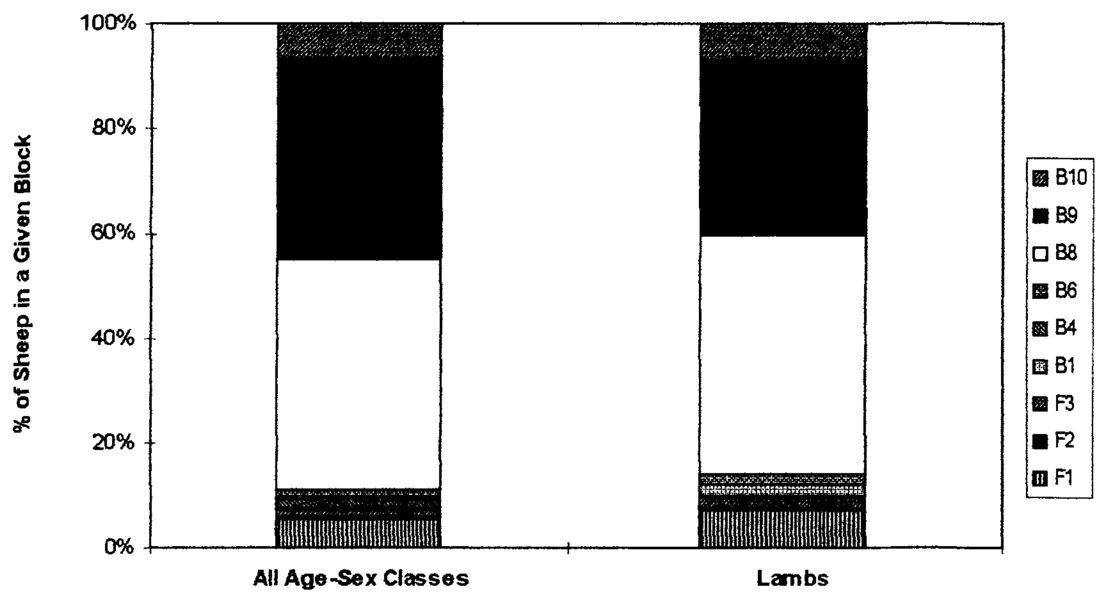
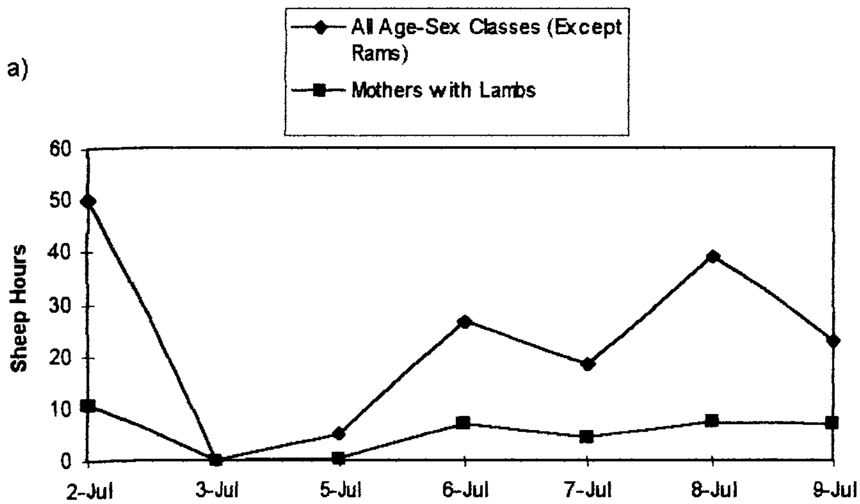


Fig. 5) Daily number of sheep hours that sheep spent at (a) Mineral Lick Area 1 and (b) Mineral Lick Area 2 during the summer study. (Sheep hours equals number of sheep observed multiplied by the time they spent at the mineral lick.) Mineral Licks were monitored between 0600 and 2200. See Fig. 1a for the location of mineral licks.

a)



b)

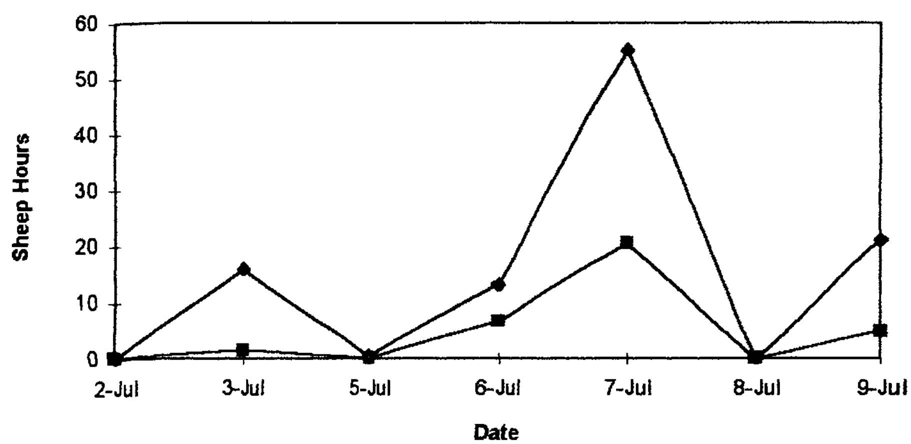


Fig. 6) Times of day when sheep (all age-sex classes except rams) arrived to mineral licks during early July. Data are pooled for Mineral Lick Areas 1 and 2. Mineral Licks were monitored between 0600 and 2200.

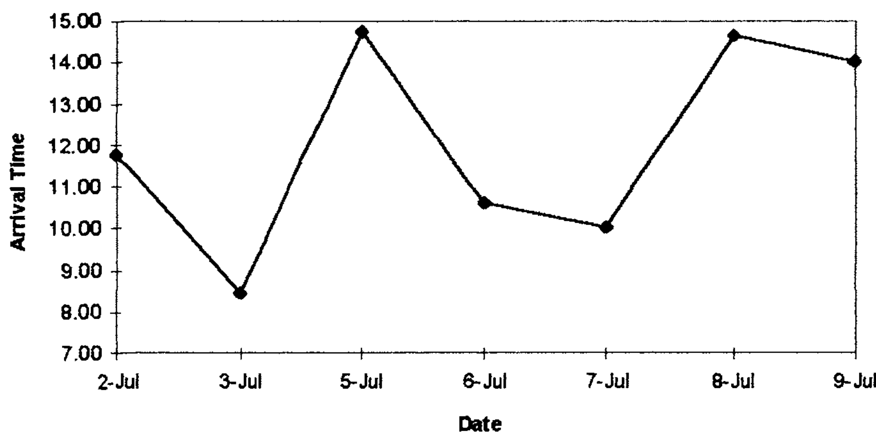
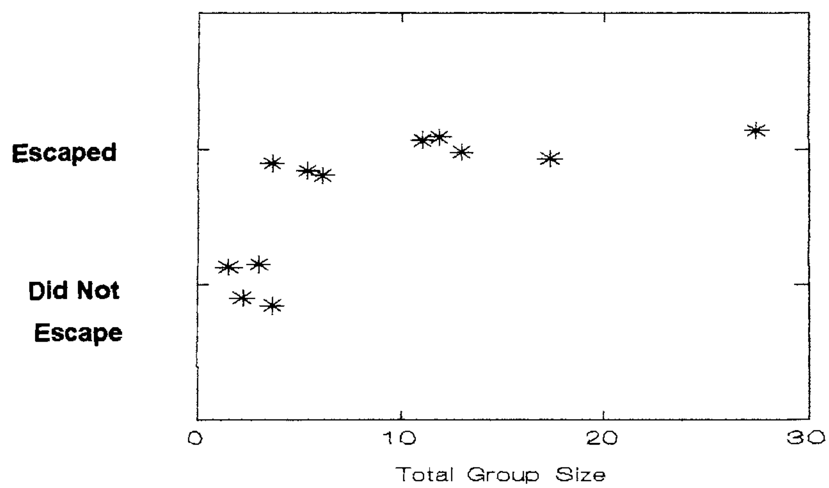


Fig.7) Effect of group size on the decision to escape from helicopters. All data are for groups of adult females and juveniles. Data points are jittered so that overlapping symbols can be read. See Table 1 for precise values.



b)

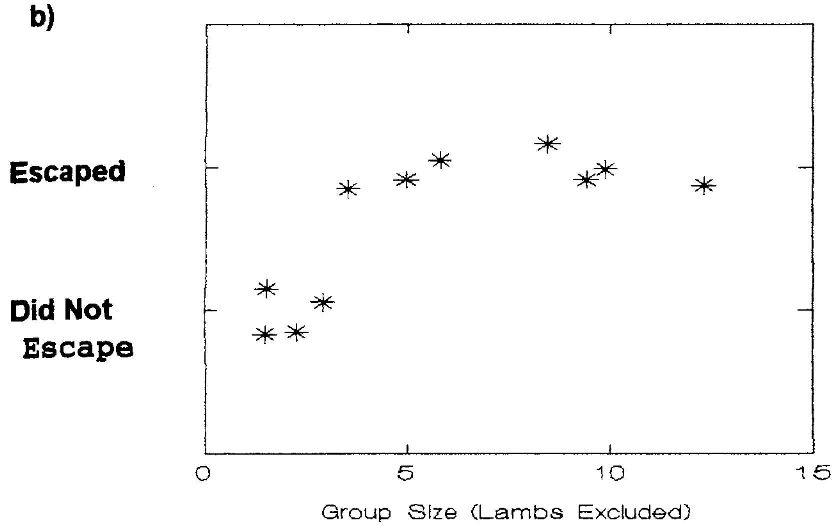
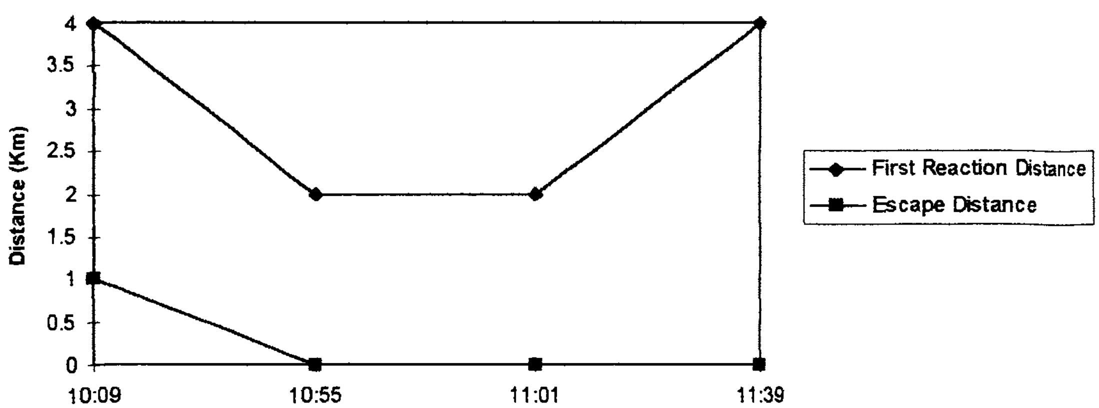


Fig. 8) Responses by a group of 16 sheep (including 6 lambs) exposed to multiple helicopter flights within a 52 minute period. See Methods for definitions of first reaction distance, escape distance, and response duration. Fig. 8a shows changes in first reaction distance and escape distance. Fig. 8b shows changes in response duration. Responses during the second - fourth flight consisted of vigilance only.

a)



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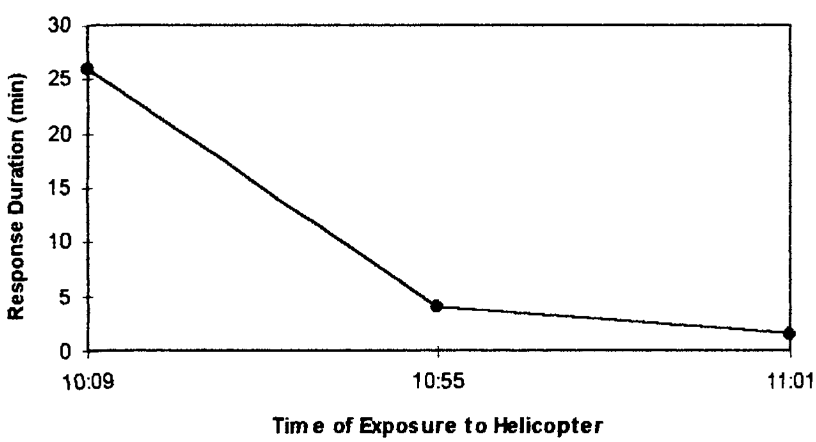
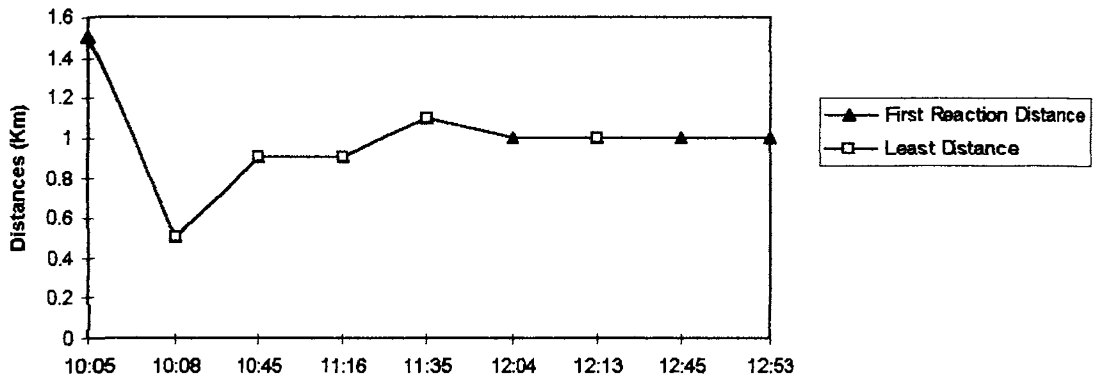


Fig. 9) Responses by a group of three sheep (2 females and 1 lamb) exposed to multiple helicopter flights within a 2.7 hour period. The sheep did not escape, and all responses consisted of vigilance. See Methods for definitions of first reaction distance, least distance, and response duration. Fig. 9a shows changes in first reaction distance, and the helicopter flights during which sheep showed no overt response. The latter have no first reaction distance, and instead are represented as least distance. Fig. 9b shows changes in response duration.

a)



b)

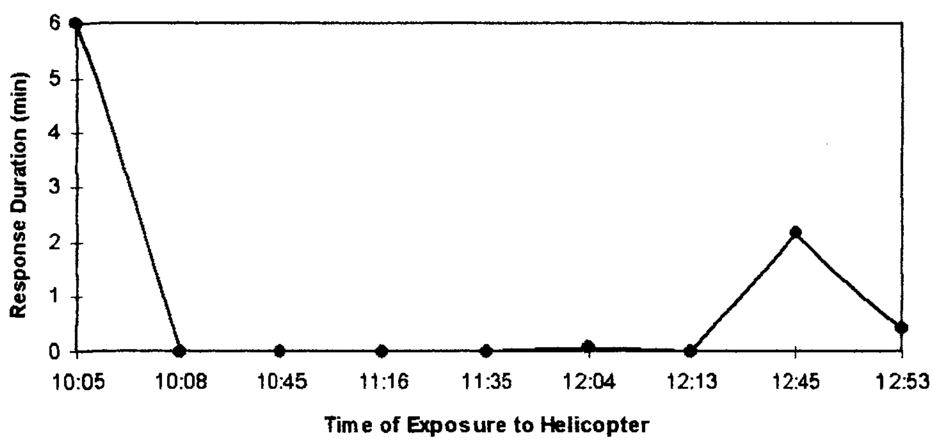


Table 1) Responses of sheep to independent events of helicopter disturbance. See methods for definitions of independence and of variables. In records of escape distance preceded by ">" sign, sheep went out of sight over a ridge-top while they were still escaping. For the "Escaped" variable, "+" indicates that sheep escaped from the helicopter, and "-" indicates that they did not escape. When sheep did not escape, the response consisted primarily of vigilance. All groups are of adult females and juveniles.

Group Size (Number of Lambs Included)	Escaped	First Reaction Distance (km)	Least Distance (km)	Response Duration (min)	Escape Distance (km)	Helicopter Time (min)
5 (3)	-	2.5	2.5	0.08	0	?
3 (2)	-	1.5	0.85	6.0	0	10.0
2 (1)	-	2.0	2.0	?	0	?
2 (1)	-	?	1	?	0	?
13 (0)	+	?	?	?	?	?
6 (0)	+	?	0.5	4.4	?	?
27 (10)	+	2.5	1.5	4.8	0.15	?
17 (7)	+	4.0	2.0	26.0	> 1.0	17.0
4 (0)	+	2.5	0.5	?	> 0.85	?
7 (3)	+	2.0	2.0	7.0	0.4	?
13 (3)	+	1.0	0.4	?	> 1.0	3
11 (3)	+	2.0	2.0	?	0.5	?