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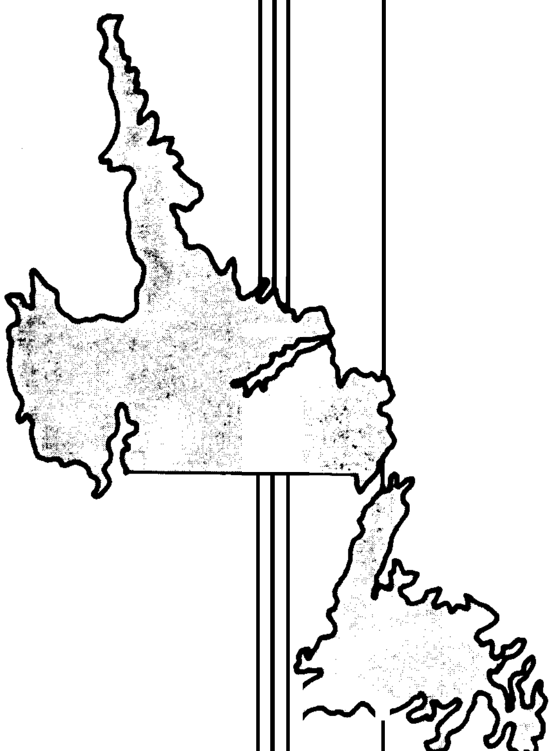

Impacts of Low-Level Jet Fighter Training on Caribou Populations in Labrador and Northern Quebec

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DEPARTMENT OF
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Minister

Impacts of Low-Level Jet Fighter Training on Caribou Populations in Labrador and Northern Quebec

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by

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ABSTRACT

The impacts on caribou (Rangifer tarandus) of low-level jet fighter training activity at Canadian Forces Base - Goose Bay (Labrador) were investigated during the 1986-88 training seasons (April-October) . Visual **observations** of low-level (30 m **agl)** jet overpasses indicated a strong startle response but otherwise short-lived overt reaction by woodland and barren-ground caribou on late-winter, alpine tundra habitat. In 1986 and 1987, the daily and cumulative impact of jet overflights was monitored season-long on 10 woodland caribou with satellite-tracked **radiocollars,** which provided daily indices of activity and movement. Half the animals were 'Targets' to which jet activity was directed; the other five caribou were avoided to serve as 'Controls' . In 1988, the Control caribou were from a neighboring population that had never been overflown. Level of exposure to low-level flying within the exposed population did not significantly affect activity, distance traveled daily, or general patterns of home range use, although comparison with the unexposed population did suggest potential effects, particularly regarding calf survival. The results indicate that significant impacts of low-level overflights can be minimized through a program of active and passive avoidance. However, there are other aspects of low-level flying activity with a greater potential for negative impact: loss of habitat through fire, increased hunting pressure from base-related personnel, and the unknown effects on

caribou of ingesting the aluminum chaff used for radar jamming, to name several.

Key words: caribou (*Rangifer tarandus*), low-level flying, jet airCraft, helicopters, disturbance, activity, movements, home ranges, calf survival, Labrador

INTRODUCTION

The continuation and expansion of military low-level flight training activities in the North have increased concern regarding the impacts of this activity on caribou (Ranaifer tarandus) . These impacts can be divided into two classes: short-term behavioral responses that indicate the energetic costs and the potential for injury resulting from individual overflights, and long-term population responses that indicate the cumulative effects of flying activity on population demographics and habitat use. Previous studies of aircraft impacts on caribou have largely focused on the short-term effects of fixed-wing, propeller-driven aircraft and helicopters (Calef, et al., 1976; Miller and Gunn, 1979; Gunn, et al., 1985). These studies have shown that the severity of an animal's reaction is a function of aircraft type and altitude, and a number of biologically-relevant variables (group size and composition, season, etc.). Long-term population responses either have not been assessed or have been inferred from the short-term responses observed. The impacts of jet aircraft, on the other hand, have only been assessed indirectly through the demographics and habitat use patterns of caribou frequently exposed to jet activity (Davis, et al., 1985) . The short-term effects of jet activity have not been systematically investigated.

Low-level jet training activities in Labrador and northern Quebec are proposed to increase three-fold by 1996 (Anonymous, 1989) . In addition, further expansion of military training activity has been proposed through the establishment of a NATO Tactical Fighter Centre at Goose Bay, Labrador, which is currently in the environmental review process (Anonymous, 1989) . Our study was designed to investigate the potential short-term and long-term effects of this low-level flying activity by fighter-type jet aircraft on the caribou populations inhabiting the low-level training area. Short-term effects were assessed by observations of the reactions of caribou to low-level overflights, and by determining the relationship between an animal's daily exposure to low-level flying activity and its daily movement and activity level. Long-term effects were assessed by determining the relationship between an animal's total seasonal exposure to low-level flying and its corresponding calf survival and habitat use patterns.

LOW-LEVEL JET FIGHTER TRAINING IN LABRADOR

Component 1

The present era of low-level training exercises by Allied forces was initiated at Canadian Forces Base (CFB) Goose Bay in 1981 by the Royal Air Force (RAF) and German Air Force (GAF). These were joined by the Royal Netherlands Air Force (RNLF) in 1987. Current low-level flying activities are specified under a Multi-national Memorandum of Understanding and are coordinated through the Military Coordinating Centre (MCC) at CFB Goose Bay. MCC also acted as a liaison for this study. The number of aircraft flights (sorties) has increased from approximately 1500 in 1981 to over 6000 in 1988, and is projected to reach a maximum of 18 000 per year by 1996. Most of these would involve flying at altitudes under 150 m above ground level **(agl).** Currently (1989), the training season runs from early April through early November, and would extend from March through November by 1996. In addition to low-level jet training, approximately 1000 helicopter sorties per year are anticipated by the mid-1990's.

At present, about half of the 94 permitted aircraft are operated from CFB Goose Bay. Jet fighter aircraft currently used include the RAF Tornado, the GAF Alpha-Jet, F-4 phantom, and Tornado, and the RNLF F-16. Occasional low-level flying is done by Canadian Air Force **(CAF) F-18's** and United State Air Force (USAF) F-16's.

Two areas are currently used for low-level training (Fig. 1). The northern low-level training area (LLT 1) of 67,000 km^2 is the principal flying area. It consists of three contiguous units, within which flights to within 30 m agl are permitted. This area is connected to a smaller (32,000 km^2) southern low-level training area (LLT 2) by two transit corridors, and both training areas are connected by transit corridors to CFB Goose Bay. Minimum altitude permitted in these transit corridors is 80 m agl. The exposure of different sites to low-level flying activity varies significantly within the training areas (Fig. 2). In particular, some areas of the southeastern section of LLT 1 are exposed to up to 250 flights per month, whereas most areas in the outer two units receive less than 10 sorties per month. The extreme southeast corner of LLT 1 is the most heavily overflown

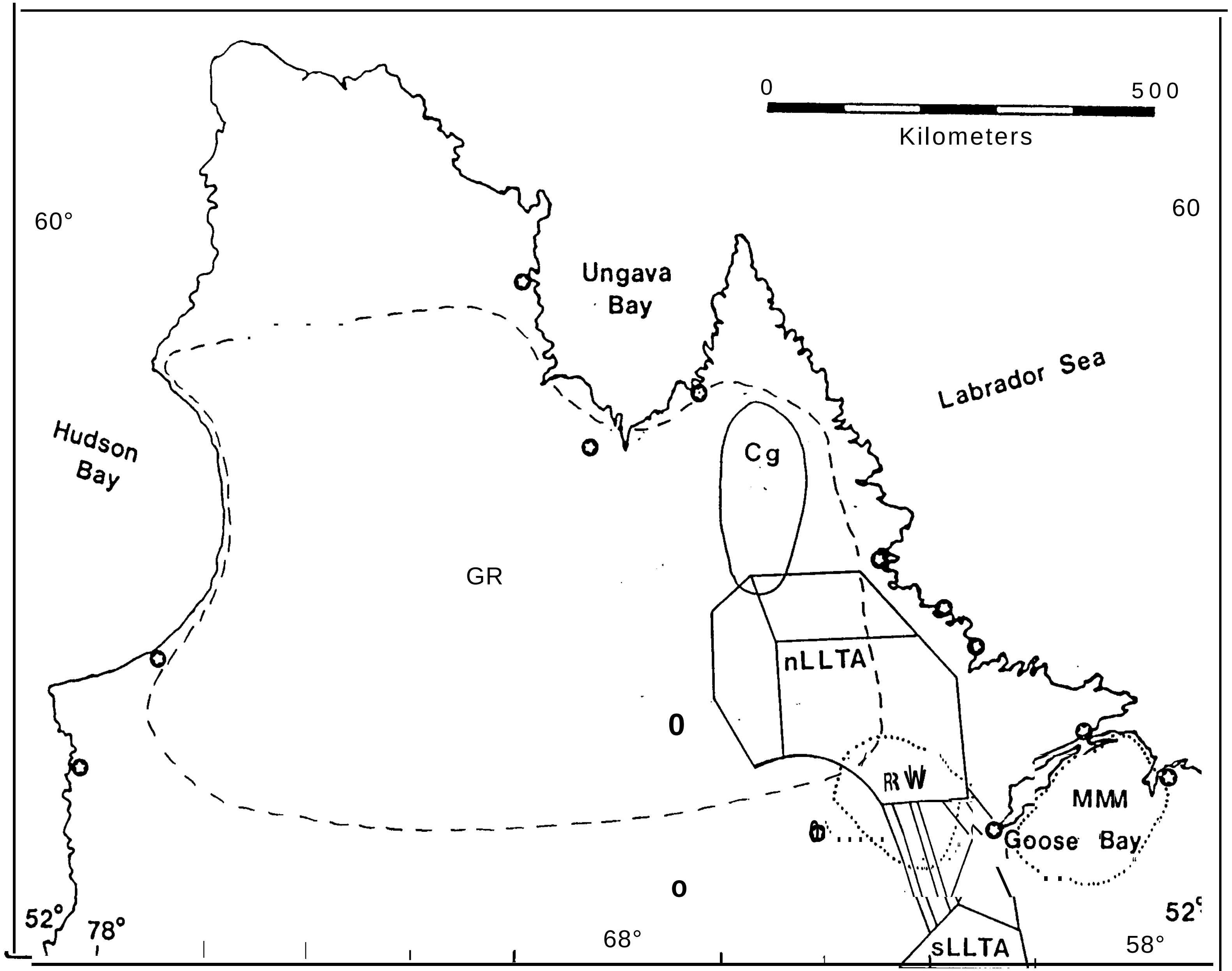

Figure 1. The study area and approximate ranges of three caribou populations in Labrador and northern **Quebec.** The George River (GR) **population** range is **indicated** by the dashed line (- - —). Cg = calving grounds of the GR population. The ranges of **woodland** caribou ara denoted by dotted **lines (•••••••):** RW = Red Wine Mountain populat ion; MM = Mealy Mountain populat ion. nLLTA = the northern **low-level** training area; sLLTA = the **northernmost** portion of the southern low-level training area. The three units of the nLLTA are indicated, as are the corridors **between** the **LLTA's** and **CFB** Goose Bay. Permanent **communities** are indicated by circled stars (✪).

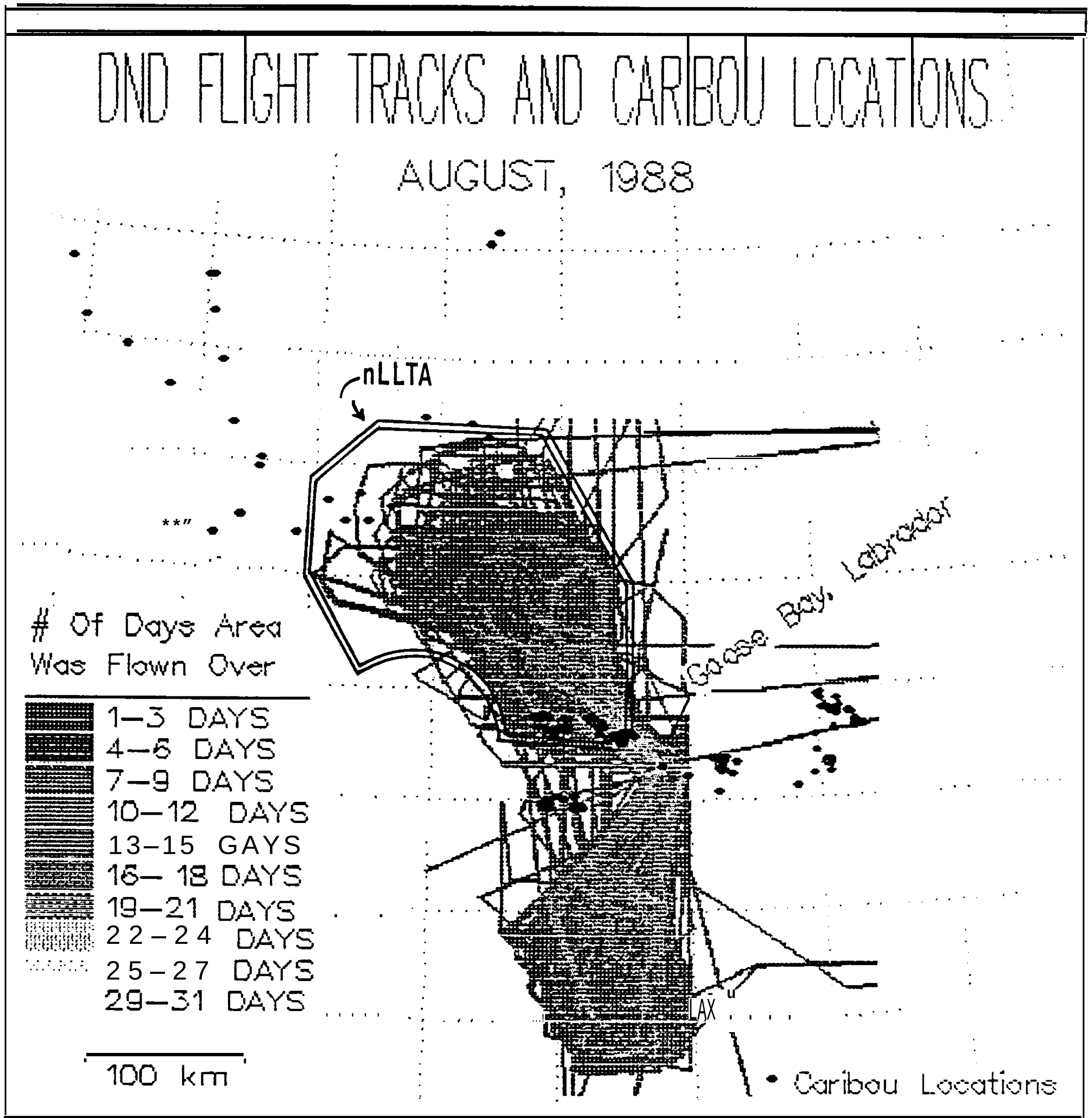

Figure 2. **The density of exposure to low-level jet flying activity within the low-level training areas (LLTA).** Only the **northern low-level training area (nLLTA) is outlined. Higher density of exposure is indicated by lighter portions within the LLTA's. The flight track data** used to generate these exposure levels

because it provides the most direct entry and exit for Goose Bay, while of the two transit corridors the eastern-most receives the majority of the flying activity.

Training exercises consist of navigation, evasion and simulated attacks on ground targets. Typically, two or more aircraft comprise a mission, and either fly in combat formation to provide mutual support or attempt to locate or evade one another. Much of the training involves the use of terrain features to provide cover from radar, so river valleys are common flight paths. Flights speeds are typically 775-825 km-hr. No supersonic flying is permitted at present.

<u>Component 2</u>

The Department of National Defence has proposed the establishment of a NATO Tactical Fighter Training Centre at CFB Goose Bay (Anonymous, 1989). Current forms of low-level training, at 125% of proposed 1996 levels, would continue. In addition, a variety of new forms of training, involving an additional 17,500 sorties per year, would be established. Two-thirds of these would be engaged in massive exercises involving up to 90 aircraft playing a variety of defensive and offensive roles about an assigned target. The other third would involve high altitude (>1500 m agl) air combat manoeuvring (dog-fighting) within a activity, LLT 1 would be extended to the southwest and east. The number of personnel involved directly with base operations would increase from about 2000 today to over 6600 in 2001.

STUDY AREA

The study area includes the ranges of three caribou populations (Fig. 1). Two woodland caribou (R.t. caribou) populations inhabit the southern portion of the study area. The Red Wine Mountain (RWM) population inhabitats a 23 000 km^2 area which includes the southern portion of LLT 1, as well as range to the south. During winter, most members of the population can be found within LLT 1, whereas a portion of the population migrates out of LLT 1 prior to calving, and remains to the south or west of the training area until after the fall rut. The Mealy Mountain (MM) population inhabits a 22 000 km^2 area east of Goose Bay and is far removed from both training areas. The George River (GR) population of barren-ground caribou (R.t. groenlandicus) utilizes the northern and northwestern sections of LLT 1 on a periodic basis, usually at some point during the post-calving period between June and August, but also at times during the winter, when they may travel much farther south and even into the range of the RWM population.

the upper elevations of the Red Wine Mountains is alpine tundra and consists of grasses, sedges, mosses, lichens, and low shrubs. In late winter, when high winds keep many of the hill-tops relatively free of snow, caribou congregate on the mountains when snow in the lower elevations becomes too deep for efficient foraging (Brown, 1986). Lower elevations in the Red Wine Mountains have an open lichen-woodland cover, similar to that described below.

A level plateau that averages 400 m elevation surrounds the Red Wine Mountains. The plateau is classified as a subarctic 'northeastern transition! forest between the closed-canopy boreal forest to the south and a band of forest-tundra to the north (Rowe, 1972). Vegetation is mainly open lichen-woodland dominated by black spruce (*Picea mariana*) or black spruce-balsam fir (*Abies balsamea*), with tamarack (*Larix laricina*) common on wetter sites. The associated ground cover is primarily lichens (*Cladina* spp.), Labrador tea (*Ledum groenlandicum*), various berries (especially *Vaccinium* spp.), and low shrubs. Many areas of upland barrens, with a cover similar to the Red Wine Mountains, occur. A mosaic of ribbed fens, string bogs, streams, shallow ponds, and lakes occurs throughout the plateau. Stands of tall decidious vegetation, composed of trembling aspen (*Populus tremuloides*), white birch (*Betula papyrifera*), and willows (*Salix* spp.) occur

Bay is 0.0 C; mean July temperature is 15.8 C and the January mean is -17.2 C (AES 1982-1988).

Five communities with a combined population of approximately 10,000 inhabitants are located on the periphery of the RWM caribou range (Fig. 1) . A seasonally usable, single-track, gravel road traverses the southern portion of the study area and connects the towns of Goose Bay and Churchill Falls. Access into the study area is generally available only by air or snowmobile from November to April, and by air or boat (perimeter only) in May to October.

Population estimates of RWM caribou obtained in the 1980's have indicated a low but stable population of about 700 animals (Phillips, 1982; Brown 1986; Veitch, 1990), despite the prohibition of hunting since 1975.

Mealy Mountain Population

In size, physiography, vegetation, snowfall and other weather parameters, the MM caribou range is very similar to that of the RWM population. However, human access is easier. Like RWM caribou, MM caribou congregate on the mountains during late winter in response to deep snow in the surrounding lowlands, and disperse into the lowlands in spring to calve (Hearn and Luttich, 1987) .

(Hearn and Luttich, 1987). Despite this increase, however, illegal hunting appears to be a significant mortality factor at present (Hearn and Luttich, 1987).

George River Population

The GR population currently utilizes a range in excess of 600 000 km^2, stretching from its calving grounds in northern Labrador west to Hudson Bay between latitudes 53° and 59° N. (Fig. 1). In Labrador, this range varies from the extensive upland tundra of the calving grounds immediately north of LLT 1 to late winter/early spring habitat in the open taiga and on the alpine tundra of higher elevations in the southern portion of LLT 1. Much of the populations range in LLT 1 consists of the transitional zone between the relatively dense stands of spruce-balsam fir forest in the south and the barren tundra of the north (Rowe, 1972). This transition zone supports willow, dwarf birch, lichens and mosses in upland areas and spruce forest in valleys and protected lowlands, interspersed with extensive open bogs.

Caribou use of this range varies seasonally and has also varied historically. From the late 1950's through the late 1970's, a significant proportion of the herd wintered in LLT 1 (Bergerud, 1967; Berger and Luttich, 1985). During the same period, the population increased from 15 000 to more than 200

Red Wine Mountains. By mid-May, most are generally in migration toward the calving grounds, so that by June few remain in the southern two-thirds of LLT 1. During calving, most females are north of LLT 1, although since 1984 the calving grounds have expanded to the south southwest. Thus the southern-most 5-10 % of the calving ground is now within the northwest corner of LLT 1. During the post-calving period, caribou may move throughout the northern portions of the training area, but as most are moving relatively quickly either to the southwest or north, their time spent in the zone is rather brief.

METHODS

This study was designed to investigate the impact of low-level flying on free-ranging caribou. Two criteria constrained the methods chosen. First, the level of exposure to low-level flying had to be measured reliably, since low-level flying over any individual animal was expected to be unpredictable and sporadic in nature. Second, the method for measuring exposure had to be unobtrusive, as it was felt that disturbance from monitoring activities could be more significant than that caused by low-level flying. The two methods chosen, direct visual observations conducted on late-wintering areas and remote monitoring using satellite telemetry, seemed to best fulfill these requirements.

Observational Approach - Directed Overflights

Visual observations provide detailed information on the immediate, short-term effects of low-level flying. However, they also require a field observation team, which must locate and maintain contact with the study animals until overflights can be completed. To minimize potential disturbance, visual observations were only attempted when caribou were in open habitat with good vantage points from which caribou could be observed without influencing behaviour. For the woodland caribou, this limited observations to a brief late-winter period on the Red Wine Mountains just prior to dispersal to lower, forested habitat. Although the potential period for visual observations of the barren-ground caribou was longer, the seasonality of their movements through LLT 1 also limited visual observations to this same late-winter period.

Because overflights over any given point are so infrequent and their area of impact likely narrow, it was necessary to actively direct jets over the caribou under observation. On the day prior to attempted observations, MCC alerted each airforce, provided a rendezvous point in the observation area, and requested it be included in flying exercises planned for the next day. Given favorable weather, a field crew, including a forward air controller from MCC, left by helicopter for the observation area early the next morning. Once in the observation area, a high-level (150-300 m agl) search was conducted to find a suitable group of caribou. Radio-collared animals were used to expedite the search. Once a group was sighted, we landed near a suitable vantage point, using ridge crests for concealment and taking the movements of the animals and lay of the land into account. Observation equipment was set up and we waited for the first jets to arrive. If the caribou moved out of sight in the meantime, we searched out another group and vantage point.

When a jet neared the rendezvous point, radio contact was established with the forward air controller, who guided the pilot to the caribou. Pilots were directed to fly directly over the caribou at normal operational speed (775-825 $km \cdot h^{-1}$) and at minimum elevation (30 m agl). We conducted this "worst case" approach because we felt we could not obtain a large enough sample size to reliably study the effects of both varied elevation and distance from flight track. However, unintentional deviations from our requested "worst case" situation provided observations on overflights at higher elevation and greater distance from the animals. Elevation and distance to animals was estimated by the observers and was often confirmed by the pilots. In general, several jets arrived together and flew over the animals at intervals of less than one to several minutes. If the jets had fuel for additional overpasses, these were requested and occurred within the next several minutes.

Observations were videotaped using a Panasonic WV-3250 (18X) video camera with a Panasonic AG-2400 video cassette recorder (1987-88) and a Panasonic AG-160 (6X) camcorder (1988). The 18X camera was tripod mounted and was used to record in detail the animals' behaviour. It remained focused on the centre of the group, unless all animals left the frame during an overpass. The

6X camera was used to provide a broader view of the group and, if possible the jet, and was usually shoulder mounted and moved to follow the animals. A spotter kept the camera operators appraised of the jet's approach and overpass. He recorded the moment of overpass, elevation and distance of the jet to the animals, type and airforce of jet, and other pertinent data onto a cassette recorder and the soundtrack of the cameras. Thus several audio and video records were obtained for each overpass. Following the overpass, the spotter also recorded the general activity of the caribou group and indicated when the group slowed and stopped. In addition, periodic verbal and videotape records were taken of the caribou's behavior throughout the day.

Caribou responses to overpasses by helicopter were also observed for comparative purposes. As the effect of helicopters on caribou has been extensively studied before (Calef et al., 1976; Miller and Gunn, 1979; Gunn et al., 1985), we limited these observations to three days, using either a new group or waiting at least 30 minutes before conducting observations. After warming up, the helicopter flew away from the caribou, using the ridge as cover, made a broad circle about the animals, and then approached them either toward or perpendicular to the observation team. Approaches were at normal cruising speed (130-160 $k \cdot h^{-1}$) and at several different elevations, if possible, although only one to two overpasses were usually completed before the animals were out of sight.

Videotapes were analysed using a Panasonic AG-1830 VCR. For most overpasses, the behaviour of animals was noted at one-second intervals from 5-10 s prior to the overpass to the point where behaviour returned to its pre-overpass state. Behaviors were classified as: lying, standing, feeding (standing with nose to ground), walking and running. If the camera had remained fixed throughout the overpass and animals moved across our field of view rather than toward or away, then the number of body lengths moved per five second interval was determined. If no suitable video record was available for an overpass, audio records were used to characterize the general response of the group.

Experimental Approach - Woodland Caribou

Our hypothesis was that the effects of a single overflight may be subtle, but additive, so we used satellite telemetry to allow us to manipulate and measure the daily and seasonal level of exposure to low-level flying of each study animal. Satellite telemetry allowed us to locate an animal on a daily basis without disturbance, beyond the initial collaring and the constant presence of the collar, and obtain an index of the animal's total activity level during the preceding day. Using these locations, we could then remotely direct jet aircraft either toward or away from an animal's location. By manipulating exposure levels among animals, we could then determine the relation between exposure to aircraft and a caribou's subsequent movement and activity level.

Satellite Telemetry. Satellite telemetry has been described extensively elsewhere (Fancy, et al., 1988) . In brief, the satellite transmitter (PTT) (Telonics, Inc. , Generation ST-2 and

ST-3) broadcasts a brief (250 ms) digital signal on a carrier frequency of 401.65 MHz once each minute. These signals are received by polar-orbiting satellites whenever the PTT is within view. In Labrador, there are two “windows” when satellite overpasses are most common, early morning and late afternoon. To conserve battery power, our PTT's broadcast eight hours each day during one of these two windows, giving it an expected life of about nine months.

The digital signal (message) and its carrier frequency are recorded and downloaded to Service Argos processing centers in Toulouse, France and Landover, Maryland, where the message is decoded and the location is calculated. The message identifies the PTT and indicates the current status of sensors (temperature, short-term activity, long-term activity) carried in the PTT. The degree of Doppler shift in the carrier frequency is used to calculate the PTT's location. This information can be accessed by modem within a few hours of it reception by Argos.

Locations provided by Argos, although precise to .001 degree for both latitude and longitude (roughly 100 and 65 m, respectively) , vary in accuracy. Argos provides an index of location accuracy. Three levels of “guaranteed” locations (Quality 3> 2> 1) average within 1 km of the true location (Barrington et al., 1987; Fancy et al., 1988) , which compares favorably to the accuracy of locations we obtain using VHF telemetry. In 1988, a fourth “non-guaranteed” location index was added. These "non-guaranteed" locations are sometimes very accurate, although at other times they can be tens to hundreds of kilometers in error.

To minimize locational error, only the best location obtained each day was used. This was chosen first on the basis of the quality index assigned by Argos and second on the number of messages received during the overpass (more messages = better signal) . In 1988, if only a non-guaranteed location was available, this location was used only if it fell within the range of better quality locations obtained on previous and/or subsequent days.

The long-term (24 h) activity index is generated by a mercury switch within the PTT. A counter records the number of seconds for which the switch was triggered at least once. The counter starts at the beginning of a transmission cycle and continues until the next cycle begins. At that point, the count is compressed by dividing by 85 and this index, varying from O to 1023, is broadcast. The angle of the mercury switch was set using captive caribou to obtain reasonable discrimination among four classes of behaviour: lying, feeding, walking, and running (Fancy et al., 1988). With free-ranging animals this discrimination is reduced to three classes, with lying and feeding combined (S. Fancy, pers. comm. 1989) . In addition, the switches may not be always installed at the proper angle, which will result in systematic differences in the index among individuals (S. Fancy, pers. comm. 1989) . A collar attached loosely around the animal's neck produces a systematic bias in activity level (M. Ferguson, pers. comm. 1989; A. Gunn, pers. comm. 1989). However, the long-term index does provide a reliable index of relative activity for each individual caribou, and thus is quite useful for determining the relationship between daily activity level and a variety of other data collected on the same time scale.

Satellite collars were deployed each spring (April or May) at the beginning of the low-level flying season and were retrieved each winter two to four months after the low-level flying season ended. Adult female caribou were captured by darting with C02 pistol from helicopter (Bell 206B, 206L) using either etorphine (1986) or carfentanil (1987-88) combined with xylazine or acepromazine and reversed with diphrenorphine or naloxone. Whenever possible, captures were done on the barrens to minimize harassment. In May 1986, we attempted to recapture caribou originally collared in 1982-83 (Brown, 1986), both to expedite locating animals already dispersed in the lowlands, and to utilize their previous histories. In April 1987 and 1988, we attempted to recapture animals that had utilized suitable areas in past years, in order to ensure geographical separation among the appropriate individuals and to look for consistency in behaviour between years. In 1987 and 1988, collared animals were visually inspected about one week after collaring to ensure that there were no capture-related injuries or deaths.

Experimental Procedures. In 1986 and 1987, the 10 satellite collared caribou were divided equally into exposure and control groups. Prior to 0700 h daily, the most current location was obtained for each animal. These locations were 3-14 h old in 1986, depending on whether the animal's PTT was on a morning or evening transmission cycle, respectively. In 1987 all animals were on morning cycles. By 0730 h, these locations were phoned to MCC as either Target (exposure group) or Avoidance (control group) coordinates. In 1986, each Target coordinate was accompanied by a request for a specific number of overflights. Because experience indicated that a specific number of overflights could not be guaranteed, in 1987 we simply asked for as many overflights as possible over Target coordinates. Avoidance coordinates, on the other hand, were to be avoided by jets by at least 9.2 km. These requests and coordinates were then relayed by MCC to each airforce, so that the coordinates could be programmed into the day's flying.

An overflight was considered to be a jet within 1 km of a Target site. This radius was chosen to account for the inherent error in the caribou's location, any movement which occurred since that location had been fixed, and navigational error on the part of the pilot. Thus our measure of overflights, while not exact, should reflect the relative level of exposure of an animal on both a daily and seasonal basis. In 1986, we discovered that we were not getting the number of reported overflights we thought we should. Discussions with the military indicated that training priorities sometimes precluded flying the coordinates, some pilots were under the mistaken impression target caribou must be seen to be reported, while others simply did not heed our requests. To rectify these problems, both MCC and ourselves began extensive briefings for each incoming squadron in July. (Squadrons rotated every 2-3 weeks.) At the same time, we began unannounced field truthing exercises. At irregular intervals, we provided MCC with a set of dummy coordinates for either a Target or an Avoidance site. Then we flew to that site by helicopter or light aircraft and recorded all jet activity around it. Upon our return, we compared our results with the overflights reported to us (for Targets) and simply noted the number of times our Avoidance sites were violated. These data (Table 1) indicated both sloppy reporting for Targets and a failure to avoid the control animals. Further discussions with the military suggested that navigational error might account for these discrepancies. Computer-guided aircraft like the Tornado and F16 could precisely overfly a set of coordinates, whereas less sophisticated aircraft like the F4 might be off by as much 1.6 km, which concurred with our own field observations. In addition, occasional overpasses of Avoidance sites might occur unintentionally during an exercise, as one jet maneuvered to evade another. To rectify these problems, new procedures were implemented in 1987.

In 1987, MCC took a more direct role in coordinating the overflight requests and enforced a high level of compliance. MCC forwarded overflight requests as before and reviewed each overflight data sheet on a daily basis. Reports were checked for accuracy in time against MCC records of aircraft flight times and discrepancies were noted and investigated immediately. Field-truthing in 1987 indicated that more than 80% of actual overpasses were reported and less than 5% involved overflights which were reported but not observed by us (Table 1) . In addition, overflights of Avoidance sites were rare. Thus the

TABLE 1. Results of field-truthing observations in 1986 and 1987. Observers were stationed at a set of coordinates that had been given to the military as a target for overflights. Observations of jet activity over the coordinates were compared to reports of overflights later provided by the military.

Year	Number of sites	Percent of observed overflights that were reported		Percent of reported overflights that were observed	
1986	4	54%	(n = 26)	45%	(n = 31)
1987	7	82%	(n = 56)	96%	(n = 46)

field-truthing exercises indicated that the results from 1987 were a good reflection of actual exposure.

Procedures were changed during the third field season in 1988. In conjunction with the Environmental Impact Statement (Anonymous, 1989) being prepared for the Department of National Defence, records of all flight tracks flown in the low-level training areas were kept. These flights tracks consisted of a list of coordinates which represented turning points during the flight. For some aircraft (F16, F18, Tornado) these were generated by onboard computers, whereas for other aircraft (F4, RF4) these were recorded by hand. From these coordinates, flight lines were constructed from which indices of exposure were generated. Thus the decision was made to allow the military to fly unimpeded throughout LLT 1, so that a “normal” distribution of exposure to low-level flying could be obtained. The exposure of individual study animals could then be determined afterward using the flight tracks. All animals in LLT 1 would be considered Exposure animals, but would differ in their level of exposure to low-level flying due to geographical differences in low-level flying activity (Fig. 2).

Control caribou in 1988 were from the MM population. We chose to place the Control animals outside the RWM population because (1) it ensured the military completely avoided the Control animals, (2) all Control animals in the RWM population had prior exposure to overflights so could constitute a biased sample, and (3) under the 1988 study procedures, it would not be possible to avoid specific caribou in the RWM population. The MM population was chosen for its proximity to Goose Bay, its similar characteristics in terms of both caribou and habitat, and its position outside the range of low-level flying aircraft.

Exposure to Overflights. The primary independent variable was the measure of an animal's daily exposure to low-level flying. In 1986 and 1987, this was simply the total number of reported overflights each day. As indicated above, the accuracy of overflight reports from 1986 was suspect, especially for the first half of the flying season. Thus for 1986, the season will be considered in two parts: inception until 31 July, and 1 August to conclusion. For this latter period, we had available to us flight track data from the RAF Tornados. These data were used to estimate the relative number of flights through an animal's home range.

In 1988, flight track coordinates were used to determine exposure to low-level flying. The minimum distance between each flight track and a satellite-collared caribou's location was determined, and the total number of jets within 1 km, 1-3 km, 3-5 km, 5-8 km and 8-16 km was calculated for each caribou each day. The number of jets within 1 km corresponds to our definition of an overpass for the 1986-87 seasons.

Response to Overflights. Two variables were used to estimate the effects of exposure of a study caribou to low-level flying activity: daily activity level and daily distance traveled. The PTT 24-hour activity index was used as a relative estimate of daily energy expenditure. As indicated above, this index is best used to compare daily variation for an individual. Daily distance traveled was simply the distance between the two highest quality locations on successive days. Because locations were obtained during the same 8 h window each day, and because most locations were obtained within a smaller portion of this window, the actual time between locations varied from about 20-28 h. No correction was made for these differences, however, since the inherent error in the locations themselves was typically greater than the correction term would have been. Because daily distance was not normally distributed, the variable was log-transformed for all statistical analyses. If no location was obtained on a day, then no distance was calculated for either the preceding or the following 24 h period. It was hypothesized that disturbance due to low-level flying would be reflected in increased activity levels, as animals engaged in flight-related behaviors (running, walking) more frequently following overflights, and by greater daily distances traveled, as animals avoided areas after being disturbed or avoided areas that were frequently overflown.

A caribou’s activity level and movements are also influenced by other important variables, reflecting individual differences as well as seasonal and environmental factors. To control for these influences, and to remove their effects, we considered the following classes: Seasonal; Individual; and Weather.

Seasonal variables included Julian Day, Month, and Season. (Julian Day runs from 1 (1 January) to 365 (31 December).) The first two variables simply reflect the influence of calendar date at different levels of precision. As neither are probably important to caribou in and of themselves, we created the variable Season, which was composed of the Pre-calving, Calving, Insect, and Fall periods. The Pre-calving period began with the date of capture in April or May and ended on May 22 (Julian Day 142) , and included time spent in the late-wintering areas in the Red Wine or Mealy Mountains, as well as the spring dispersal into the surrounding lowlands. The Calving period was bounded by the date of earliest suspected calving and the last day in June with sub-freezing temperatures. The earliest date of calving was estimated by examining the patterns of daily activity and movements for 4-6 d periods of minimal activity and movement (S. Fancy, pers. comm. 1989) . This method was equivocal, as several caribou exhibited more than one such depression between late-May and mid-June. However, independent data on calving were not available, so Julian Day 143 was taken to be the earliest date of calving. Thus this calving period will include pre-calving movements for some animals, as well as post-calving movements for others. The Insect period was bounded by the last day with sub-freezing temperatures in the Spring, and first day with sub-freezing temperatures in the late-Summer. Temperature data used were recorded by Environment Canada in Goose Bay, Churchill Falls and Cartwright. The Fall period followed the Insect period and continued until low-level flying activity ceased.

Individual variables included the identity of the female, and the presence or absence of a calf. Each female may differ for a variety of reasons, including age, temperament and habitat preference, which may bias the magnitude of her activity and movements, as well as differences in PTT construction and attachment, which may bias the measurement of these two dependent variables. In addition, the presence of a calf may have a significant impact on her activity and movement, particularly when the calf is young. A categorical variable, Calf Survival, was used to indicate the presence (1) or absence (0) of a calf. Calf survival was determined by periodic aerial surveys starting in mid-June. Every 3-4 weeks each female was located by helicopter and briefly driven from cover (if necessary)_so that an accompanying calf could be detected. When a female lost her calf between successive surveys, it was assumed to have died in the middle of the interval.

Weather variables included minimum and maximum temperature, precipitation, atmospheric pressure, wind speed, and hours of sunlight, collected daily by Environment Canada at Goose Bay, Churchill Falls, and Cartwright. For RWM caribou, Goose Bay and Churchill Falls data were used, and for MM caribou, Goose Bay and Cartwright provided the weather data. Because the 12 weather variables for each caribou population represent highly correlated, redundant information, a Principal Components Analysis using a varimax rotation (Harman, 1976) was conducted for each population. For the RWM population, this analysis was done for all April-October weather data collected in 1986-88 (N=642 days), while for the MM population, only 1988 weather data were used. This analysis isolated three principal components for each set of data (Table 2) . Factor 1 (Temperature) was largely an

Table 2. Results of principal components analysis (PCA) on Weather data used in the present study. Data were obtained from Environment Canada for weather stations at Cartwright (C), Churchill Falls (CF) and Goose Bay (GB). PCA is based on April-October weather for 1986-88 (Red Wine) or 1988 (Mealy Mountain) .

Weather variable	Loadings of weather variables on: Component 1	Component 2	Component 3
Red Wine caribou			
Maximum temperature (GB)	0.941	0.167	0.049
Minimum temperature (GB)	0.905	-0.18-6	-0.019
Maximum temperature (CF)	0.923	0.199	0.192
Minimum temperature (CF)	0.909	-0.173	0.057
Hours of sunshine (GB)	0.205	0.784	0.104
Hours of sunshine (CF)	0.185	0.768	0.198
Barometric Pressure (GB)	-0.329	0.534	0.613
Barometric Pressure (CF)	-0.334	0.591	0.565
Precipitation (GB)	0.055	-0.711	0.031
Precipitation (CF)	0.161	-0.679	-0.018
Mean wind speed (GB)	-0.123	0.044	-0.879
Mean wind speed (CF)	-0.295	-0.104	-0.797
Total variance explained	32%	25%	18%
Mealy Mountain caribou			
Maximum temperature (GB)	0.939	0.195	-0.080
Minimum temperature (GB)	0.897	-0.092	0.143
Maximum temperature (C)	0.940	0.135	0.026
Minimum temperature (C)	0.867	-0.116	0.230
Hours of sunshine (GB)	0.305	0.623	-0.363
Hours of sunshine (C)	0.391	0.608	-0.280
Barometric Pressure (GB)	-0.344	0.349	-0.753
Barometric Pressure (C)	-0.262	0.345	-0.778
Precipitation (GB)	0.074	-0.819	0.050
Precipitation (C)	0.096	-0.791	0.064
Mean wind speed (GB)	-0.095	0.041	0.719
Total variance explained	34%	22%	18%

indicator of temperature, as both minimum and maximum temperature for both communities had high loadings. Factor 2 (Precipitation) suggested a fair weather/ poor weather component, as precipitation, barometric pressure and hours of sun all had significant loadings in appropriate directions. Factor 3 (Wind) suggested a changing weather component, as both wind speed and pressure had high loadings in opposite directions. These three normalized weather factors were then used to examine the relationship of weather to activity and movements.

Regression Analysis. The influence of low-level flying activity was examined using regression analysis on the set of variables described above and summarized in Table 3. The analysis began with a step-wise regression, using one of the two dependent variables as the Y variate, to isolate a subset of predictors. From these predictors, a model was tested using multiple regression. Residuals from this analysis were plotted against a variety of variables to determine if other systematic variation might still reside in the data. All analyses were conducted using SYSTAT on a VAX 8350 mainframe computer.

Home range patterns. The study period was divided into two seasons, late-winter and summer, with the dividing date (13 May) representing the date by which caribou had left their late-winter mountain ranges. Best daily locations with guaranteed quality indices were used to characterize an animal's home range pattern. Latitude and longitude were converted to UTM coordinates and

TABLE 3. Variables used in preliminary multiple regression analyses

Type	1986	1987	1988
Temporal:	Julian day	Julian day	Julian day
	Month	Month	Month
	Season	Season	Season
Caribou:	Individual	Individual	Individual
		Calf survival	Calf survival
			Population
Weather:	Temperature	Temperature	Temperature
	Precipitation	Precipitation	Precipitation
	Wind	Wind	Wind
Exposure:	Overflights	Overflights	# Jets < 1 km
			1 km < # Jets < 3 km
			3 km < # Jets < 5 km
			5 km < # Jets < 8 km
			8 km < # Jets < 16 km
			# Jets < 16 km
			Minimum distance to jet

plotted. Home range areas were calculated using a grid cell method (cell = 4 km^2). Total range for winter and summer was estimated using a concave polygon (Mohr, 1947) which enclosed all actual locations as well as the paths connecting successive locations. Between April and October, each caribou typically used several, discrete core areas. These core areas were characterized by non-directional movement and/or multiple locations within individual grid cells. A convex polygon was constructed about each of these core areas and the area was determined using the same grid cell method. Locations for animals which were followed more than one year were compared between years and the distance between locations obtained on the same date in different years was determined.

Satellite Telemetry - Barren-ground Caribou

Each year, four to seven George River adult female caribou were equipped with satellite radiocollars and monitored to determine movements in the vicinity of LLT 1. Their PTT's broadcast for 8 h every third or fourth day, in order to guarantee at least one to two years of battery life, respectively. Rates of travel per day and 24 h activity levels were determined for animals prior to, during, and following their movements in LLT 1.

Overflight Stimulus

In order to characterize the nature of disturbance caused by a low-level overpass, audio recordings of overpasses were collected on two days in 1986. On the first, a forward air controller from MCC accompanied us and members of a Public Health Task Force (Anonymous, 1987) to several sites near CFB Goose Bay. Jets returning to the base were diverted over our monitoring site at a variety of altitudes. On the second, we selected a small island in the Red Wine River as a target, and asked MCC to request overflights from jets using LLT 1. Overflights were recorded on a Nagra Model 4.2 reel-to-reel taperecorder at 38 $cm \cdot s^{-1}$ using an Electro-Voice D054 omni-directional microphone. The modulometer and potentiometer of the Nagra were set to act as a sound level meter, so that peak sound pressure level as well as change in amplitude could be recorded throughout the overpass. In addition, peak sound pressure levels were determined using a Bach-Simpson Model 886 Sound Level Meter, using the fast setting on the C scale. At a later date, the Nagra recordings were analysed and peak sound pressure levels determined. Representative sonagrams were. produced using a Kay Elemetrics Model 7080 Digital Sonagraph.

RESULTS

Overflight Stimulus

Sound pressure levels were recorded at four different sites: a ridge crest; a flat open field; the shore of a lake; and an island in a river valley. There were no differences in mean sound pressure level among sites. Mean altitude for the 52 overpasses was 47$\pm$2 m agl. Regression analysis indicated that noise level was negatively correlated with our distance from the jet's flight path (r= -.817; $P<.001$) (Fig. 3), falling off an average of 8 dB per 100 m. The maximum noise level recorded was 131 dB for a direct overpass at 30 m agl, although the mean noise level for direct overpasses (within $\pm$30 m of flight track) was 115$\pm$8 dB.

Noise level increased rapidly as a jet approached, rising from ambient levels to a maximum in about 1 s (Fig. 4). Sound level then dropped immediately after the jet passed over, but did not reach ambient levels for another 10 s or more. The noise was broadband, with peak amplitudes between 1-4 kHz. The amount of warning we had of a direct overpass was dependent on background noise. On calm days we could hear the approach of a jet 10-20 s before the jet was overhead, whereas on windy days, especially when surrounded by trees, we usually had little or no advance warning of an overpass. Under the latter conditions, our own startle reactions were quite marked.

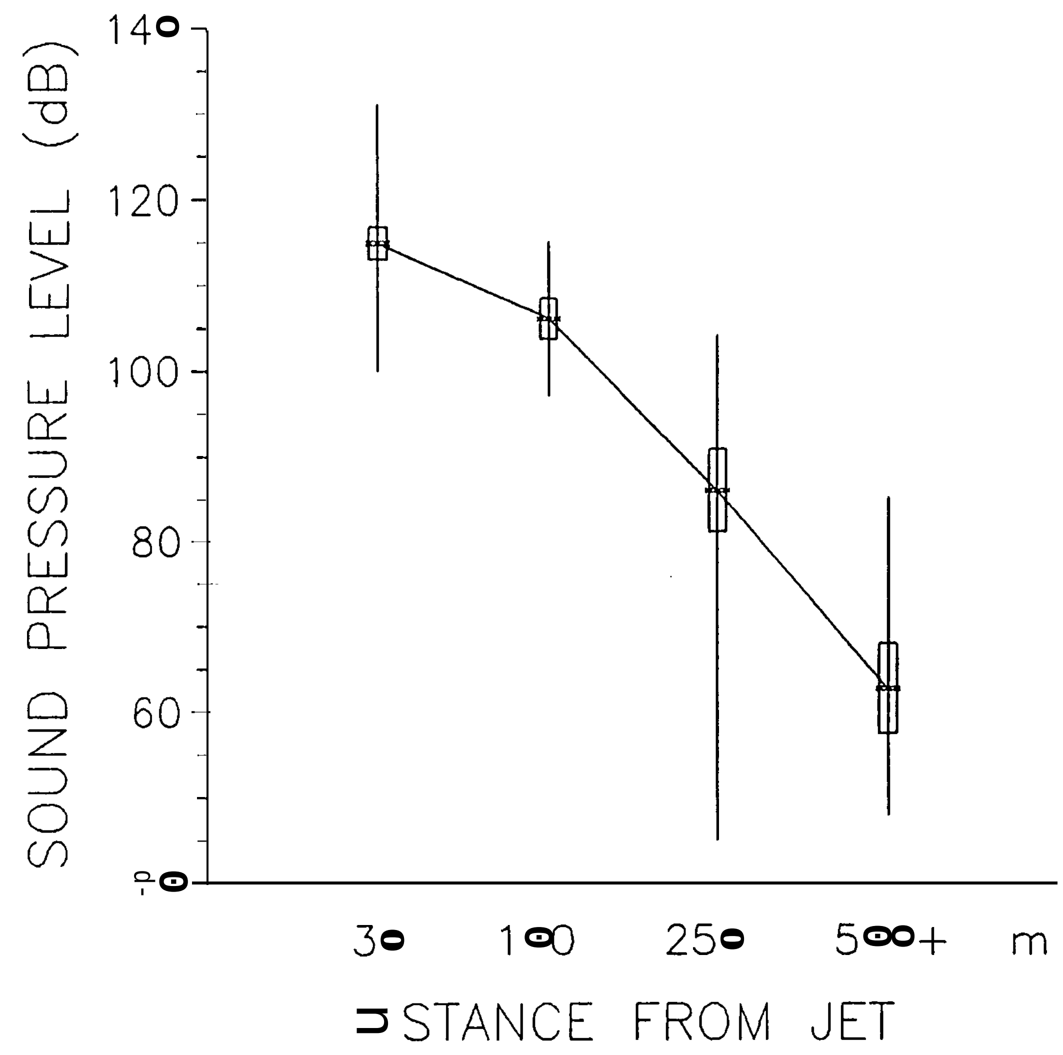

Figure 3. Mean sound pressure level (dB) of jet overpasses as a function of mean distance from flight track. Vertical bars connect minima and maxima; boxes enclose standard errors of the mean; horizontal dashes indicate the mean.

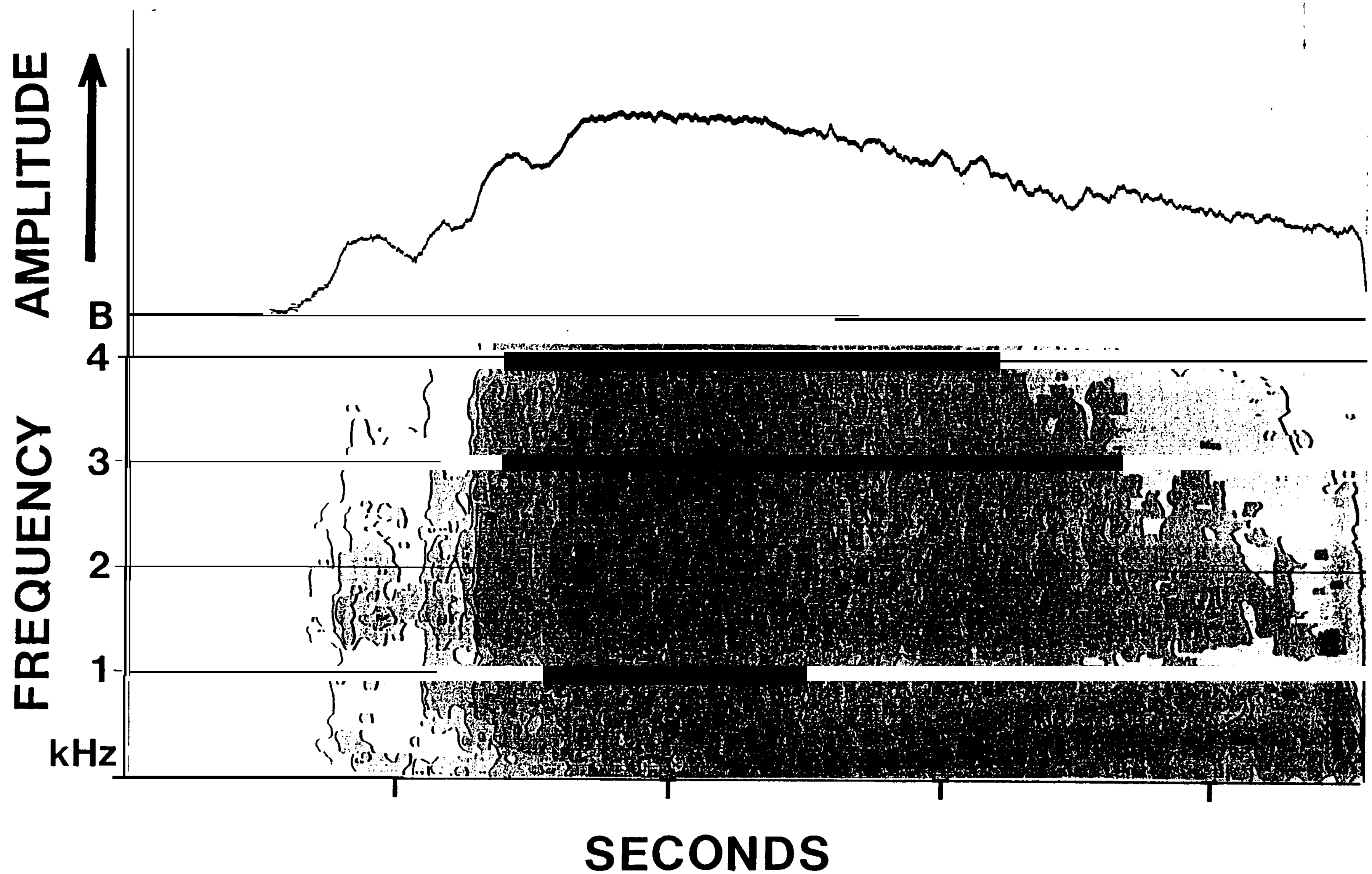

Figure 4. Contour sonagram and amplitude envelope of a low-level jet overpass (RAF Tornado) on 27 August 1986. The darker regions of the contour sonagram (bottom) represent higher sound levels. These indicate a broad band of noise with highest amplitudes between 1.5-3 kHz during the overpass, and a low frequency (0.1-0.2 kHz) band immediately after the jet passes over. The amplitude display indicates the rapid rise time from ambient noise levels (B) and more gradual fall.

Overflight Observations

Red Wine Mountain Caribou. Overflight observations were conducted on one day in 1987 and on three days in 1988 on the Red Wine Mountains. The terrain consisted of heavily-glaciated hills with little protective cover. Several kilometers of visibility were typical, and low boulders provided some cover. Vegetation was alpine tundra, with 50-80% covered with hard-packed snow.

The intent was to have each overpass directly over the animals at 30 m **agl** and at an air speed of 825 km-h-l. Deviations will be noted below. Filming conditions were usually difficult, due to very contrasting lighting (rock and bare ground against snow) , strong winds and distance. Most caribou were observed at distances of 500 m to 750 m. Thus subtle distinctions concerning behavioral responses were usually not possible. Nevertheless, we were able to classify responses to overflights. Distances moved are reported in Body **Lenghts (BL)** , approximately 1.5 m.

13 April 1987 (Wx: Clear, -5 C, Wind 40-50 km-h-1). A group of nine adult female caribou had been slowly walking across a large snow field. Three minutes before an F5 jet arrived in the area, they stopped at a snow-free patch to feed. Individuals alternated between feeding and walking to adjacent patches, with the group remaining relatively cohesive as they moved. At 1137 h, the jet flew over at 300 m agl on its approach, without a noticeable response from the animals.

At 1143 h, the jet passed directly over three caribou at 30 m agl in the same direction as their previous movements. Two startled as the jet passed and then moved forward 1-2 BL before stopping. These two stood with heads up for the next minute before walking to a nearby patch to feed. The other animal continued feeding throughout the overpass.

The jet made a second pass at 1147 h identical to the first. Two seconds prior to the pass one of nine caribou lifted its head but none moved until the jet passed. All nine animals startled and ran perpendicular to the jet’s track for 6-11 s. One began to feed 12 s after the pass and the rest had resumed feeding within 30 s.

At 1149 h, a third pass, similar to the first two, was flown. The nine caribou did not respond until just after the jet passed, and again ran off perpendicular to the jet’s path. They stopped running after 7 s, moving 4-9 BL, and soon resumed feeding. At 1152 h, a fourth similar overpass startled the animals, and each wheeled about and ran off 1-3 BL; they stopped within 5 s. Eleven seconds later they were feeding again.

Over two hours later, an F18 jet arrived to provide overflights. We were observing a different group of eight adult caribou (6 cows/2 bulls) , which had been walking and trotting over a snow field near the crest of a ridge. Occasionally when crossing snow-free patches, individuals stopped briefly to feed. Before the jet arrived, three had already walked out of sight over the crest. At 1424 h, the jet made a 300 m agl overpass with no obvious reaction from the animals. A minute later, these animals moved beyond the ridge in a direction that gave them a panoramic view of the area and the approach of the jet. Only four were in view as the jet approached. All four wheeled about just prior to the pass (1427 h) and ran away from the jet, followed by one of the animals that had previously disappeared over the ridge. They had slowed down 8 s after the pass and all were stopped 16 s after. Four seconds prior to the next overpass (1428 h), these five began to run away from the jet again, and were joined by the remaining three animals that had earlier crossed the ridge. They slowed down 3 s after the overpass, but continued to walk away for another 8 s.

At 1430 h, the jet (30 m agl) came toward the caribou as it had for the first two passes. The four closest to the jet's approach had been looking in that direction for at least 40 s. Seven seconds prior to the pass the first two turned and ran, followed by the other two 2 s later. They slowed 5 s after the pass and had stopped 3-13 s later, after moving distances of 46-51 BL. They then continued to walk away, and did not feed again until 92 s after the overpass.

At 1432 h, the F18 passed low (30 m agl) over the three trailing caribou. These animals started to run, as did the next two animals in line when the trailers approached within 5 BL. The animals slowed, but continued moving at a slow to moderate walk for 30 s after the overpass. A minute later, two animals near the end of the line began to run for no apparent reason, and others briefly followed suit, so that by two minutes after the overpass, the animals were strung out over 150 m.

Prior to the fifth low (30 m agl) overpass at 1435 h, the animals had been walking. Four seconds before the overpass, the animals began to run and continued running until 8 s after the pass. They had stopped within 20 s of the pass, and all appeared to be feeding. The last overpass at 1437 h evoked a similar response. The animals increased their pace 4 s prior to the overpass, ran until 5 s after, and had stopped within 12 s. They walked slowly toward the ridge crest 10 s later and were not visible a minute after.

28 April 1988 (Wx: Clear, -10 C. Wind NE 25-30 $km \cdot h^{-1}$). At 1030 h, two Tornado jets, traveling in-line, passed about 1 km west of 11 resting caribou. All animals remained bedded. Several minutes later, one jet returned and passed 500 m from the animals. One caribou stood; the rest remained bedded.

At 1037 h, two F16 jets approached the same caribou, a group of four (3 cows/1 calf) and of seven (all bulls) about 50 m apart. One jet broke away to delay its overpass as the first continued on. Three animals in the group of four had been standing prior to the jets' appearance; the others were bedded. The group of four caribou began to run opposite to the path of the jet as it passed at 30 m agl. The group of seven were bedded and all stood when the jet passed, and began to run 4 s later as the group of four animals approached. One second later the second jet passed (30 m agl), but all continued to move opposite its direction. Several ran briefly, although most were walking. Twenty-two seconds after the second overpass, all caribou had stopped. On average, members of the group of four moved 30 BL, while those in the group of seven averaged 21 BL, in 23 and 16 s, respectively.

Both jets circled for a second series of overpasses, 32 s after the last overpass. All 11 caribou were standing and looking in the direction of the jets' approach. Nine seconds prior to the first overpass, one caribou turned and began walking away. Four seconds later three more followed suit. One second before the overpass, the remainder turned about and began running. One second after the overpass, the "caribou turned 90° from the jet's path, with the animals overflown first turning first; the animals slowed as they turned. The second jet approached 9 s after the first; the caribou momentarily turned away from its path when it flew over at 30 m agl. One to two seconds after this, all the caribou had turned away from the jets, and by 10 s after had slowed to a walk. Ten seconds later half the animals had stopped; over the next 15 s the remainder stopped. Within 37 s of the last overpass, one animal was feeding; over the next minute three others began to feed while the remainder either stood or walked slowly about. Two hours later the animals were in the same area, some bedded, others feeding.

29 April 1988 (Wx: Clear, -6 C, Wind NE 15-20 $km \cdot h^{-1}$). At 1000 h, two groups of caribou (15 and 4) were being observed. All animals were initially standing/feeding. The larger group contained a minimum of 10 bulls and two cows, while the smaller consisted solely of bulls.

At 1025 h, three F-16's approached. Two seconds before the first jet passed (30 m agl: 150 m to the side), the larger group turned and ran away from the jets. The next two jets passed at intervals of 2 s and 1 s. The caribou were out of sight behind a ridge during the first overpass, but returned to sight 1 s after the last overpass. At this time, they were moving at a fast walk away from the jets. Within 10 s they had slowed to a walk; over the next 20 s all walked slowly. They moved an estimated 10-12 BL during the overpasses (5 s), 12 BL in the next 8 s as they slowed, and 23 BL over "the next 20 s. Just prior to the return of the jets, the caribou disappeared over the crest of the ridge, still walking slowly.

The group of four caribou were feeding prior to the 1025 h overpasses (30 m agl). Five seconds before the overpass, one looked up; 2 s later it turned and ran away from the jets. Two other animals immediately followed with the last animal turning left 1 s later. The animals ran throughout the three overpasses, but slowed after the last jet passed. Within 1 s they were walking and at 3 s they stopped briefly. One-to-three seconds later they turned and walked or trotted away from the jets. During this time they were joined by two other bulls. They were walking up a ridge when two F-16's returned 1 min later. The jets made a wide turn about 1 km away and the caribou stopped and looked in that direction for about 10 s. Then all six turned and walked off in the opposite direction. Fifteen seconds later, the two jets passed 6 s apart at low-level but 600 m and 300 m from the animals, respectively. Between the two overpasses, three of the animals ran briefly. The animals alternately walked or stood over the next minute until they disappeared over the ridge.

At 1100 h, two groups of bedded caribou (500 m apart) were under observation; group size and location was the same as for the previous observations. These groups were about 500 m apart. At 1108 h, two Tornados passed directly (30 m agl) over the larger group of 10-14 animals. All the animals stood, but did not move away. The smaller group of six showed no overt reactions to these jets that passed 300-400 m to their side.

At 1156 h, one Tornado overpassed (30 m agl) the larger group. Three animals had been standing and the remaining were bedded prior to the overpass. No overt reactions were seen. The smaller group, about 500 m from this overpass, also did not react (all remained bedded).

At 1314 h, three Tornados passed in-line directly over (30 m agl) the smaller group. One of the four bedded animals stood for 5 s, then walked 5 BL in 12 s and began to feed. Twenty-three seconds later it lay down; all four remained bedded for at least the next 3 min. The animals in the larger group were also bedded prior to these overpasses (500 m away). Three stood after the overpasses; two lay back down within the next 30 s. The last remained standing and gradually walked away from the group as it fed.

At 1344 h, one Tornado passed directly over the smaller group at 30 m agl. All the animals stood and one moved off several body lengths. Fifteen seconds later another walked 5 BL (5 s). All then remained standing for at least the next 3 min. In the larger group, all but one animal had been bedded prior to these overpasses (400 m away). These animals stood during the overpass; the animal that had been standing apart from the group ran 10 BL (5 s) and walked another 15-20 BL (45 s) back to the rest of the group.

At 1641 h, two Tornados, flying in-line, passed 20-30 m from and 30 m agl over five bulls from the smaller group. During the 8 s prior to the overpass, four animals stood and then walked or ran off in two different directions. Two that had moved off toward the jet stopped when the jet flew over while the other two continued to move away from the jet's path; both stopped just prior to the second overpass. Total distance moved ranged from 6-12 BL. Three of the animals remained where they had stopped, while the fourth slowly walked back toward the rest of the group. One minute later two were feeding, one was standing and the fourth was bedded. The fifth animal remained bedded throughout the overpasses.

At 1701 h, two Tornados overflew a pair of bedded caribou from the original smaller group of bulls. The first jet passed over (30 m agl) about 50 m away. One animal stood as the jet passed and walked 5 BL during the next 6 s; 2 s prior to the second overpass it stopped. When the jet passed directly overhead, the animal bolted 2-3 BL but stopped within 2 s, where it remained over at least the next minute.

5 May 1988 (Wx: Sunny, -6 C, Wind NW 25-30 $km \cdot h^{-1}$). At 1400 h, a group of 11 bulls was being observed. At 1456 h, this group was joined by a larger group of mostly females, some of which were accompanied by n-month-old calves. At 1506 h, 48 animals in

two groups about 150 m apart were present; all but one were bedded. The smaller group consisted of seven bulls, six cows and two n-month-old calves. Exact sex and age composition of the larger group was not determined, because of the low zoom setting used on the camera, although a visual inspection indicated a lower percentage of bulls in this larger group.

A single Tornado directly overflew (30 m agl) the smaller group at 1539 h (about 150 m from the other group). These bedded caribou showed no anticipation of the overflight. All animals scrambled to their feet and were moving away within 1 s after the pass. Over the next 4 s they moved at a fast walk to run, but were slowing after the first 1-2 s; some had stopped within this period. Of the 15, the median distance moved during the 5 s after the overpass was 7 BL (range 4-10). Within 8 s of the overflight, all had stopped; within 15 s, some began to feed or slowly walk about. Over the next minute, an average of five animals were feeding, one walking, one bedded, and eight were standing at any moment. The larger group anticipated the overpass. All were bedded 5 s prior to the overpass when the first heads went up. Three seconds later they stood and most were running as the jet passed. Within 8 s all had stopped after moving 8-12 BL. The first animal began to feed 16 s later and within a minute most were feeding or slowly walking. Two and one half minutes after the overpass, several animals lay down, although the majority continued to feed.

At 1545 h, another single Tornado passed about 100 m behind the smaller group and 50 m behind the larger group. Two animals ran briefly (2 s) beginning 2-3 s after the overpass, and two more ran briefly (1 s) as one of the first two caribou passed by. Of the eight that had been feeding prior to the pass, only one stopped. Otherwise, there were no other overt reactions to this pass. The same was true for the larger group. Three animals ran for distances of 3-6 BL, beginning 3 s after the overpass, and four feeding animals picked up their heads. The majority continued to feed and the three or four animals that were bedded remained down.

At 1636 h, a single Tornado passed 500 m from the caribou. Of the eight animals filmed in the smaller group, five stood 2 s after the pass while the others remained bedded. Two of the standing animals began to feed in 4 s and 10 s, and these bedded 6 s and 23 s later, respectively. The remaining three continued to stand. In the larger group, all animals had been bedded prior to the pass and the majority stood but did not move off after the overflight.

Fourty-six seconds later the jet made a direct overpass of both groups. Five of the eight animals being filmed in the smaller group got up and ran as the jet passed, moving in a small arc a total of 3-5 BL. Their initial direction was with that of the jet, but they quickly changed direction as the jet passed overhead. The remaining three animals stood within a second of the overpass, but did not run. All stopped within 5 s of the pass, one began to feed 10 s after the pass; 5 s later two more began feeding. In the larger group, the animals scattered in random directions as the jet passed over. Most had stopped moving within 4 s and all were stopped by 7 s after the pass; none moved more than 3-6 BL.

Summarv. The responses of RWM caribou to jet overpasses are summarized by group in Table 4. No obvious differences related to group composition were apparent. Overall, caribou ran an average of 7 seconds and moved 12-16 m (8 BL's) in response to a direct overpass. Caribou began to react just after the jet passed (range -7 s to +2 s), and typically began to slow almost immediately. The four earliest responses occurred for one group that was walking along a high ridge with a good view of the approaching jet. Behaviour prior to an overpass seemed to influence the subsequent level of reaction; the group that had been traveling prior to the initiation of overpasses, ran longer than did other groups. The median response to the high (150 m) or distant (>150 m) overpasses was nil; no overt reactions were noted. If animals did react to these overpasses, they usually only stood.

George River Caribou. Overflight observations of George River caribou were conducted on two days in May 1988, on a rugged, upland tundra region 270 km northwest of Goose Bay. Trees were restricted to the deeper valleys and the lower elevations about this region. Sharp, high (30-40 m) ridges provided good observation. Several thousand animals had used this upland for quite some period, as judged by the poor condition of the exposed vegetation. One of our satellite-collared caribou (GRF006) had spent 135 days in the area (3 December - 17 April) , never more

TABLE 4. Median responses to low-level jet overpasses by Red Wine Mountain population caribou, as a function of group composition. Response is indicated as seconds running, with distance moved (BL's) in parentheses. If distance moved could not be determined (?), the highest figure for the day or group was used in calculating group medians. Cow groups may also include n-month-old calves.

Group Composition	Size	Date	Overpass category (m agl/m to horizontal) Direct (30/0)	Low/wide (30/50+)	High (300/0+)
cows	9	13/04/87	2(2), 7(?), 11(9), 5(3)		o(o)
	4	28/04/88	23(30)		
	33	05/05/88	7(6)	10(12), o(o), o(o)	
Cows/Bulls	8	13/04/87	16(?), 15(?), 20(51) 24(?), 24(?), 16(?)		o(o)
	11	28/04/88	25(?)	o(o)	o(o)
	15	29/04/88	o(o), o(o), o(o)	13(24), O(0), O(0)	
	15	05/05/88	5(10), 5(5)	o(o), o(o)	
Bulls	7	28/04/88	16(21)		
	4-6	29/04/88	o(o), o(o), 10(12), 4(3)	9(?), O(0), O(0)	
Median Group Response			7(8)	o(o)	o(o)
(number of groups)			(9)	(4)	(2)

than 35 km from our observation site. Snow covered 70-80% of the ground with a very hard crust.

6 May 1988 (Wx: Cloudy w/snow, -8 C, Wind NE 35-50 $km \cdot h^{-1}$). One Tornado was directed over a group of 30 females with seven n-month-old calves that were walking in-line about 50 m from us. Its first pass was about 75 m above the caribou, 25 m to the side, and in the same direction as their travel. They increased to a trot as the jet passed, but slowed to a walk again within 6 s. A minute later the jet passed in the same direction again, this time at 30 m agl and 20 m to the side. The animals increased pace to a fast walk 4 s prior to the pass, slowed 4 s after the pass and within the next 5 s, had stopped and were looking in the direction the jet had gone. By 25 s after the overpass, most had resumed their travel at the same pace and in the same direction as previously.

The next overpass a minute later was opposite to the path of the caribou. The caribou stopped 5 s before the jet's approach at 30 m agl and 100 m in front of them. Two animals turned back and moved several body lengths; the rest simply stood. A minute later, the fourth and last overpass occurred 200 m in front of the animals. All of the animals stood throughout this pass. Within 30 s the animals resumed walking in their original direction and were quickly out of sight.

The same jet also passed over a group of about 20 caribou (sex/age unknown) that were feeding atop a ridge about 500 m away. Taped notes (there was no video) indicated the animals were feeding and showed no obvious reactions to the passes, which were directly over the animals.

13 Mav 1988 (Wx: Mostly clear. -3 C, Wind NE 15-25 $km \cdot h^{-1}$). We located several groups of caribou, each of which numbered in the hundreds, in an area of rugged ridges. We set up on the crest of the ridge, which gave us a panoramic view of a large, relatively flat valley 30 m below us, at 1233 h. No caribou were below the ridge, but about 50 animals were resting or feeding at the head of the valley 700 m away. At 1234 h, more caribou began to stream into the valley and at one time approximately 90% were running down the valley in our direction. Within one minute the number of caribou had increased to more than 500. These animals continued to move down the valley so that the lead two thirds were directly below our observation site. At 1240 h, 95% of the caribou were either standing or feeding. At 1248 h, only 10% of the caribou on snow were standing, while 40% of those on snow-free ground stood or fed. The rest were bedded when the first jets arrived a minute later. Three independent surveys (total caribou = 276) indicated an average composition of 58 cows: 19 n-month-old calves: 23 bulls. The filming conditions were the best we encountered.

At 1250 h, two F16's directly overflew the caribou at 50 m agl. All quickly scrambled to their feet after the first jet passed. All animals were standing 3 s after the overpass and looking in the direction of the receding jet. When the next jet passed over 22 s after the first, only 4 of the estimated 200’ animals in view moved. Ten seconds after this second pass, the first animals had resumed feeding or were lying down. Over the next minute, animals continued to bed, while 60-80% resumed feeding.

At 1251 h, three F16 jets returned. The first jet "flew directly over the caribou at 30 m agl, followed 13 s later by the second jet along the same path. The third jet flew over 10 s later at 60 m agl. All the caribou stood in response to the first overpass and turned toward the disappearing jet. Most had stopped within 4 s of the pass. As the second jet passed, most animals startled in its direction for about 1 BL and then turned about, trotting off in the opposite direction but slowing as they did so. Although the majority had stopped running within 6 s, others continued to move at a fast walk. By the next overpass, only 10% of the animals were still moving. The response to the third overpass was more variable. Some animals, particularly those already moving prior to the pass, increased their pace and continued moving away from the disappearing jets. Others, which were about 50 m from the jet's path, did not move at all and many continued feeding.

At 1253 h the three F16's flew over the caribou at 30 m agl from the opposite direction to the previous flight paths. Prior to the overpass, 90% of the animals were standing or feeding. The first animals began to run 2 s prior to the pass; the majority were running 1 s prior. The animals ran in the direction of the pass and although they began to slow as soon as the jet passed, they continued to move in its direction. One second prior to the second pass they began running again, and were slowing within a few seconds. Only 6 s after the overpass, 75% of the animals had stopped moving. The third jet flew over particularly low (25 m) 17 s after the previous overpass. Again, the animals began running in its direction about 1 s prior to its overpass; 75% had stopped within 6 s of the overpass. As for the previous set of overpasses, the level of reaction to the overpasses was dependent on the animals' distance to the jets' flight tracks (Table 5) . In addition, whereas those animals nearest the jets' path tended to move parallel to the path, those offset to the jet's track tended to run obliquely or perpendicular to it.

Over the next 4 rein, the movement of caribou shifted back from the direction taken during the jet overpasses, and followed the original path of the group prior to the jets' appearance. The animals were either walking at a slow to moderate pace (1 BL/s) , feeding, or lying down.

At 1300 h, two F16's made three overpasses each. We missed recording the first jet, which passed over the caribou at relatively high altitude. The second jet, which we filmed, passed over at about 60 m. The animals began moving prior to this jet's overflight, but 90% had stopped within 10 s after the overpass, and only one animal (of about 100 in all) was still moving. These two jets returned in 39 s. The caribou again began moving about 1 s prior to the first overpass, initially running away from the jet and then turning about as the jet passed and moving opposite its direction. As the second jet passed over 6 s later the animals merely slowed momentarily before continuing to move away

TABLE 5. Median distance moved by individual George River caribou during overflights by F16 jet aircraft on 13 May 1988. Distances are reported in Body Lengths (1.5 m) as Median (Range) with the sample size indicated on the second line. Interval -5s was the 5 s interval immediately preceding the overpass, etc. Altitude is asters above ground level. All airspeeds were approximately 800 km. h-l. Median distance moved in relation to distance from flight track was determined for the 10 s period following the overpass, except for the overpass at 1253.07, for which it vas based on the 3 s prior and 7 s following the overpass, and for the overpass at 1300.39, for which It was based on only the 5 s after the overpass. (nd = no data available)

		Five Second Interval In Relation to overflight				Relative Distance to Flight Track	
Time	Altitude	-5s	+5s	+10s	+15s	Closest Half	Farthest Half
1250.00	50	0 (o-3)	4 (2-7)	0 (o-9)	0 (o-o)	nd	nd
		20	20	20	20		
1250.22	50	0 (o-o)	0 (o-o)	0 (0-0)	0 (0-0)	nd	nd
		20	20	20	20		
1251.19	30	0 (o-o)	5 (2-9)	0 (o-2)	nd	4 (3-8)	1 (l-3)
		20	20	20		20	20
1251.32	30	0 (o-o)	5 (1-16)	0 (0-3)	nd	5 (1-11)	2 (l-3)
		20	20	20		20	20
1251.42	60	0 (o-3)	4 (0-14)	3 (0-18)	0 (0-6)	11 (3-23)	4 (0-16)
		20	20	20	20	20	20
1253.07	30	0 (0-4)	13 (4-221	nd	nd	17 (6-23)	5 (0-16)
		20	20			20	20
1253.14	30	13 (4-22)	10 (0-28)	o (0-4)	nd	20+ (7-28+)	3 (0-12)
		20	40	40		20	20
1253.29	25	0 (o-4)	12 (4-21)	2 (0-6)	o (0-4)	19+ (14-25]	10 (4-19)
		40	40	40	20	20	20

(Table 5 cent inued)

1300.00 60	2 (0-10)	14 (O-26)	3 (0-15)	0 (o-3)	26 (13-41)	8 (0-17)
	40	50	50	20	20	20
1300.39 30	0 (o-4)	6 (1-14)	nd	nd	9 (3-14)	6 (1-8)
	41	47			20	20
1300.45 30	6 (1-14)	14 (4-221	10 (0-16)	4 (o-7)	21 (5-30)	27 (17-38)
	41	47	42	20	20	20
1301.49 40	3 (0-6)	15 (7-19)	nd	nd	nd	nd
	20	20				
1301.56 40	4 (2-7)	3 (o-5)	o (o-9)	1 (o-9)	nd	nd
	20	20	20	20		
Grand med ians	o (0-13)	6 (0-15)	o (o-lo)	o (o-4)	17 (4-26)	5 (l-27)
	13	13	10	7	9	9

from the direction of the jets. Ten seconds after this second overpass, most of the animals were walking and 20 s afterwards, 10-15% had stopped.

At 1301 h, two F16 jets flew perpendicular to the path taken by all the previous jets, flying over our position on the ridge and then directly over the caribou in front of us. Most of the caribou had been moving to our right prior to the overpass. Just after the jet overflew the ridge, the group of caribou in its path ran directly away; after it passed they swung back to continue their previous movement to our right. The second jet, which passed over 7 s later and about 50 m to the right of the first jet, caused those animals moving to the right to either turn back in a semicircle, or simply stop, depending on whether they were closer or farther away from the intersection between their path and the jet's.

Summary statistics for these 13 overflights indicate that the typical animal reacted as the jet passed overhead and then ran or walked away for less than 5 s (Table 5) . During that time, it moved an average of 6 BL, or an estimated 10-15″ m. However, these responses were quite variable, and for some overpasses, individuals moved an average of 34 BL, or 50-60 m. In addition, the magnitude of the animal's response was dependent on how close the animal was to the flight track of the jet. Those directly under the jet's path ran three times farther, on average, than those that were 50 m or more away (Table 5).

Helicopter Overpasses

13 April 1987. A series of four overpasses by a Bell 206L helicopter were conducted on the Red Wine Mountains over a group of eight adult male caribou; this group apparently had not been subjected to jet overflights earlier that day. The first pass was made at 30 m agl. The animals were walking as the helicopter approached and paused to look in its direction 13 s prior to the overpass. They started trotting away 8 s before the pass and did not begin to run until the helicopter was nearly overhead. As the helicopter passed, the group swung away from its path and started slowing 8 s later. They were stopped 20 s after the pass. The animals picked up their pace 12 s Prior to the second overpass and were running within 2 s. As the helicopter passed the animals were lost from sight. When next seen 50 s later they were walking. As the helicopter approached for the third overpass, they began running 12 s before the pass, turned around as the helicopter passed overhead, and began slowing down just after their turn. During the run prior to their turn, they moved 46 BL. After their turn, they moved an additional 31 BL at a fast walk, and then continued to walk at a slower pace thereafter. The animals began running 8 s prior to the last overpass, veered away as the helicopter passed over, but continued running another 11 s before slowing down. However, it was another minute before all the animals had stopped.

5 May 1988. Three overpasses were flown on the Red Wine Mountains using a Bell 206L helicopter. These were done 36 min

after the last jet overpasses of a group of eight bulls, which had been resting or feeding in the interim. Nine seconds before the first overpass at 90 m agl, the caribou stopped feeding and began to run 4 s before the helicopter passed over. The animals turned aside as the craft passed and slowed. All were stopped 11 s after the pass and 10 s later had resumed feeding. One minute later the helicopter passed at 60 m agl. The animals began to run 4 s before the pass, veered aside as it went overhead, and continued to run for another 10 s. All were stopped 18 s after the pass. The final pass was flown one minute later at 30 m agl. The animals began to trot away 7 s before the pass and broke into a run 2 s before it passed over. As it did so, the group split in two, both groups swinging away from the helicopter's track and slowing; they were stopped 8 s after the pass.

13 May 1988. A series of five overpasses of GR caribou were made by an A-Star 300D helicopter. These were flown one hour after the last set of jet overpasses, at altitudes of 30-150 m agl. Several hundred animals were in the valley. Sex and age composition have been noted above. Most (90%) of those on snow-free ground were feeding, while those on snow were either standing or walking. Initially the animals had been moving to our right, out of the valley from whence they came, but later they moved back to our left, filling the valley as it had been for the jet overflights.

Fourteen seconds prior to the first pass (30 m agl), the caribou began to move and were running within 3 s. Seven seconds before the pass all animals were running away from the helicopter. As it passed, the animals swung back but continued to run for 5 s more. Twenty-two seconds prior to the next overpass (60 m **agl)** the caribou stood and faced the helicopter. They began to run 17 s before the pass, and again turned aside as the helicopter passed. The same reaction held for the next three overpasses, with the animals beginning to run 10-20 s before the overpass, veering aside as the helicopter passed, and then slowing as they moved away from the helicopter. More than half the animals had left the valley by the time the helicopter overflights were completed; those that remained mostly walked to our right where the others had left. Three minutes later the majority of those that remained were feeding.

Data on median distance moved indicated that the caribou ran longer and farther in response to the helicopter overpasses than to the jet overpasses (Tables 5 and 6). The greatest total median distance moved in response to a jet was 34 BL. This was exceeded by every helicopter overpass by a factor of two or more. **Most of** the response to the helicopter occurred prior to the overpass, whereas the reverse was true for the jet overpasses. Finally, all caribou in the valley responded to the helicopter by running, whereas caribou responses to the jets were more variable, and only those closest to the actual flight track showed the greatest response (Table 5) .

TABLE 6. Median distance moved by individual George River caribou daring overflights by A-Star 3000 helicopter on 13 May 1988. Distances moved in Body Lengths (1.5 m) are reported as Median (Range), vith the sample size indicated on the second line. Interval -5s vas the 5 s interval immediately preceding the overpass. Altitude is meters above ground level. All airspeeds vere approximately 150 km.h-1. Codes: nd-cm = no data due to camera movement; oof = caribou moved out of frame during 5 s period and therefore total distance moved is underestimated.

		Five Second Interval in Relation to overflight							
Time	Altitude	-20s	-15s	-10s	-5s	+5s	+10s	+15s	+20s
1410.00	30	0 (0-4) 20	1 (0-7) 24	18 (7-30) 24	42 (29-47) 22	28 (22-32) 8	nd-cm	nd-cm	14 (11-201 15
1411,27	60	20 (15-27) 16	27 (15-33) 16	28 (23-35) 10	45+(oof) 10	nd-cm	14 (3-23) 13	17 (15-22) 13	nd-cm
1413.00	90	23 (10-28) 10	23 (16-33) 12	30 (19-39) 13	3$ (28-40) 10	38 (28-451 10	39 (23-46) 10	0 (0-7) 20	nd-cm
1414.26	120	nd-cm	12 (5-23) 18	15 (11-20) 17	18 (11-23) 16	18 (0-28) 19	2 (0-6) 18	3 (0-8) 18	3 (0-5) 18
1415.50	150	9 (0-14) 16	10 (8-15) 20	15 (9-18) 15	14 (7-24) 16	2 (0-5) 19	0 (0-2) 20	0 (0-2) 20	0 (0-2) 20
Overall median		15 (0-23) 4	12 (l-27) 5	18 (15-30) 5	38 (14-45) 5	23 (2-38) 4	8 (0-39) 4	2 (0-17) 4	3 (0-14} 3

Satellite Telemetry - Woodland Caribou

A total of 18 RWM and 4 MM caribou were captured, equipped with PTT's, and monitored between 1986 and 1988 (Table 7) . One Red Wine animal was tracked for three low-level flying seasons, four were tracked for two seasons, and the remaining animals for a single season. Two animals died during a low-level flying season and two died within a month or two after a season ended (Tables 8-10). Two PTT's failed very soon after deployment and three others failed after five to seven months; the remainder operated throughout the low-level flying season. Overall, locations were obtained on 82% of available days (N = 4906), improving from 76% in 1986 to 92% in 1988, allowing us to calculate daily distance traveled for 74% of days. Activity indices were obtained on 97% of possible days.

1986 low-level flying season. Difficulties encountered in coordinating military flying in the first few months, necessitated dividing the data into two periods: May-July and August-October. A comparison of the number of overflights reported with the number of flight tracks passing through an animal's homerange indicated the two variables were significantly related during the second half ($r = 0.89$; $p<0.01$) ; too few flight track records were available for the first half. This correlation suggested that the overflight reports for the second half of the flying season were a reasonable indication of the animals' exposure.

The mean 24 h activity index of animals followed throughout

TABLE 7. Summary of woodland caribou that were followed with satellite telemetry during the present study. Animals captured prior to 1986 were studied by Brown (1986).

Caribou ID#	Capture date	Age at capture	PTT deployed
Red Wine caribou			
RWF013	03/19/82	4	
RWF013	05/15/86	8	4905
RWF013	12/24/86	9	
RWF013	04/04/87	9	4905
RWF013	12/11/87	10	
RWF013	0.4/02/88	10	4903
RWF013	12/21/88	11	
RWF016	03/20/82	3	
RWF016	05/15/86	7	4909
RWF016	12/24/86	8	
RWF016	04/04/87	8	4909
RWF035	03/27/83	3	
RWF035	05/23/86	6	4903
RWF035	12/22/86	7	
RWF037	03/26/83	3	
RWF037	05/13/86	6	4907
RWF037	12/22/86	7	
RWF037	12/09/87	8	
RWF037	04/02/88	8	4907
RWF037	12/21/88	9	
RWF039	05/09/86	11	4900
RWF039	12/31/86	12	
RWF039	04/05/87	12	4900
RWF04 O	05/09/86	11	4901
RWF040	12/21/86	12	
RWF041	05/09/86	8	4902
RWF043	05/09/86	13	4904
RWF043	12/24/86	14	
RWF044	05/12/86	13	4906
RWF044	12/24/86	14	
RWF044	04/05/87	14	4906
RWF044	12/13/87	15	

(Table 7 continued)

RWF045	05/15/86	11	4908
RWF045	07/05/86	12	
RWF046	04/04/87	10	4901
RWF046	12/09/87	11	
RWF047	04/05/87	3	4902
RWF047	12/09/87	4	
RWF048	04/05/87	5	4903
RWF048	12/09/87	6	
RWF050	04/10/87	6	4904
RWF050	12/13/87	7	
RWF051	04/05/87	9	4907
RWF051	12/07/87	10	
RWF052	04/05/87	3	4908
RWF052	12/11/87	4	
RWF052	05/11/88	4	4921
RWF052	12/21/88	5	
RWF053	04/07/88	3	4901
RWF053	12/24/88	4	
RWF055	07/04/88	2	4904
RWF055	12/24/88	2	
Mealy Mountain Caribou			
MMF001	04/10/85	6	
MMF001	04/14/88	9	4902
MMF002	04/02/85	4	
MMF002	04/14/88	7	4905
MMF003	04/10/85	10	
MMF003	04/14/88	13	4906
MMF004	04/20/85	1	
MMF004	04/14/88	4	4900
MMF004	05/11/88	4	4920

Table 8. Summary of satellite telemetry data collected from woodland caribou of the Red Wine population during the 1986 low-level flying season. Julian days represent the period during which PTT data were collected for this study.

Caribou	Total days	Julian days	Location days	Distance days	Activity days	Fate
RWF013	171	135-305	132	101	171	Recaptured 12/86
RWF016	170	136-305	116	87	170	Recaptured 12/86
RWF035	153	144-296	104	74	153	Recaptured 12/86
RWF037	172	134-305	151	132	172	Recaptured 12/86
RWF039	176	130-305	128	98	176	Recaptured 12/86
RWF040	176	130-305	81	69	104	Recaptured 12/86
RWF041	106	130-235	87	75	106	Mortality (Day 235)
RWF043	176	130-305	163	150	176	Recaptured 12/86
RWF044	173	133-305	148	135	173	Recaptured 12/86
RWF045	42	136-177	40	37	42	PTT failure (Day 177)
Total	1515		1150	958	1443	
Percent of Total			76%	63%	95%	

Table 9. Summary of satellite telemetry data collected from woodland caribou of the Red Wine population during the 1987 low-level flying season. Julian days represent the period during which PTT data were collected for this study.

Caribou	Total days"	Julian days	Location days	Distance days	Activity days	Fate
RWF013	208	97-304	75	51	187	Recaptured 12/87
RWF016	17	97-113	14	11	17	PTT failed (Day 114)
RWF039	206	97-302	109	75	199	Mortality 11/87
RWF044	177	97-273	103	90	166	PTT failed (Day 273)
RWF046	206	97-302	194	185	204	Recaptured 12/87
RWF047	208	97-304	190	177	206	Recaptured 12/87
RWF048	208	97-304	202	198	205	Recaptured 12/87
RWF050	210	95-304	196	184	207	Recaptured 12/87
RWF051	209	96-304	193	184	207	Recaptured 12/87
RWF052	208	97-304	196	184	206	Recaptured 12/87
Total	1857		1472	1339	1804	
Percent of Total			79%	72%	97%	

Table 10. Summary of satellite telemetry data collected from woodland caribou of the Red Wine and Mealy Mountain populations during the 1988 low-level flying season. Julian days represent the period during which PTT data were collected for this study.

Caribou	Total days	Julian days	Location days	Distance days	Activity days	Fate
Red Wine caribou						
RWF013	203	94-296	128	101	199	PTT Failed (Day 296)
RWF037	157	94-250	149	140	157	PTT Failed (Day 250)
RWF052	181	133-307	176	170	180	Recaptured 12/88
RWF053	175	99-279	167	160	175	Recaptured 12/88
RWF055	120	188-307	120	120	120	Recaptured 12/88
Total	836		740	691	831	
Percent of Total			89%	83%	99%	
Mealy Mountain caribou						
MM001	119	106-224	113	108	119	Mortality (Day 224)
MM002	202	106-307	188	174	202	Recaptured 2/89
MM003	202	106-307	201	199	202	Recaptured 2/89
MM004	175	133-307	165	154	175	Recaptured 2/89
Total	698		667	635	698	
Percent of Total			96%	91%	100%	

the low-level flying season varied nearly two-fold among individuals (Table. 11). Mean daily distance traveled ranged from 2.0-3.7 km-day. Reported number of overflights varied from none to an average of 3.4 per day (Table 11). The two caribou exposed to the greatest number of overflights had intermediate values for both daily activity and distance traveled.

1987 low-level flying season. As in 1986, both daily activity levels and distances moved varied nearly two-fold among the animals (Table 12). The variation in exposure to overflights was similar to that reported for 1986, ranging from none to 4.5 per day among the caribou. The two most overflown animals had both the highest and the lowest mean activity indices, and moderate to high values for daily distance. The three animals never overflown had relatively low mean activity indices, but low, medium and high values for daily distance traveled.

1988 low-level flying season. For RWM caribou, exposure to low-level flying was estimated using military flight track data. Overall, 2712 flight tracks representing 5612 jets were available (Table 13). These accounted for 83% of all sorties flown in 1988. The number of turning points represented by each flight track ranged from 10 or less for the F4, F16 and F18 to about 20 for the Tornado.

Exposure levels based on these flight tracks varied more than 10-fold among the RWM caribou (Table 14). Two animals had an average of one jet or more per day within 1 km of their location,

Table 11. Daily **averages** for the 24 h activity index, distance traveled and number of reported overflights for satellite-collared Red Wine caribou during the 1986 study season. Data are presented as **mean±sd** (number of days) .

Caribou	Activity Index		Distance Traveled (km)		Overflights reported	
RWF013	141±56	(171)	2.8±2.2	(101)	3.455.3	(165)
RWF016	208±68	(170)	3.4±2.5	(87)	0.1±0.6	(165)
RWF035	122±47	(153)	3.0±2.3	(74)	0.131.3	(153)
RWF037	143±66	(172)	3.1±2.4	(132)	0.0±0.0	(165)
RWF039	137±53	(176)	3.7±2.2	(98)	0.0±0.0	(165)
RWF040	192±57	(104)	3.1±2.4	(69)	0.0±0.0	(165)
RWF041	116±53	(106)	2.0±2.9	(75)	0.7±2.1	(95)
RWF043	119±60	(176)	2.6±3.0	(150)	0.4±1.6	(165)
RWF044	156±58	(173)	2.9±2.5	(135)	2.8±5.0	(165)
RWF045	97~7 3	(42)	2.8±2.7	(37)	0.1*0.5	(37)
Grand mean	146±66	(1443)	2.9±2.5	(958)	0.8±2.9	(1440)

TABLE 12. Daily averages for the 24 h activity index, distance traveled and number of reported overflights for satellite-collared Red Wine caribou during the 1987 study season. Data are presented as mean±sd (number of days).

Caribou	Activity Index		Distance Traveled (km)		Overflights reported	
RWF013	98±46	(187)	3.0±2.2	(51)	3.2±5.1	(208)
RWF016	111±65	(17)	3.1±2.1	(11)	0.0±0.0	(17)
RWF039	113±48	(199)	3.5±2.3	(75)	0.0±0.0	(206)
RWF044	137±48	(166)	2.7±2.6	(90)	1.5±2.9	(177)
RWF046	122±54	(204)	4.0±2.6	(185)	0.2±1.2	(206)
RWF047	143±54	(206)	3.5±2.4	(177)	0.8±2.0	(208)
RWF048	128±56	(205)	3.5±2.3	(198)	0.1±0.6	(208)
RWF050	111±49	(207)	2.4±2.4	(184)	0.0±0.0	(210)
RWF051	110±57	(207)	2.6±2.5	(184)	0.1±0.4	(209)
RWF052	174±47	(206)	3.5±2.2	(184)	4.5±6.6	(208)
Grand Mean	126±56	(1804)	3.2±2.4	(1339)	1.1±3.4	(1857)

TABLE 13. Summary of 1988 flight track data. The number of flight tracks available for each type of jet and air force, and the number of turning points represented by those tracks, are detailed below. The average number of turning points per track are indicated in parentheses. Total jets equals the number of aircraft represented by the flight track data., whereas total sorties is the total number of jets flying during the 1988 season (April - October) . The number in parentheses is the percent of this total that is represented with track data.

			Number of:		
Airforce	Jet	Flight tracks	Turning points	Total jets	Total Sorties
CAF	F18	14	106 (7.6)	27	89 (30%)
GAF	Alpha	162	2397 (14.8)	446	481 (93%)
GAF	RF4	442	4685 (10.6)	562	572 (98%)
GAF	F4	285	2921 (10.2)	667	1439 (46%)
GAF	Tornado	540	9957 (18.4)	1065	1065 (100%)
RAF	Tornado	662	13700 (20.7)	1266	1429 (89%)
RNLF	F16	622	5297 (8.5)	1579	1683 (94%)
Total		2727	39063 (14.3)	5612	6758 (83%)

TABLE 14. The number of jets passing within specified distances of satellite collared Red Wine caribou during the 1988 study season. The data are presented as the total number of jets within each specified range of distances during the period the animal was followed by satellite telemetry (top rev), the mean (±sd) number of jets on a daily basis (middle), and the range in number of jets passing ona daily basis (bottom). The last column indicates the number (and %) of days during which at least one jet passed within 1 km of the caribou.

Caribou	Days	<1km	> 1km < 3km	> 3km < 5km	> 5km < 8km	> 8km < 16km	Number of Days within 1 km
RWF013	203	208	292	334	498	965	52 (26%)
		1.0±2.5	1.4*3.1	1.6±3.3	2.5±4.3	4.8±6.6	
		(0-14)	(0-18)	(0-21)	(0-24)	(0-33)	
RWF037	157	68	134	138	119	371	22 (14%)
		0.4±1.3	0.951.9	0.9±2.3	0.8±2.0	2.4±3.7	
		(0-7)	(0-9)	(0-15)	(0-11)	(0-18)	
RWF052	175	300	425	484	505	705	62 (35%)
		1.7±3.6	2.4±4.9	2.8±4.5	2.9±4.8	4.0±6.7	
		(0-21)	(0-44)	(0-24)	(0-29)	(0-43)	
RWF053	181	19	40	17	65	143	10 (6%)
		0.1±0.7	0.2*1.1	0.1?0.4	0.4±1.3	0.8±2.8	
		(0-7)	(0-lo)	(0-3)	(0-9)	(0-24)	
RWF055	120	37	77	120	113	250	11 (9%)
		0.3±1.8	0.6±1.9	1.0±2.2	0.9±2.1	2.1±3.5	
		(0-19)	(0-lo)	(0-14)	(0-12)	(0-20)	

whereas the other three were exposed once every 2.5 to 10 days.

Mean activity indices and daily distances traveled for RWM animals were similar to previous years (Table 15). Overall, there was no significant relationship between an animal's exposure to overflights and either of these two variables. For MM caribou, mean activity indices and daily distance traveled were less than those obtained for the RWM animals in 1988, but were comparable to RWM animals in previous years (Tables 11, 12 and 15).

Regression analyses of activity and daily distance traveled. The 24-h activity index and daily distance traveled are correlated variables, as directional movement is one component contributing to the total activity index. Thus daily distance traveled was one of the predictor variables used in the regression analysis for the 24-h activity index (but not vice versa) . After a series of preliminary analyses using the full set of variables indicated in Table 3, variables with little power were eliminated from the model. For 1986, the number of overflights was not a significant predictor for either half of the low-level flying season; therefore, further analyses were done using the full dataset. The 1988 variable "# Jets <1 km" was used as the measure of exposure, as the same criteria held for determining exposure levels in 1986 and 1987.

Few variables were significantly related to the daily distance traveled by the animals (Table 16). In 1986, only Season was a significant predictor of distance traveled, with daily distance increasing slightly throughout the season. In 1987,

TABLE 15. Daily averages for the 24 h activity index, distance traveled and number of reported overflights for satellite-collared Red Wine and Mealy Mountain caribou during the 1988 study season. Data are presented as mean±sd (number of days).

Caribou	Activity Index	Distance Traveled (km)	Overflights (# jets < 1 km)
Red Wine caribou			
RWF013	138±62 (199)	2.5±2.8 (101)	1.0±2.5 (203)
RWF037	114±53 (157)	3.5±2.5 (140)	0.4±1.3 (157)
RWF052	162±55 (175)	3.9±2.2 (160)	1.7±3.6 (175)
RWF053	168±59 (180)	2.9±2.3 (170)	0.1±0.7 (181)
RWF055	143±51 (120)	3.8±2.4 (120)	0.331.8 (120)
Grand mean	146±60 (831)	3.3±2.4 (691)	0.8±2.3 (836)
Mealy Mountain caribou			
MMF001	135±78 (119)	2.6±3.8 (108)	
MMF002	111±62 (201)	2.7±2.9 (173)	
MMF003	135±74 (201)	2.3±2.5 (198)	
MMF004	108±30 (174)	2.7±2.1 (153)	
Grand mean	121±64 (695)	2.6±2.7 (632)	

TABLE 16. Contribution of predictor variables to the variance in the daily distance traveled and the 24 h activity index, as determined by multiple regression. Only those values significant at $p < 0.05$ are shown.

Predictor Variable	1986 Season % Explained	P	1987 Season % Explained	P	1988 Red Wine % Explained	P	1988 Mealy Mountain % Explained	P
Dependent variable = Daily Distance Traveled								
Individual	-		0.9%	0.002	2.1%	<0.001	-	
Calf survival	-		0.4%	0.013	-		-	
Julian Day	4.1%	<0.001	-		-		-	
	0.7%	0.01	-		-		-	
Wind	-		-		1.3%	0.002	-	
Dependent variable = 24 h Activity Index								
Daily distance	15.4%	<0.001	18.6%	<0.001	11.2%	<0.001	21.6%	<0.001
Temperature	2.0%	<0.001	7.7%	<0.001	8.6%	<0.001	7.1%	<0.001
Season	1.6%	<0.001	-		3.4%	<0.001	1.1%	<0.001
Individual	1.4%	<0.001	1.5%	<0.001	1.2%	<0.001	2.2%	<0.001
Calf survival	na		0.3%	0.033	1.0%	<0.001	-	
Overflights	-		3.5%	<0.001	-		na	

na = not applicable

Season, Calf survival and Individual were significant predictors. Daily distance was lowest during the Calving period, and highest in the Insect and Fall periods, and also increased after a female had lost her calf. In 1988, Individual differences were noted among the study animals for the RWM population, whereas no significant predictors were found in the MM population. When the RWM and MM datasets for 1988 were considered together, the Population variable accounted for the greatest amount of variance (1.8%); on average, MM caribou moved significantly shorter distances on a daily basis than did RWM caribou. The total amount of variance explained by these correlated variables, however, was under 5% in any year. The level of exposure to low-level flying, as measured by the number of overflights, was not related to the distance an animal travled each day.

Overall, daily distance traveled accounted for about 15% of the variance in the 24-h activity index each year (Table 16). Temperature, a weather component, accounted for another 5%, while Season, Individual and Calf survival accounted for the remaining 5%. The 24-h activity index was positively correlated to temperature, and was lowest during the Calving period and highest during the Insect period. It also was higher for females not accompanied by calves, even when their greater daily travel rates were taken into account. In all, these correlated variables accounted for between 20-32% of the variance in the 24 h index. Overflights was significantly correlated only in 1987. For the combined RWM and MM datasets in 1988, the Population variable accounted for 1.7% of the variance, behind the 17.5% and 7.7% of variance accounted for by daily distance traveled and the temperature component, respectively; MM caribou had lower 24-h activity indices, even when their shorter daily travel rates were taken into account.

Calf survival. Calf survival for the 10 females followed during 1987 was relatively high through early August (Table 17), but when the animals were recaptured in December, only three were still accompanied by calves. The ratio of calves to cows for our sample of satellite collared animals did not differ from that of a larger sample of non-radioed females observed in December (Table 17), indicating that calf survival was not influenced by collaring activities.

Calf survival for the 10 radiocollared RWM caribou followed during 1988 was relatively low and dropped early in the summer (Table 18). When these females were observed in December, only one was accompanied by a calf, a ratio similar to that observed at the same time in a larger sample of non-collared females, indicating much poorer calf recruitment in 1988 compared to 1987. For the two years, the correlation between an animal's exposure to overflights and the subsequent survival of its calf was negative but not significantly so ($r = -.308$; $n = 14$).

Calf survival was relatively high for MM caribou in 1988, but only four animals were surveyed (Table 19). One female was never seen with a calf; she was later found dead of unknown causes in mid-August.

TABLE 17. Survival of calves of radio-collared Red **Wine Mountain** female caribou during the 1987 study year. The reproductive status of non-collared females observed during the calf survival **surveys** is also indicated.

Caribou	Survey Date 23 June	17 July	08 August	09/11 December
RWF013	Y	Y	Y	Y
RWF016	Y	Y	Y	M
RWF039	N	N	N	M
RWF044	Y	Y	Y	N
RWF046	Y	N	N	N
RWF047	Y	Y	Y	N
RWF048	Y	Y	Y	Y
RWF050	Y	Y	Y	Y
RWF051	Y	N	Y	N
RWF052	N	N	N	N
% With Calf	80.0	60.0	70.0	30.0
Sample of Non-collared Female **Caribou**				
% With Calf (n)	-	.	100.0 (1)	30.6 (186)

N - no calf observed following female

Y - calf seen following female

M - female dead at **time** of survey

TABLE 18. Survival of calves of radio-collared Red Wine Mountain female caribou during the 1988 study year. The reproductive status of non-collared females observed during the calf survival surveys is also indicated.

Caribou	11 June	04 July	21 July	11 August	17 September	22/24 December
	Survey Date					
RWF013	N	N	N	N	N	N
RWF037	N	N	N	N	N	N
RWF047	N	N	N	N	N	N
RWF048	Y	Y	Y	Y	N	N
RWF050	Y	N	N	N	N	N
RWF051	Y	N	N	N	N	N
RWF052	N	N	N	N	N	N
RWF053	Y	Y	Y	Y	Y	Y
RWF055	NC	N	N	N	N	N
RWF056	NC	Y	N	N	N	N
% With Calf	50.0	30.0	20.0	20.0	10.0	10.0
Sample of Non-collared Adult Females						
% With Calf	50.0	60.0			22.2	13.8
(n)	(2)	(5)			(9)	(73)

N - no calf observed **following female**

Y - calf seen following female

NC - female not collared at time of survey

TABLE 19. **Survival** of calves of satellite-collared Mealy Mountain caribou during the 1988 study year.

	Survey Date			
Caribou	11 June	30 June	11 August	17 September
MMF001	N	NS	M	M
MMF002	Y	Y	NS	N
MMF003	Y	NS	Y	Y
MMF004	NS	Y	Y	Y
% With Calf	75.0	75.0	50.0	50.0

N - no calf observed following female

NS - female not seen during survey

Y - calf seen following female

M - female dead by time of survey

Home range patterns. Late-winter ranges of all 1987 study animals were on the Red Wine Mountains. A survey conducted in mid-April indicated that nearly the entire population was concentrated atop the mountains. Eight of the nine females with active PTT's left the mountains between 12-21 April; the last left on 5 May. This latter animal was one of two never seen with a calf that year. In 1988, the RWM population used several other late-wintering areas in addition to the Red Wine Mountains. One area 70 km north of the mountains was shared with several thousand GR caribou, while smaller numbers of GR caribou were also using the Red Wine Mountains. The four RWM caribou collared at this time did not abandon their wintering areas until 9-13 May. Two GR caribou collared on the Red Wine Mountains also began their spring migration during the same period (7 and 13 May).

One of the three 1988 MM caribou left its winter range in the Mealy Mountains on 11 May, whereas the other two left their late-winter areas on the coastal plain between 22-30 April.

Although estimated winter home ranges were twice as large in 1988, these differences appeared due to the larger sample sizes available in 1988 (Table 20) . The one 1987 animal that remained on the mountains twice as long as any others that year, used an area comparable in size (100 km^2) to the animals in 1988.

Summer range patterns varied among caribou. Some used only one core area, whereas others used two to four separate core areas over the summer (Figs. 5-11;Tables 21 and 22) . Movements out of these core areas also varied among individuals, ranging from relatively uncommon (6% of total locations) to frequent (40%

TABLE 20. Estimated areas of late-winter homeranges (April-13 May) used by satellite radiocollared woodland caribou of the Red Wine Mountain and Mealy Mountain populations. If more than one discrete area was used, each is listed separately. Sample size (N) = number of location-days.

	1987		1988	
Caribou	Area (km²)	(N)	Area (km²)	(N)
Red Wine caribou				
RWF013	64	(12)	128	(40)
RWF037			52,44	(23,14)
RWF039	48	(12)		
RWF044	20	(5)		
RWF046	52	(lo)		
RWF047	60	(14)		
RWF048	48	(8)		
RWF050	36	(8)		
RWF051	40	(8)		
RWF052	100	(29)		
RWF053			96	(31)
Mealy Mountain caribou				
MMF001			48,60	(15,13)
MMF002			48	(26)
Mean	52±22	(12±7)	95229	(32±6)

TABLE 21. Estimated areas of summer core **ranges occupied by satellite radiocollared woodland caribou** of the Red Wine and Mealy Mountain populations. If an animal had more than one discrete core area, each area is **listed** separately in ascending size. Sample size (n) is the number of location-days during which the animal was found in the corresponding area. Means (±SE) are calculated on total core area for each animal.

	1986		1987		1988	
Caribou	Area (km^2)	(n)	Area (km^2)	(n)	Area (km^2)	(n)
Red Wine caribou						
RWF013	160	(117)	160	(49)	144	(75)
RWF016	56,152	(20,76)	-			
RWF035	52,56	(54,30)	-			
RWF037	44,48,56,84	(21,28,11,31)	-		48,48,76	(15,31,26)
RWF039	68,88	(23,65)	24,48,132	(9,19,52)	-	
RWF040	52,84	(17,54)	-			
RWF041	92	(81)				
RWF043	12,72,88	(21,46,61)	-			
RWF044	40,52,76	(14,45,44)	40,52,72	(14,32,36)	-	
RWF045	[48	(29)]	-			
RWF046			32,56,80	(29,24,71)	-	
RWF047			28,30,56,96	(22,9,22,80)	-	
RWF048			28,56,68,76	(22,40,40,38)	-	
RWF050			168	(175)		
RWF051			132	(123)		
RWF052			36,156	(14,129)	168	(120)
RWF053					92	(127)
RWF055					116	(81)
Mealy Mountain caribou						
MMF001					44	(57)
MMF002					48,64,64	(60,36,38)
MMF003					44,72	(53,65)
MMF004					100	(144)
Mean±SE	158±15		181±10		138±15 (RW)	109±27 (MM)

TABLE 22. Estimated area of total summer range used by satellite radiocollared caribou of the Red Wine and Mealy Mountain populations. Samples size (n) = total location-days on summer range/number of location-days not found in a core area.

Caribou	1986 Area (km²)	(n)	1987 Area (km²)	(n)	1988 Area (km²)	(n)
Red Wine caribou						
RWF013	424	133/16)	316	(63/14)	264	(85/10)
RWF016	1088	117/21)				
RWF035	624	(98/14)				
RWF037	1484	151/60)			1516	(108/36)
RWF039	1572	128/40)	964	(97/17)		
RWF040	636	(81/10)				
RWF041	312	(87/6)				
RWF043	2276	(165/37				
RWF044	1364	(148/45	968	(98/16)		
RWF045	[1332	(39/10 1				
RWF046			2180	(183/59)		
RWF047			1392	(176/43)		
RWF048			1560	(194/54)		
RWF050			168	(187/12)		
RWF051			744	(185/62)		
RWF052			784	(166/23)	756	(167/47)
RWF053					892	(144/17)
RWF055					976	(116/35
Mealy Mountain caribou						
MMF001					648	(84/27
MMF002					2368	(161/27
MMF003					1900	(194/76)
MMF004					432	(164/20)
Mean±SE	1086±216		1008±209		881±201 (RW)	1337±472 (MM)

[1 = PTT removed early in summer; data not used in calculating grand mean

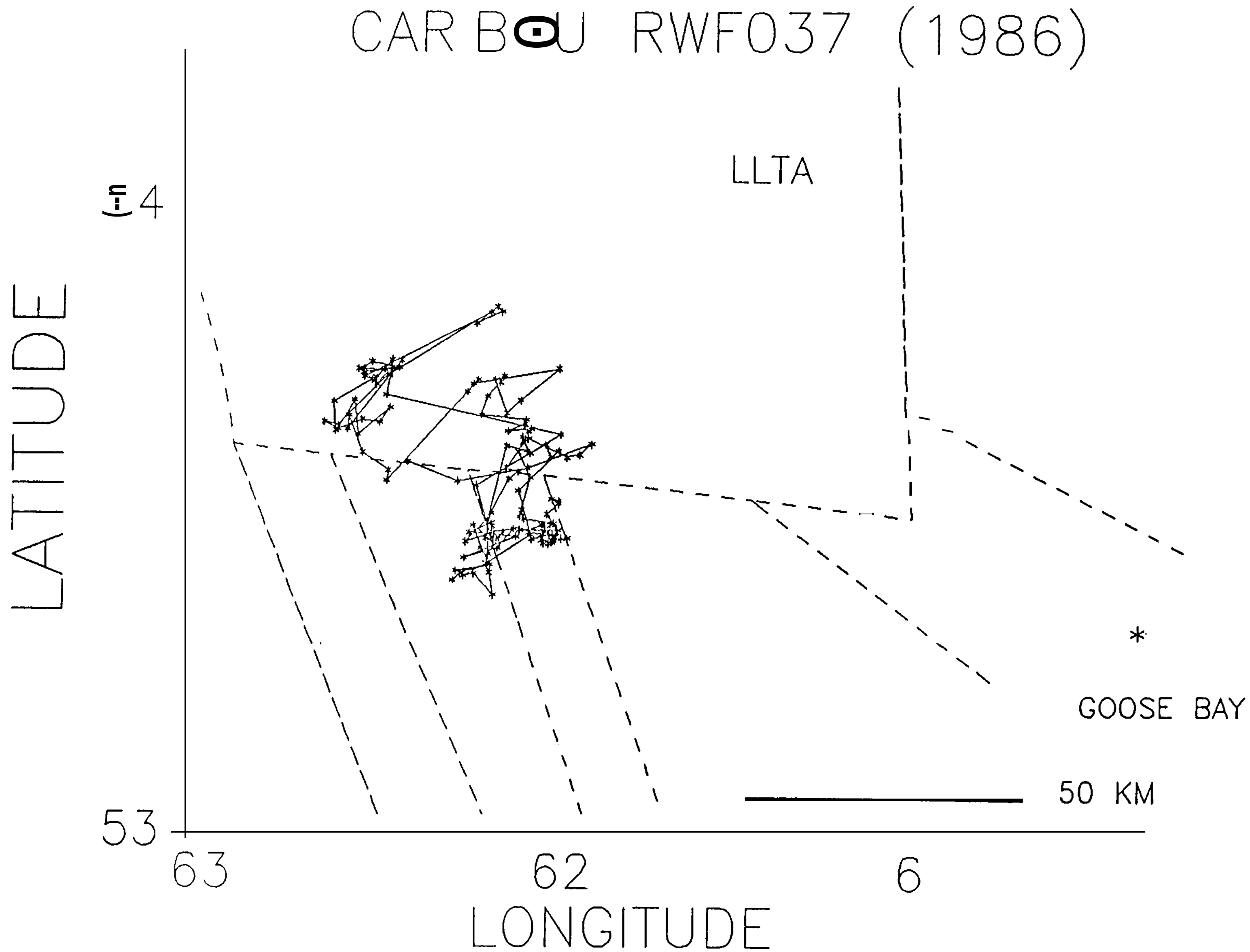

Figure 5. Satellite-acquired locations for Red Wine caribou RWF037 during the 1986 low-level flying season. The northern low-level flying area (LLTA) and its connecting corridors are indicated with dashed lines. Consecutive locations are connected by a solid line. Compare to Figure 6 for the same animal.

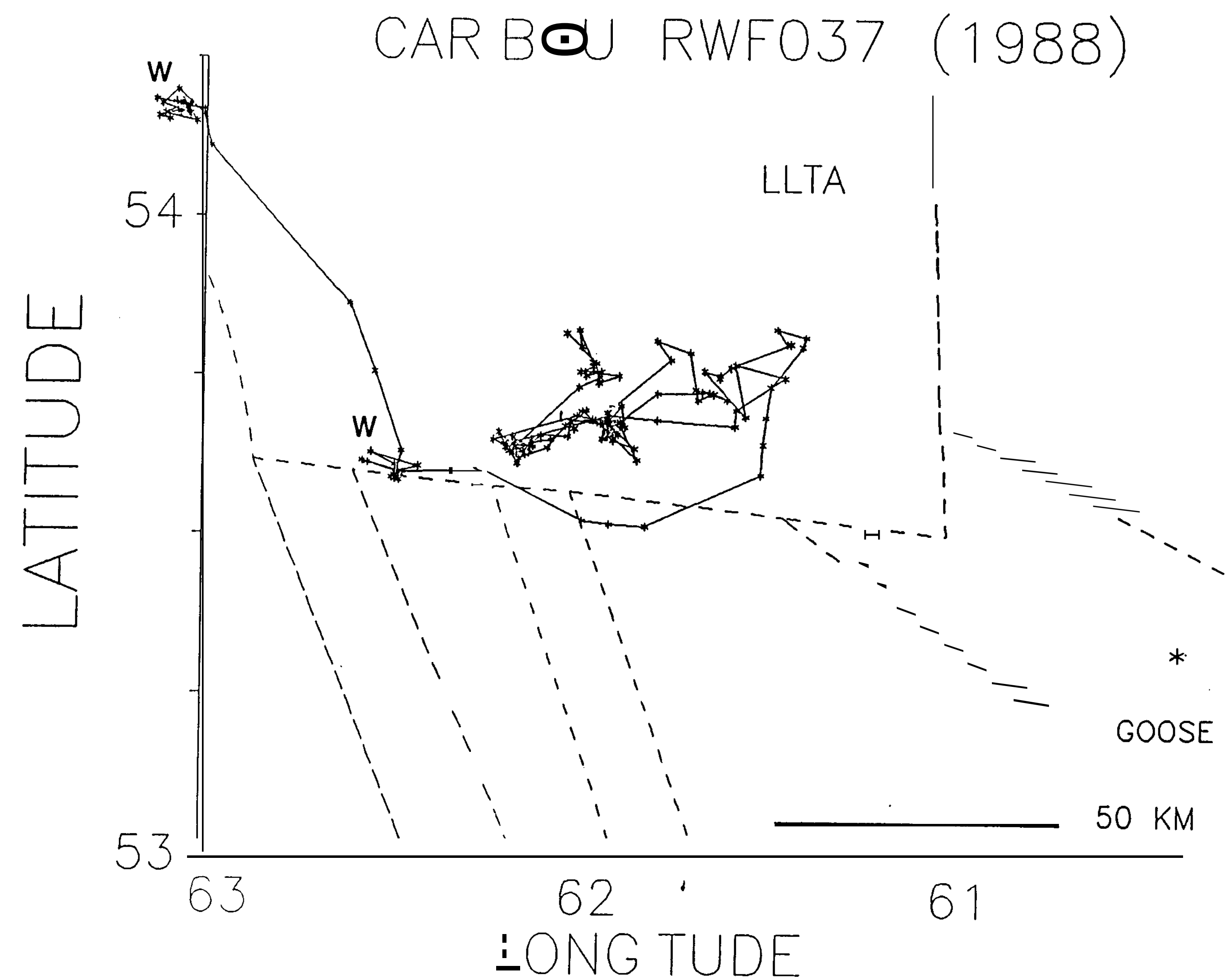

Figure 6. Satellite-acquired locations for Red Wine caribou RWF037 during the 1988 low-level flying season. The northern low-level flying area (LLTA) and its connecting corridors are indicated with dashed lines. Consecutive locations are connected by a solid line. W = late-winter area. Compare to Figure 5 for the same animal.

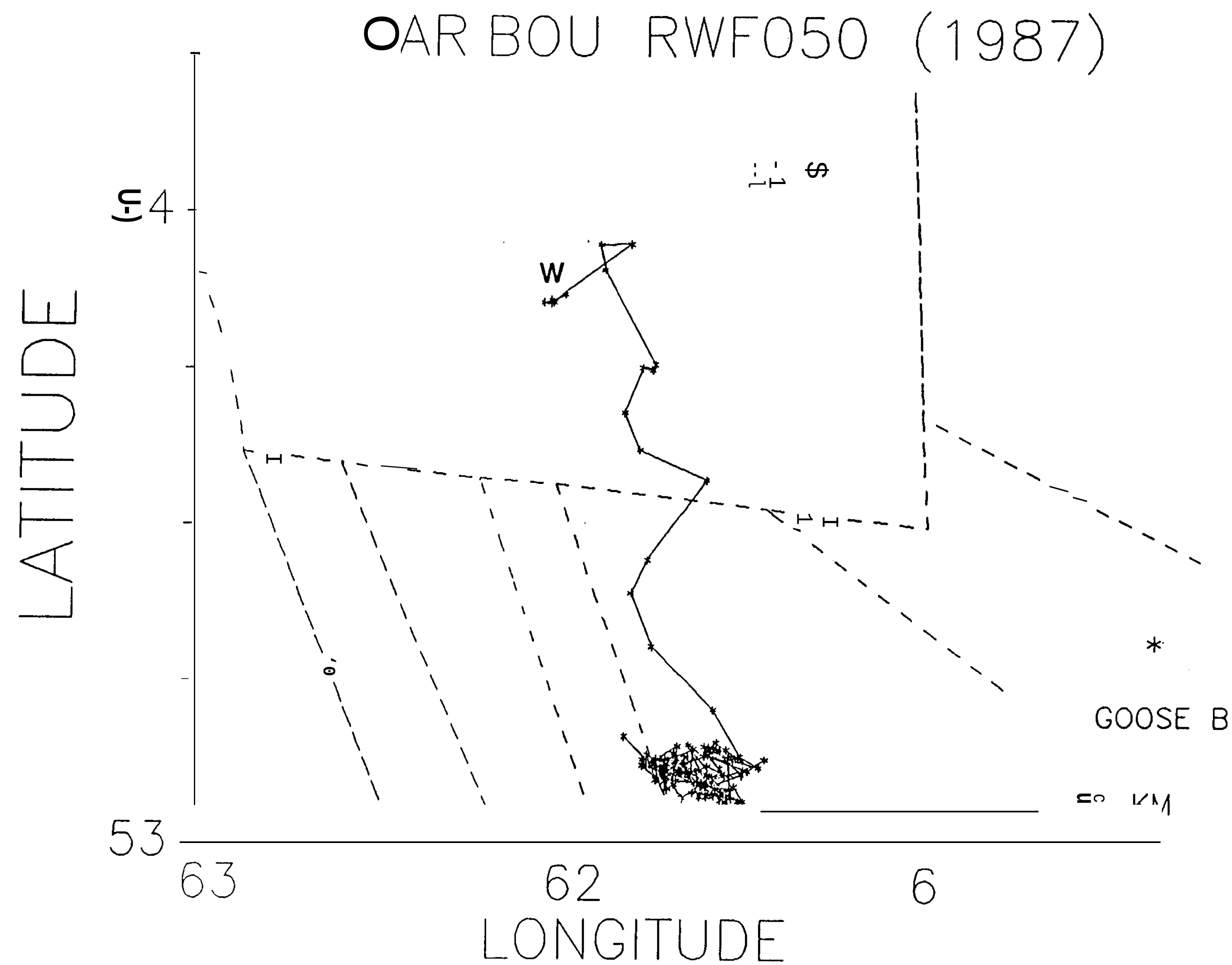

Figure 7. Satellite-acquired locations for Red Wine caribou RWF050 during the 1987 low-level flying season. The northern low-level flying area (LLTA) and its connecting corridors are indicated with dashed lines. Consecutive locations are connected by a solid line. W = late-winter area on the Red Wine Mountains. This animal used only one core area during summer.

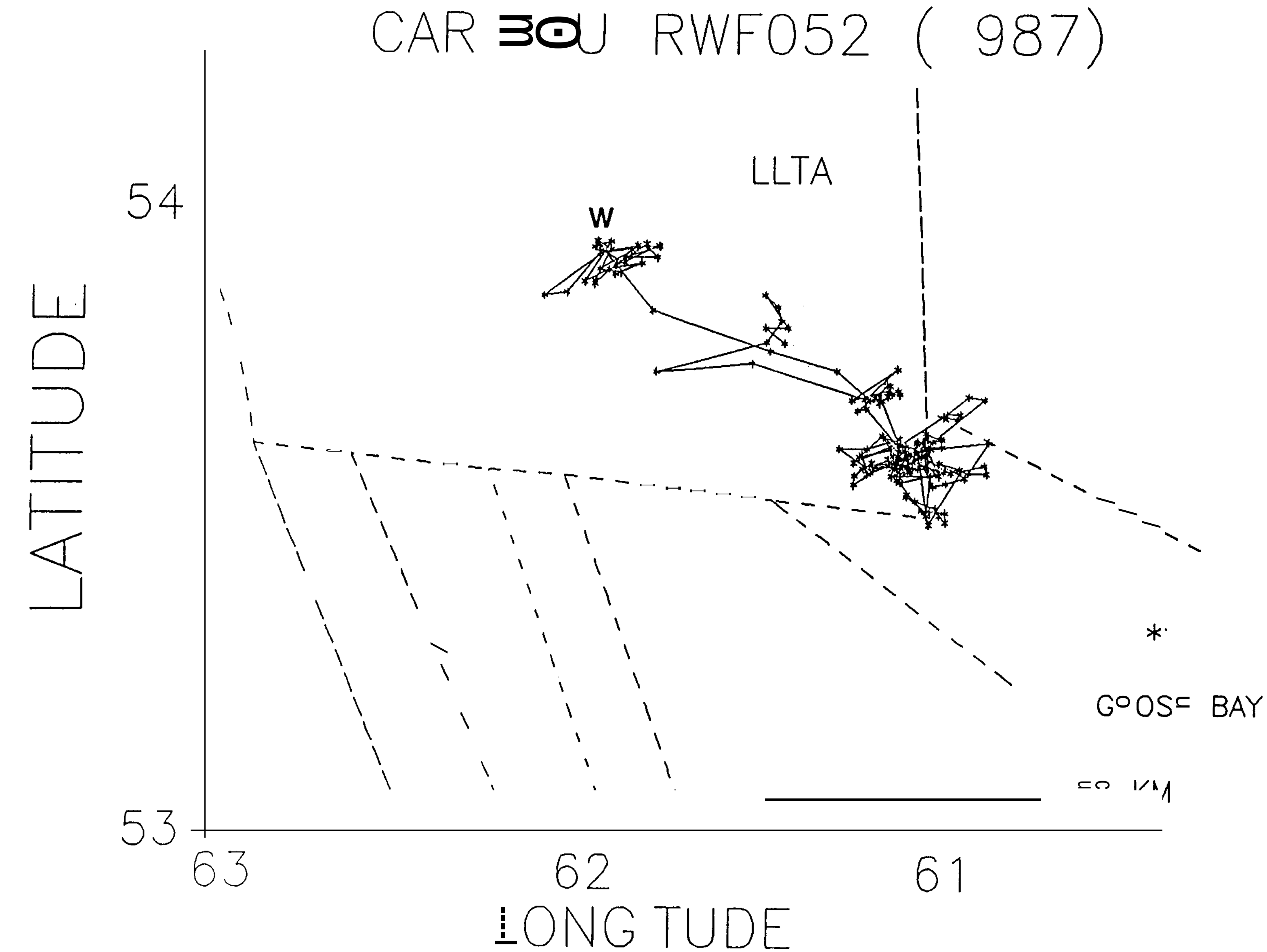

Figure 8. Satellite-acquired locations for Red Wine caribou RWF052 during the 1987 low-level flying season. The northern low-level flying area (LLTA) and its connecting corridors are indicated with dashed lines. Consecutive locations are connected by a solid line. W = late-winter area on the Red Wine Mountains. Compare to Figure 9 for the same animal.

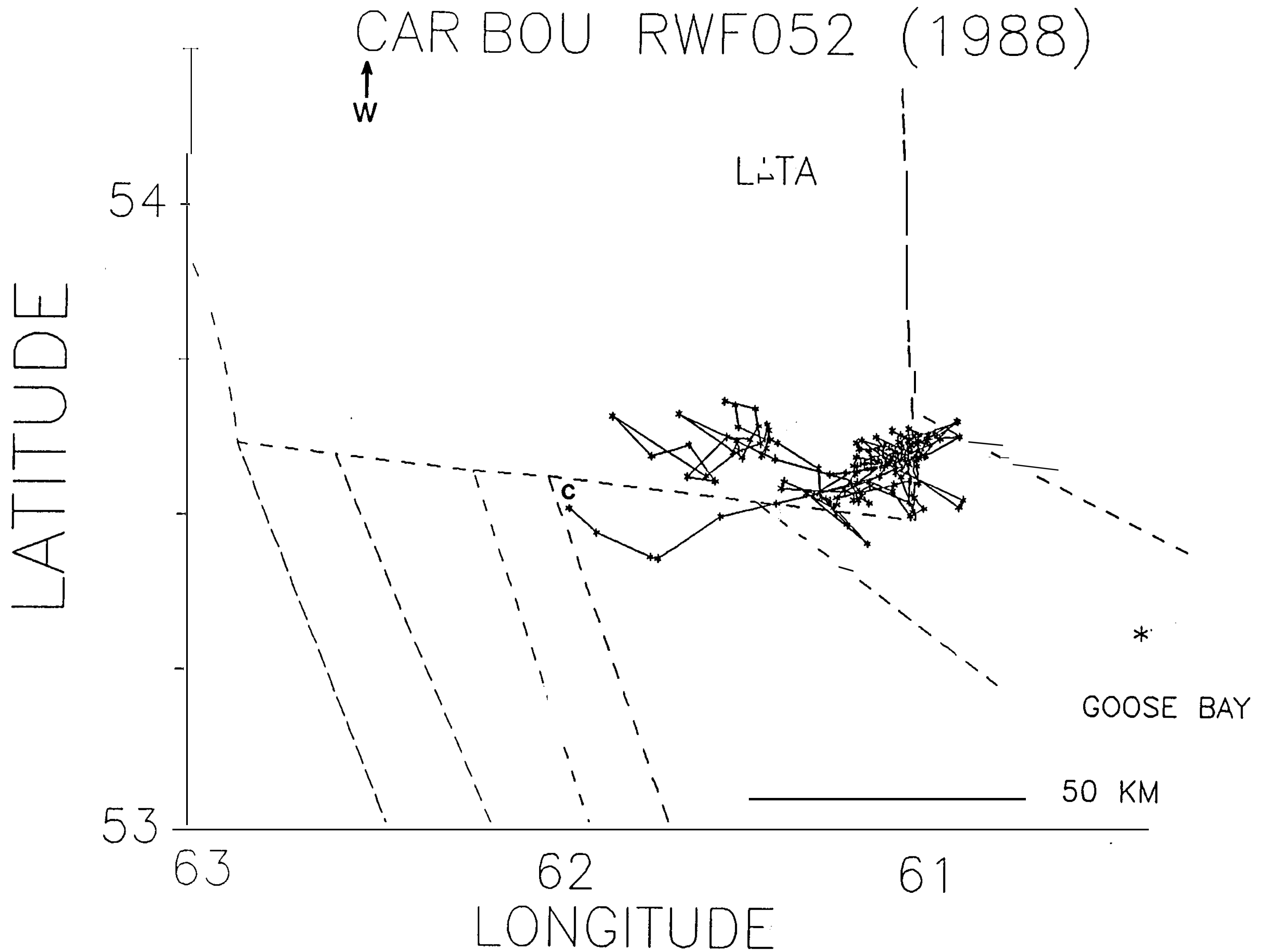

Figure 9. Satellite-acquired locations for Red Wine caribou RWF052 during the 1988 low-level flying season. The northern low-level flying area (LLTA) and its connecting corridors are indicated with dashed lines. Consecutive locations are connected by a solid line. W = late-winter area; this animal was located at 54.5 N with several thousand George River caribou and could not be singled out for capture. C = capture site on spring migration to summer range. Compare to Figure 8 for the same animal.

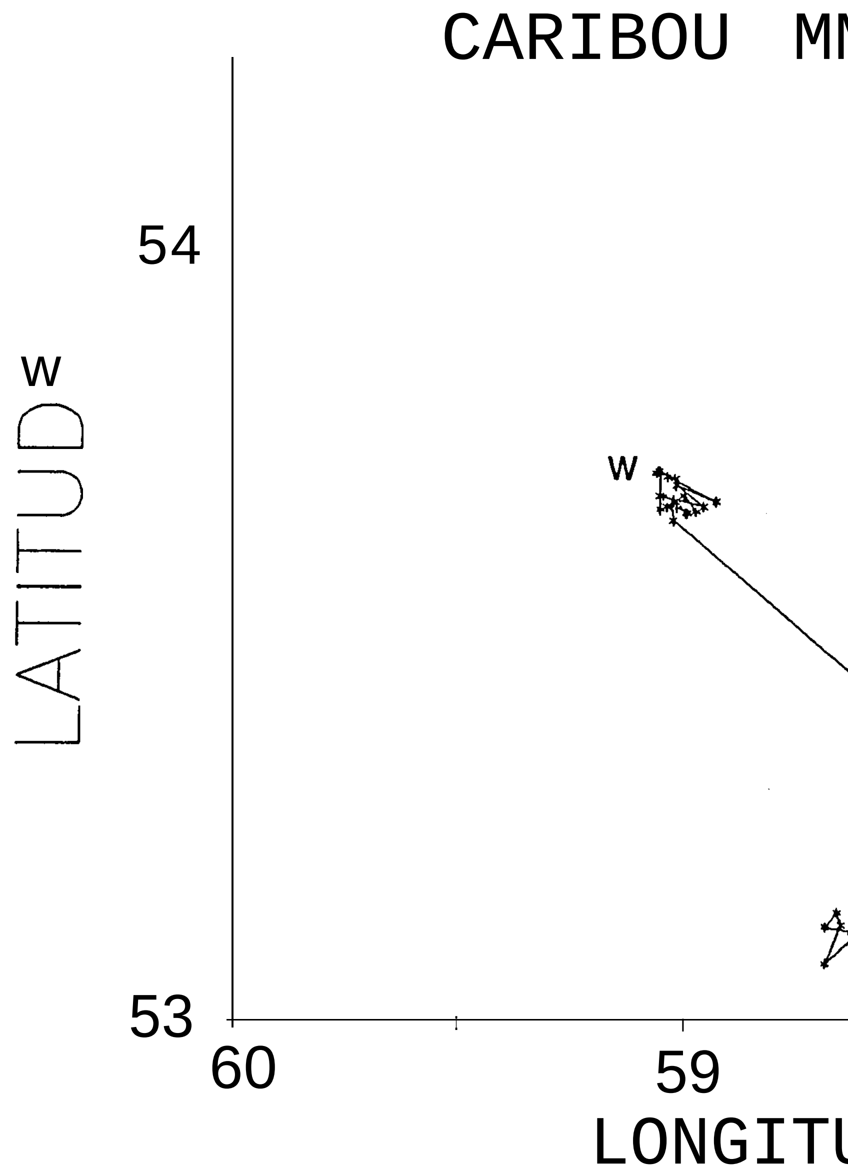

Figure 10. Satellite-acquired locations for Mealy Mountain ca
used. W = late-winter area on Mealy Mountains.

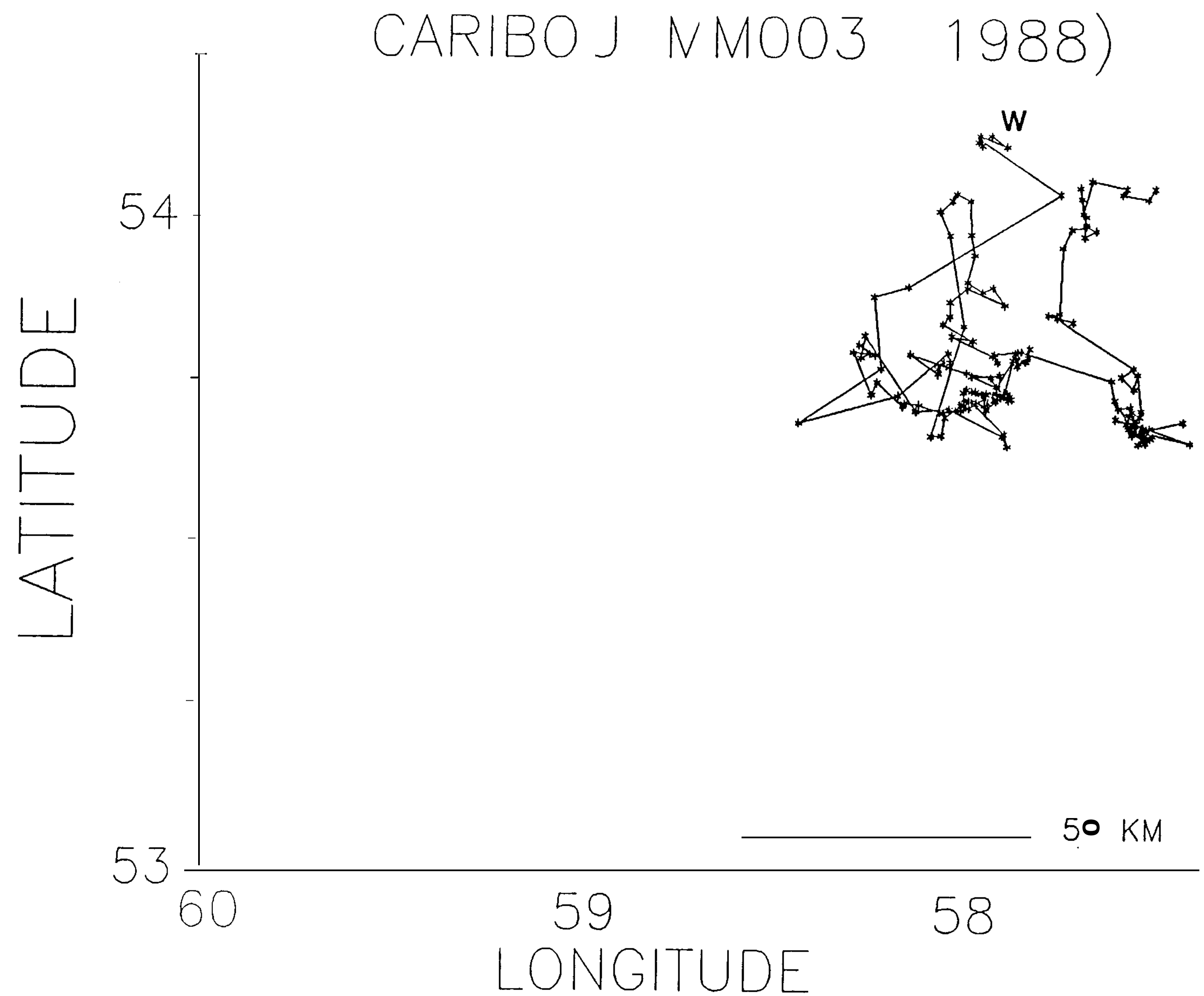

Figure 11. Satellite-acquired locations for Mealy Mountain caribou MM003 during the 1988 ow-level f ying season. The same scale as for Figs. 5-9 was used. W = late-winter area on coastal plain.

of all locations) . There were no differences among years or populations in terms of the number of core areas used or the proportion of locations obtained outside these cores. The total area represented by these cores ranged between 92-232 km^2 for the RWM caribou and between 44-176 km^2 for the MM animals. An ANOVA indicated there were no significant differences among years, populations or level of exposure of low-level flying in core home range size (F_s= 1.943; $P>0.1$), and that there was no relationship between homerange size and the level of exposure of an animal to low-level jet overflights ($r = 0.18$, $p>0.05$).

Total summer range, which encompassed both the core areas and other areas through which the animal traveled without settling down, varied extensively among individuals (Table 22) . Some used areas of only a few hundred square kilometers, whereas others ranged extensively over several thousand square kilometers. There were no significant differences in total summer range among years or populations, or related to exposure of animals to overflights (F_s= 0.906; $p>0.4$) .

Individuals varied in the predictability of range use from year to year (Table 23). The majority returned to the same general area in subsequent years. RWF013, for example, used the same single core area between 1986 and 1988 in a heavily overflown area. The central 26% of this area was used all three years, while surrounding portions were used either two years (20%) or one year (54%). Following spring movements to that area, her locations on the same date in different years were rarely more than 20 km apart, and during July and August, were never

TABLE 23 **Percent overlap between core ranges used in dlf ferent years and aean distance between** locations obtained on the **same** calendar date In different **years for five Red Wine caribou.** **Data for RWF013 are summed over three seasons. Sample size is indicated** in parentheses.

Caribou	Years	Percent overlap	Mean distance (±SD) between locations: April 1	nay	June	July	August	September	October
RWF013	1986/87/88	26%	21.4±17.6	19.6±12.2	7.5±4.2	3.6±1.9	4.2±2. 0	9.3±4.7	16.5±8. 0
			(22)	(54)	(511	(14)	(11)	(9)	(3 I
RWF037	1986/88	0%	-	36.2±18.3	26.9±14.7	30.0±13.4	26.2±10.5	37.6±5.7	-
				(16)	(28)	(20)	(24)	(7)	
RWF039	1986/87	58%	-	26.9±9.4	11.7±8.8	5.4±4.5	6. 5±3.7	10.0±3.6	-
				(19)	(17)	(1)	(8)	(11)	
RWF044	1986/87	14%	-	41.4 ±11.3	12.954.5	30.4±6.8	27.1±2.4	21.1±3. 0	-
				(19)	(29)	(7)	(2)	(2)	
RWF052	1987188	76%	-	21.3 ±20.5	5.2±3.9	8.0±4. 5	8.3?4.0	27.6 ±15.2	26.5±7.5
				(19)	(28]	(24)	(28)	(27]	(24)

more than 8 km apart. During a previous study (Brown, 1986) she was located on 12 of 13 surveys in the same core area during the summers of 1982-85. Another 1986 animal (RWF016) had also been followed previously, and was likewise found within the same summer areas on 12 of 13 surveys between 1982-85. In addition, she also made the same late-summer movements in 1982 and 1983 as in 1986. In 1987, her PTT failed early, but calf survival surveys indicated she still was using the same summer area. She died in the fall or early-winter within the fall area used during previous years. Two other females (RWF039 and RWF052) also returned to the same summer core areas in subsequent years (Table 23).

At the other extreme were RWF044 and RWF037 (Table 23). Only one of RWF044's five core areas were used both years, while there was no overlap at all among the core areas RWF037 used in 1986 and 1988. RWF037 had also been followed by VHF telemetry since 1983. All eight of her 1983-85 survey locations fell within her 1986 summer range, but only three of these corresponded to her 1988 summer range. A third 1986 study animal (RWF035), followed since 1983, showed an overlap for only half of her eight earlier locations.

An animal's exposure to low-level flying was not related to its subsequent use or abandonment of its core areas. RWF013 and RWF052 were the two most overflown animals, yet they returned to the same summer areas. RWF044, also often overflown, reused one area but abandoned two others. The one area she used heavily both years was along the high density flight corridor connecting LLT 1 with CFB Goose Bay. The two least overflown animals in this sample differed markedly. RWF039 used the same core area each summer, whereas RWF037 did not.

Satellite Telemetry - Barren-around Caribou

Eleven GR caribou were captured, equipped with PTT's and monitored for periods varying from 19-875 days between June 1986 and October 1988 (Table 24) . These caribou moved extensively throughout the Labrador and northern Quebec (Fig. 12) , averaging 10 km-d-l (Table 24). Most spent very little time (<4%) in LLT 1. However, one female spent 167 days in LLT 1 during winter 1987-88. She did not leave her wintering area for the calving grounds until about 16 April. Four other GR caribou at similar latitude (55°) began their spring migrations on about 6, 13, 17 and 17 April, respectively. Two GR females (GRF010 and GRF011) which were captured and collared on the Red Wine Mountains began'their spring migrations several weeks later, as did another GR caribou at similar latitude (53°) and the RWM caribou.

There were seven periods during which satellite-collared GR caribou passed through LLT 1 (Table 25) . Four of these periods occurred during the summer migration after the animals left the calving grounds, one occurred during the spring migration to the calving grounds, and the other two were during fall migrations. When moving to or from the calving grounds, only the upper northwest corner and the area immediately south of the calving grounds in LLT 1 were used. The caribou were either traveling to or returning from summer or winter range in the western half of

TABLE 24. Summary of data collected from barren-ground caribou followed in the present study. Daily distance traveled is only presented for animals followed at least 100 days.

Caribou	Date of capture	Age	Days in NLLTA/ total days	Daily distance traveled (km)	24 h activity
GRF001	06/07/86	3	21/675	10.3±8.5	169±95
GRF001	06/12/87	4			
GRF002	06/11/86	5	30/732	10.0±8.5	174±97
GRF002	06/12/87	6			
GRF003	06/11/86	5	0/19	PTT Failed	
GRF004	06/07/86	5	29/875	9.8±7.5	182±106
GRF004	08/23/87	6			
GRF005	06/11/86	5	25/734	9.4±7.6	179±123
GRF005	08/23/87	6			
GRF006	06/12/87	2	182/500	10.3±7.2	158±92
GRF006	06/16/88	3			
GRF007	06/13/87	4	0/39	Mortality (08/01/87)	
GRF008	08/07/87	3	16/449	7.9±6.6	203±61
GRF008	06/19/88	4			
GRF009	06/13/87	6	0/84	Mortality (12/15/87)	
GRF010	04/07/88		54/68	PTT Removed	
GRF011	04/07/88	7	37/210	11.7±11.6	218±157
GRF011	06/15/88	7			

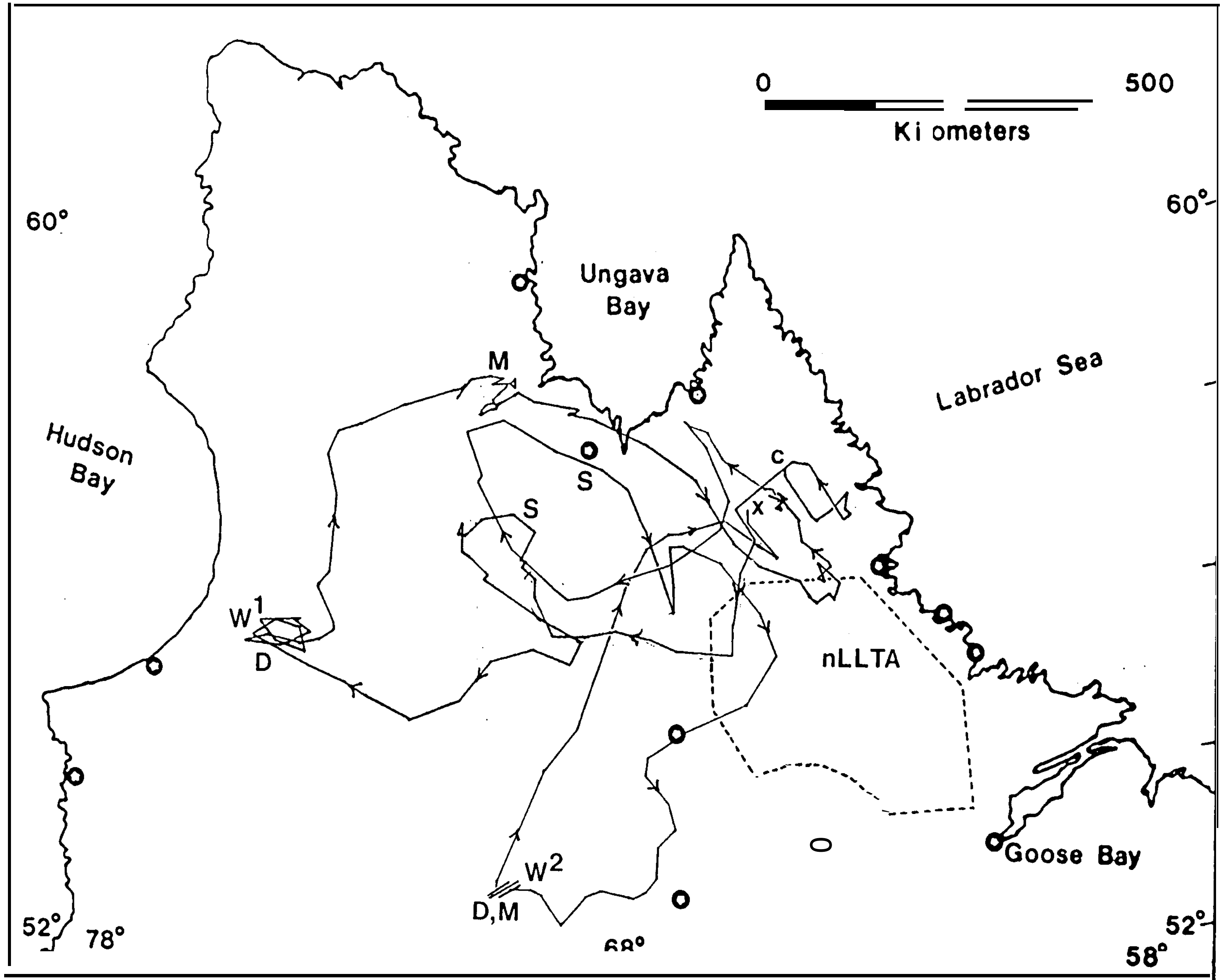

Figure 12. Movements of George River caribou GRF002 between June 1986 and June 1988. C = 1986 capture location. X = 1988 recapture location when PTT removed. General areas where located are indicated by month as: M = March; S = September; D = December. W1 = Winter area 1986-87, occupied for 45 days. W2 = Winter area 1987-88, occupied for 129 days. nLLTA = northern low-level training area.

TABLE 25. Daily travel rates and 24 h activity levels of satellite-radiocollared George River caribou using the nLLTA compared to those caribou traveling elsewhere during the same time of year. The data were compared for periods of equal length prior to, during and after the period when the nLLTA was visited. Sample size refers to the number of animals visiting the nLLTA (I) to the total sample of individuals (T), and the number of location-days for each of the sampling periods (P1,P2,P3).

Period	Sample size [I/T(P1,P2,P3)]	Ratio (nLLTA values/non-nLLTA values) for: Daily distance traveled (km) Prior to	During	After	24 h Activity index Prior to	During	After
06/23-07/17/86	2/5 (3,3,3)	1.63	1.30	2.28	1.88	1.94	2.04
07/28-08/24/86	2/4 (3,3,2)	1.16	0.80	2.98	0.58	0.75	1.37
04/10-06/07/87	2/4 (5,5,5)	1.40	0.44	2.73	0.83	0.73	1.29
07/21-08/15/87	1/7 (3,3,3)	1.94	0.46	2.33	0.68	0.92	1.03
09/29-11/14/87	2/6 (5,5,5)	1.22	0.80	1.32	1.07	1.33	1.02
10/28-12/15/87	1/6 (5,5,6)	0.93	1.04	0.92	1.03	0.64	0.72
07/15-09/01/88	2/4 (4,4,4)	0.93	0.84	0.94	0.58	0.64	0.75
Median ratio (nLLTA/non-nLLTA		1.22	0.80	2.28	0.83	0.75	1.03
Median travel rate (km.d-1 and 24 h activity index:							
Caribou using nLLTA		17.4	11.7	14.5	198	214	245
Caribou not using nLLTA		14.5	12.3	11.3	192	199	192

the Ungava Peninsula. During these periods, portions of the outer zones of LLT 1 were closed to low-level flying by the military so that migrating caribou could be avoided. The two fall incursions occurred in the western portion of LLT 1 after low-level training had ended. Therefore, it is unlikely that any of these caribou were overflown while they were in LLT 1.

Daily distance traveled and 24 h activity indices for intervals prior to, during and following their movements in LLT 1 were compared between the caribou which used the zone and those animals that did not. Caribou which used LLT 1 were generally traveling extensively prior to their entry in LLT 1, during their spring, summer or fall migrations. In five of seven cases, the animals slowed their movements by an average of 40% when in LLT 1. At this time, both their movement rates and their activity levels were lower than those of other animals which were not using LLT 1 at that time (Table 25) . Following their time in LLT 1, these caribou increased their rate of travel (but not their activity level) , although on average they were traveling less extensively after leaving LLT 1 than they had been prior to entering it. After leaving LLT 1, these animals were traveling at a higher rate than those animals that had not used LLT 1. Their activity levels, however, were not different (Table 25) .

The three satellite-collared GR caribou which used LLT 1 for extended periods did not differ in movement rates or activity levels from animals residing outside LLT 1, except during periods when migratory movements occurred. Caribou GRF006 began her spring migration prior to the beginning of low-level flying, and during the same period as other animals at the same latitude. Caribou GRFO1O and GRF011 were exposed to low-level flying for 19-24 days prior to their migratory movements, during which time they experienced at least 18-21 overpasses within 1 km of their location. However, these two animals did not leave their wintering areas until the RWM caribou also did, about 1-2 weeks later than another GR female at the same latitude, but 500 km to the west.

DISCUSSION

Short-term Impacts of Low-level Jet Overflights

Overflight stimulus. Our analysis of jet overpasses indicated that the sound stimulus was brief, with a rapid rise time (<1 s) and more gradual fall. Peak sound pressure levels in excess of 120 dB occurred with direct overpasses at 30 m agl, but peak levels were typically less and fell off rapidly (8 dB/100 m) as distance from the flight track increased. Similar decreases in sound pressure level would be expected with increasing altitude (Anonymous, 1989). Beyond 150 m from the jet's flight path, the mean sound pressure level for jet overpasses was under 90 dB, which other studies have shown to be less aversive in a range of domestic and wild mammals (Manci, et al., 1988) . Thus the "disturbance footprint" caused by the noise of an overpass is probably confined to a width of about 300 m. Since most low-level training flights are at 30-150 m agl (Anonymous, 1989) , every jet has the potential for producing a significant disturbance within this 300 m corridor.

Data collected in 1988 on satellite-collared caribou and jet flight tracks indicate that overflights close enough to elicit maximal disturbance are relatively uncommon under present levels of flying (Table 26). RWF052, which spent most of the 1988 low-level flying season in the heavily-used southeast corner, would have experienced one or more overpasses within this 300 m-wide "maximal disturbance corrider" once every 10 days, on the average. By 1996, however, the three-fold increase expected in

Table 26. The number of days on which jets passed close enough to collared caribou to have likely caused either "strong" or "mild" intensity reactions (after Calef et al., 1976). The data were calculated using the 1988 flight tracks and the locations of satellite collared Red Wine caribou to determine the daily minimum distance from a jet for each animal.

Caribou	Days	Strong reactions (jet < 0.15 km)		Mild reactions (jet < 0.30 km)	
RWF013	203	10	(5%)	24	(12%)
RWF037	157	7	(4%)	13	(8%)
RWF052	175	17	(10%)	23	(13%)
RWF053	181	6	(3%)	8	(4%)
RWF055	120	5	(4%)	7	(6%)

low-level flying activity could increase this exposure significantly. If no changes in the overall distribution of flight tracks occur, she would be exposed to maximally disturbing overpasses every three-to-four days.

Behavioral response to overflights. The most common initial response to a very sudden, intense noise is the "startle reflex", with its concurrent activation of the sympathetic nervous system (Moller, 1978). Sounds with the most rapid rise times and highest peak levels should cause the most intense startle reactions. In this context, such sounds would be generated most often by direct, low overpasses. Overpasses displaced from the animals have both slower rise times and lower peak levels, and consequently would be less startling. The presence of background noise (i.e., wind in trees, running water) can mask the initial increase in sound level, thereby enhancing the startle effect. These conclusions are consistent with the observations of caribou being overflown by jets. In the majority of cases, the animals did not react until immediately after the jet passed, with maximal reactions showed by animals directly under the jet and minimal reactions for animals only 100-150 m away from the jet's path. These observations suggest that the initial response to an overpass is caused by the sound of the overpass, not the sight of the jet.

Following the initial startle, the animals' response followed a time course very similar to that of the overpass itself. If animals began to run, maximum rate was reached almost immediately and within 5-10 s they had stopped. Following an overpass, the caribou often oriented to the receding jet, apparently watching it. The observation that the caribou usually turned as the jet passed and moved opposite to its direction also suggests that the visual image of the jet becomes an important focus after the initial startle. On those occasions when caribou had a good vantage point from which to observe a jet prior to an overpass, the animals typically reacted before the pass, thereby running a longer period before the jet overtook them and they subsequently slowed. These latter, more extensive responses are most likely in open habitat; caribou in forested habitat would be unlikely to see jets except briefly as they receded.

Within the minute following an overpass, most animals appear to relax their vigilance and either resume previous behaviour or engage in other, non-vigilant behaviour. An overpass, even a series of overpasses, did not appear to greatly alter the animals' general activity, except momentarily, and recovery was usually within minutes. Those animals that had been moving resumed traveling after the exposure, usually in the same general direction; those that had been resting or feeding also resumed those behaviors after the overpass.

The type and level of immediate response observed with the helicopter overpasses differed from that observed with the jets. The slower air speed of the helicopter gave advance warning of its presence and thus reduced the "startle" impact. On the other hand, the caribou began to run sooner and ran significantly longer than for jet overpasses. Following a single helicopter overpass, the animals were displaced much farther than for jet overpasses. The longer overpass time of a helicopter suggests that they may condition greater avoidance responses over time than would jet aircraft, as the latter are rarely observed by the animals' prior to the overpass. In addition, helicopters are the only aircraft likely to actively pursue caribou, either through the pilot's curiosity or during wildlife management operations (i.e., capturing/collaring, classification surveys). Thus caribou may learn to associate helicopters with the same threat posed by predators, intensifying the response over time. It may be more difficult for caribou to habituate to stimuli that occasionally act like predators (helicopters) than to stimuli that do not (jets) .

Calef et al. (1976) divided the responses of Porcupine Herd caribou exposed to light aircraft and helicopters into five classes: "Panic", animals stumbled into one another or inanimate objects; "Strong Escape", animals trotted or ran off, usually continuing after the aircraft has passed; "Mild Escape", animals walked or trotted a short distance; "Stationary", animals stood if previously bedded or stopped feeding; and "No Response". Of these response classes, "Panic" would be most likely to result in injury. In the present study, the typical response to a jet overpass was "Mild Escape". "Strong Escape" and "Stationary" responses were seen to occur in similar proportions, while "Panic" responses were not observed. The response noted during the present study to helicopter overpasses was invariably a "Strong Escape".

The majority of studies have noted stronger reactions toward aircraft disturbance (helicopter and light aircraft) during the winter period (summarized by Shank, 1979), although results do vary from study to study (Calef et al., 1976; Fischer et al., 1977; Gunn et al., 1985; Klein, 1974; McCourt et al., 1974; McCourt and Horstman, 1974; Miller and Gunn, 1979; Surrendi and DeBock, 1976). Our observations were conducted on the late-winter areas of both Red Wine and George River populations, prior to their spring migrations. Thus, although we were not able to conduct observations of jet overpasses during other periods of the year, it is unlikely that responses would be significantly greater than those obtained here during the late-winter. However, empirical confirmation for this prediction should be sought.

Previous studies have found that larger groups of caribou are more reactive to light aircraft and helicopter disturbance than smaller ones (Fischer et al., 1977; Gunn et al., 1985; Klein, 1974; McCourt et al., 1974; McCourt and Horstman, 1974; Miller and Gunn, 1979; Surrendi and DeBock, 1976) . Our limited data on helicopter overpasses also suggested that the larger George River group ran longer and harder than the smaller Red Wine groups. On the other hand, we did not find a significant difference in distance or time running in response to jet overpasses that could be related to group size. Median time running was about 5 s for both populations, and for groups of varying size within the Red Wine population. Whatever the factor (i.e., social facilitation) responsible for the heightened responsiveness of larger groups to helicopters and light aircraft, the brief stimulus provided by a jet aircraft, and the rapidly waning response it generates, may not allow sufficient time for that factor to reach an effective threshold.

Group composition has been shown to influence the response of caribou to light aircraft and helicopter disturbance, with cow/calf groups being most reactive and bull groups being least reactive (Fischer et al., 1977; Gunn et al., 1985; Klein, 1974; Miller and Gunn, 1979; Surrendi and DeBock, 1976). We found no significant differences among bull only, mixed cow/calf/bull, or cow/calf groups to jet overpasses; median responses and extremes were similar for all three classes. The relative briefness of the animals' response would have made it difficult to detect differences, had there been any, and the season we conducted our observations precluded a test of the reactivity of cows with recently-born calves, which others have shown to be more reactive (Fischer et al., 1977; Klein, 1974; Miller and Gunn, 1979).

Finally, it was noted by Surrendi and DeBock (1976) that caribou in open habitat were less reactive than caribou in heavily-forested habitat to helicopter and light aircraft disturbance. We could not test this for jet overflights, as all our observations were conducted on alpine tundra. However, in the course of routine checks by helicopter on calf survival and on the status of animals a week after capture, we noted that some (<10%) caribou in black spruce forest would not run despite continued circling at tree-top level, whereas caribou in open habitat invariably ran from the close approach of the helicopter. These results suggest that caribou may be less reactive to aircraft disturbance when in forested habitat, contrary to the conclusion of Surrendi and DeBock (1976). Indeed, we noted our most extreme reactions to jet overpasses from a group of caribou on a high, exposed ridge that provided extremely good visibility.

The above information indicate that the greatest impact of low-level flying jet aircraft will be due to the startle reactions caused by low, direct passes. There are a number of situations where strong startle responses may be detrimental to caribou. During the calving period, disruption to the cow/calf bond or injury to the calf may decrease calf survival (Banfield, 1974; Calef, 1974; Cowan, 1974; Miller and Broughton, 1974; Miller et al., 1988). Research on domestic livestock, which are typically less reactive to disturbance than wild ungulates (Manci, et al., 1988), has shown that milk production (Ely and Peterson, 1941) and calf thyroid function (Ames, 1971) may be reduced following exposure to loud, auditory stimuli. Should this occur, calves exposed to frequent overflights may grow slower early in life and consequently suffer higher mortality from increased predation or inability to cope with inclement weather or the energetic demands of summer migration or insect harassment. This effect would be exacerbated when poor summer range has already placed both cow and calf into a negative energy situation. Startle reactions may also be detrimental in situations where sudden movements can result in injury because of ground conditions and social factors. Ground conditions would include rugged topography where falls are likely, especially when ice cover reduces traction. Social factors would include periods when animals are congregated in groups, especially when the groups are constrained by environmental factors, such as deep snow, river crossings, or icy ridges. Sudden mass movements, although of short duration, could result in injuries if safe paths for retreat are limited. We collected evidence of accidental deaths near waterfalls and along steep ridges during this study, and approximately 10 000 George River caribou drowned in a river crossing accident in 1984 (Doucet *et al.*, 1988) . Startle responses may also increase vulnerability to predation if predators rely on movement to detect prey. Brown (1986) showed that black bears (*Ursus americanus*) prey most heavily on adult Red Wine Mountain caribou when they were on the Red Wine Mountains. Woodland caribou, which disperse during calving as an anti-predator strategy (Bergerud *et al*., 1984a; Bergerud and Page, 1987), may become more vulnerable if frequently startled from cover.

Impact of low-level flying on energy expenditure. Of our two daily measures of impact, the 24 h activity index appears to be most valid. First, this index was significantly and consistently correlated to a number of biologically-relevant variables. Second, it is an absolute measure of a particular class of behaviour (head movement) that is related in predictable ways to standard measures of activity (running, walking, feeding/resting) . Daily distance traveled, on the other hand, contains a significant amount of error (20-40%) on the scale of movements made by woodland caribou (2-4 km-day-l) . Second, when movements are not strongly directional, daily distance will underestimate actual distance traveled. Therefore, as a measure of reaction to low-level flying, daily distance traveled in and of itself is probably too coarse to reveal any effects of low-level flying, should they be present. Rather, location data are much better suited to analyze home range use, which is a more valid indication of long-term disturbance (see below) . The 24-h activity index, on the other hand, does appear to be a sensitive indicator of the short-term influence of jets on activity.

The data from the satellite collared animals indicated that neither the 24-hour activity index nor the daily distance traveled were consistently related to the degree of exposure to low-level flying aircraft. These findings are consistent with the directed overflight observations, which indicated that the animals' reactions to an overpass were short-lived. Studies using heart rate telemetry, however, have shown that the metabolic costs of disturbance often continue after any initial overt response has ended, and frequently occur in its absence (Kanwisher et al., 1978; Moen et al., 1978; MacArthur et al., 1979), although in the latter case the energy expenditure is slight, being equivalent to moving a few body lengths (Floyd et al., 1988). The overt response of a bighorn sheep (Ovis canadensis canadensis) to a helicopter overpass (MacArthur et al., 1979) paralleled that of caribou to jets in the present study; thus it is likely that heart rate similarly remains elevated for several minutes following a jet overpass. The one significant correlation between exposure and activity index in

1987 suggests that under higher levels of exposure, as occurred when particular animals were being deliberately overflown by jets on a daily basis, a slight increase of a few percent in activity level may occur; no influence of exposure was seen in 1988 when specific caribou were not being deliberately overflown. Therefore, it is possible that under the higher levels of low-level flying activity expected by 1996, some animals may begin to show significant although relatively low (<5%) increases in energy expenditure, consistent with Geist's (1971) calculations on the costs of harassment in caribou. These effects would most likely be seen in Red Wine Mountain caribou inhabiting the most heavily used corridors in LLT 1.

Daily distance traveled, the Temperature component of the weather variables, Season of year, and Individual difference were consistently correlated to the 24-h activity index, to the same relative degree, each year. The relationship with distance traveled is expected, as the index discriminates well among the behavioral classes of running, walking and feeding/resting (Fancy et al., 1988; S. Fancy, pers. comm. 1989). For George River caribou, the correlation between distance traveled and 24-h activity levels is very high (r = 0.8-0.9) during periods of directional migration, but drops to much lower values during non-migratory periods (Barrington, unpubl.). The Red Wine Mountain caribou, being much more sedentary, move back and forth within relatively small areas and thus display a lower correlation between distance traveled and 24 h activity level. In addition, the average distance traveled each day by the woodland caribou (3 km) incorporates a significant error component from the uncertainty associated with the location itself (<1 km) (Barrington et al., 1987; Fancy et al. 1988).

The Temperature component received its highest loadings in the PCA from daily maximum temperatures. The positive relationship between the Temperature component and activity level most likely indicates insect harassment (Curatolo, 1975; White et al., 1975, Boertje, 1985; Dau, 1986), as it reflects the contribution of Temperature above that already explained by the daily distance traveled. Although this component explains only 7% of the variance in 24 h activity level, it is an admittedly crude, regional measure of weather conditions, and thus only approximates the immediate temperature, humidity and wind conditions that influence insect activity about an individual caribou. In a study of George River caribou on the postcalving grounds in 1988, Camps and Linders (1989) showed that insect harassment drastically alters activity budgets and can place the animals into a severe energy deficit. Time spent feeding during daylight hours dropped from 64% to 33% when mosquitoes appeared, and to 4% when oestrid flies emerged. Walking increased from 14% to 59% when mosquitoes emerged, but dropped back to 27% when both insect pests were present. Standing, low (<3%) during both the pre-insect and mosquitoes periods, increased to 65% once oestrids emerged. These differences between the two insect periods reflect the different behavioral strategies of caribou to mosquitoes and oestrid harassment (Espmark, 1968; Curatolo, 1975) . In terms of energetic costs, the mosquito season brought an increase of 14%, while the emergence of oestrids increased this cost a further 19% (Camps and Linders, 1989). As a consequence of poor forage, lactating females were expected to lose about 0.2 kg-day-l during the mosquito season. Fancy (1986) found that daily differences in the level of insect harassment had a significant effect on the energy balance, indicating that extreme insect harassment could prove lethal. Camps and Linders (1989) found three dead (strongly emaciated) lactating females during the peak of mosquito occurrence in 1988, and one of our satellite-collared George River females died of apparent malnutrition during the postcalving period in 1987. Her bone marrow fat content was 37%, the lowest recorded for George River caribou to date. Thus during the summer season, both Red Wine Mountain and George River caribou face about two months of nearly continuous, energetically draining harassment from mosquitoes, black flies and oestrid flies. Therefore, in comparison to insect harassment, disturbance from low-level flying is slight, but it will be additive and could push animals below a minimum 'energy budget' threshold.

Daily distance traveled was not found to be correlated with any single variable on a consistent basis. Rather, daily distance traveled was largely a function of the animals' home range patterns. Some individuals extensively used only one or two restricted core areas, and thus traveled less than those using either multiple core areas or having extensive movements outside localized cores. The number of core areas utilized, the extent of movements outside of cores, and home range area were not related to levels of exposure to jet overflights; the four Mealy Mountain females exhibited the same range of variability as did the sample of Red Wine caribou. In 1987, females with calves moved shorter daily distances than those without, indicating that the presence of a calf constrains a female's movements. Mealy Mountain females moved shorter distances on a daily basis, regardless of calf survival, than Red Wine Mountain females did the same year. However, small sample size and variation from year to year within the Red Wine population do not permit the conclusion that Mealy Mountain caribou consistently move less, and that exposure to low-level flying influences this difference.

Summary. Direct observations indicated that the behavioral responses to overflights were of moderate intensity (startle and brief run) but were short-lived (seconds rather than minutes), although internal physiological impacts likely continued for several minutes following an overpass. Given the small 'Disturbance footprint" of an overpass, and the low probability of receiving overflights for many animals, it is likely that most animals will not be adversely affected by low-level flying activity and significant energy expenditures and disrupted movements are unlikely to occur. Compared to the inescapable harassment from insects, the occasional energetic costs of an overflight are minimal. However, the strong initial startle to low, direct overpasses does have the potential to lead to injury or death during certain periods of the animals' life cycle or under particular circumstances, and as a consequence, this potential cannot be ignored. Adherence to the program of monitoring and avoidance outlined below should greatly minimize the realization of adverse impacts from the startle response.

Long-term Effects of Low-level Jet Overflights

Effects on calf survival. No significant relationship between an animal's seasonal exposure to overflights and its subsequent calf survival was noted. However, the correlation between exposure to overflights and calf survival was a modest and negative -0.304, and while not significant, was also based on a relatively small sample size (n = 14). The single satellite radiocollared female from 1988 which successfully raised her calf to December was the least exposed of the five to low-level flying. In addition, the small sample of radiocollared Mealy Mountain females, which were not exposed to low-level flying by military jets, experienced higher calf survival in 1988 than the larger sample of Red Wine Mountain females. Therefore, we cannot rule out the possibility that exposure to low-level overpasses may exert a subtle, but real, negative impact on calf survival.

If low-level flying does influence calf survival, this influence may be of a threshold nature. Calf survival (to April) in the Red Wine Mountain population was 32% in both 1982/83 and 1983/84, and was 45% in 1986/87 (Veitch, 1990), showing no evidence of a decline during the first 6 years of low-level flight training. During the same period, survival of Mealy Mountain calves was similar, although Mealy Mountain caribou were not being exposed to low-level flying. Hearn and Luttich (1987) estimated that calves comprised 18% of the Mealy Mountain population in spring 1987, as compared to a similar estimate of 19% calves in the Red Wine Mountain population at the same time (Veitch, 1990). Veitch (1990) indicated that calf recruitment rates for Labrador woodland caribou, including the Red Wine Mountain population, were among the highest reported for any North American caribou. Therefore, at least through 1987, there is little evidence to indicate that low-level flying was exerting a negative effect on calf production and survival for the Red Wine Mountain population.

In 1988, however, the Red Wine caribou experienced lower calf survival than the population had in 1987; most females (70%) were located without calves within a month of calving. This loss of calves was apparently population-wide, as December calf:cow ratios were 40% lower than in the previous year (Veitch, 1990). As low-level flying activity has increased yearly since the early 1980's, it is possible that the impact of low-level flying has now exceeded a critical threshold, resulting in depressed productivity by cows and/or increased mortality of calves in 1988.

Through 1987, the Red Wine Mountain population has shown no growth, despite a reasonably high calf recruitment (Veitch, 1990), whereas the Mealy Mountain population has more than doubled (Hearn and Luttich, 1987). Veitch (1990) suggested that high adult mortality from predation may have been an important factor limiting the growth of the population during that time. The early loss of calves in 1988 is also consistent with predation mortality, as both black bears and wolves (Canis lupus) are relatively common in the study area, and have been shown to be responsible for three-quarters of the adult mortalities of known cause (Veitch, 1990). Thus, although the low calf production in 1988, and the negative correlation between calf survival and exposure to low-level flying, suggest that current levels of training may have reached a level where negative impacts of calf production will become noticeable, other explanations also merit consideration. Because the evidence is equivocal, further study of the possible link between low-level flying and calf production is necessary for both woodland caribou populations.

Effects on habitat use. The pattern of home range use for the woodland caribou varied among individuals, with some using multiple core areas and others limiting movements to a single core. Within the Red Wine population, these patterns were not related to an animal's exposure to low-level flying aircraft. The finding that Mealy Mountain caribou, which are not exposed to low-level flying aircraft, showed the same variety of home range patterns seen for the Red Wine population further indicates that animals are not being forced out of their home ranges or to move frequently within their home range by low-level jet activity.

The pattern of home range use was idiosyncratic among those woodland caribou that were followed for more than one season, as has been found for woodland caribou elsewhere (Hatler, 1986). Some reused the same core areas in different years, whereas others moved into new areas between years. Whether an animal returned to the same core area in subsequent years was not related to her relative exposure to overflights in former years. Two of the animals which had home ranges that were frequently subjected to overflights still returned to the same relatively restricted summer ranges. One of these had used the same area since she was first collared in 1982 (Brown, 1986) . One of the criticisms directed against disturbance studies is lack of baseline data prior to the disturbance (Geist, 1975) . Such was necessarily true for the present study. However, data from several of the animals goes back to the second year of low-level flying (1982), when 70% fewer sorties were being flown. In addition, comparative data are available from a similar, neighboring population that has never experienced low-level military jet fighter training. Comparative data over years and populations indicate that low-level flying activity one year will not prompt an animal to abandon its home range the next. Those animals that did use different areas among years apparently did so for reasons other than exposure to aircraft.

The George River population has not consistently used LLT 1 since the late 1970's (Dalton and Luttich, 1986) . Prior to the late 1960's, LLT 1 had been an important wintering area for the population (Berger and Luttich, 1985). During the present study, the animals' movements through LLT 1 were associated primarily with their migration to and from the calving grounds north of LLT 1. The pace of the animals' movements associated with LLT 1 did not indicate that the animals were being driven through the area by jet activity. In fact, because the probability of an overflight in the two outer zones of LLT 1 is so low, and because these zones were closed to low-level flying at the time caribou were present, it is likely that very few if any caribou were directly exposed to low-level flying.

Three satellite collared George River caribou used LLT 1 during winter 1988. One was associated with a large concentration of animals numbering in the thousands; the other two were captured from a small (<100) group on the Red Wine Mountains. The movements and activity levels of these animals did not seem to be affected by the resumption of low-level flying in mid-April. Rather, the timing of their spring migration was consistent with that of other satellite-collared caribou at the same latitude outside LLT 1, indicating the importance of seasonal factors (i.e., snow depth) in their migration.

Summary. Evidence indicates that low-level jet activity, at present levels and type, does not appear to have caused caribou to abandon their home ranges and move elsewhere. Similar conclusions concerning possible caribou range abandonment have been reached in regard to other forms of human disturbance (Bergerud, et al., 1984b). The evidence concerning the potential impact of low-level flying on population dynamics (as measured by calf survival), on the other hand, is equivocal. The sample size obtained was not sufficient to permit an adequate test. However, the negative correlation between exposure to overflights and calf survival, coupled with the continued depression of population growth in the Red Wine population, and the potential negative impacts of strong startle responses, indicate that the relation between overflight exposure and calf survival warrants further research.

Management Recommendations - Low-level Flying (Component 1)

Component 1 of low-level training in Labrador and northern Quebec involves the continuation of the current flying activities, as specified by a Multi-national Memorandum of Understanding between Canada and a number of NATO nations. No changes from current practices will occur, except that the number of sorties flown is expected to increase three-fold to 18 000 annually, with about 2700 occurring at night. The flying season will extend one month at both its beginning and end (Anonymous, 1989) . DND has indicated that avoidance will be the primary mitigation measure to avoid disturbance of caribou (Anonymous, 1989) . To coordinate this avoidance, a geographical information system (GIS) will be developed. The recommendations below assume the implementation of this GIS-based avoidance system.

The success of the program outlined here depends on mutual trust and cooperation between military and wildlife management personnel. Toward this end, it is recommended that wildlife personnel regularly brief military personnel on the local caribou populations and the reasons behind the mitigation program. Information concerning the biology and movements of the caribou should be regularly shared with the military. In addition, information collected and action taken by the military with regard to caribou should be routinely provided to wildlife personnel, through regularly monthly meetings involving MCC, the CFB Goose Bay environmental officer, and wildlife biologists.

Mitigation of long term effects - summer. At the current level of flying activity, no long-term effects are expected for home range use in the Red Wine population, although the potential for adverse effects on reproductive success cannot be ruled out. A three-fold increase in flying activity, on the other hand, could exert a negative impact on both if the increased number of sorties is not managed to ensure more equitable distribution within LLT 1. The present distribution of flying activity is concentrated along several corridors which run directly through the range of the Red Wine population. If the brunt of the increased flying is borne by these corridors, caribou within them may be exposed to unacceptably high numbers of overflights. To minimize this potential, it is recommended that:

(1) The distribution of flight tracks be monitored on a continuing basis so that exposure levels throughout LLT 1 are known. Flights tracks, including information on time, elevation, jet type and flying formation, should be obtained for all sorties using LLT 1. This information should be compiled by DND and updated on the GIS system, and be made available to the provincial wildlife department or its designate responsible for monitoring the caribou populations. From these flight tracks, and the exposure levels determined from them, a strategy for more evenly distributing this exposure should be developed in consultation with wildlife biologists familiar with caribou;

(2) An aptitudinal division of the **entry/exit** corridors be established so that jets in-transit through the Red Wine range (Latitudes < 54° N) do so at higher altitudes (>300 m) to minimize ground-level disturbance;

(3) During the calving and immediate post-calving period (25 May - 25 June) , jets passing through the Red Wine population's main calving areas should be restricted to a minimum altitude of 450 m. In this regard, it may be useful to extend the **entry/exit** corridors farther to the north during the calving period;

(4) Throughout the year, the Red Wine Mountains be closed to low-level flying (see below); and

(5) No targets should be established within the spring and summer range of the Red Wine population (< 54° N) .

The above measures will reduce the overall impact of flying activity for individual caribou, and may even result in a decrease from the exposure currently experienced.

The increase to 1000 helicopter sorties by 1996 may have more potential for disturbance than the low-level jet activity. This and other studies indicate that caribou react most adversely to helicopters. In addition, helicopter crews can magnify this potential if they deliberately fly over caribou that are encountered. To minimize these potential impacts;

(1) All helicopter sorties within LLT 1 should maintain a minimum altitude of 600 m; and

(2) Helicopter crews should be instructed to avoid direct overpasses of caribou that are encountered during a sortie, even if that means a temporary deviation from their course. Annual

briefings by wildlife personnel to discuss the impacts of helicopters on caribou would serve to heighten awareness and increase complinace with flying regulations.

Because of the short-term and presently limited use of LLT 1 by George River caribou, their movements should be monitored and groups should be avoided whenever they are using LLT 1. Because the animals are typically moving fairly rapidly at this time, closure or aptitudinal restrictions (> 600 m) should follow biologically-relevant migration corridors. Until better information on movements and habitat use are available, the current practice of closing the northern section of LLT 1 during the calving and first month post-calving should be continued.

Mitigation of long-term effects - winter. During the late-winter period, Red Wine and George River caribou are found in localized concentrations. Deep and/or heavily-crusted snow may greatly limit foraging opportunities, decreasing food intake while increasing energy expenditures. In addition, hazardous terrain or icy conditions may increase the likelihood of startle-induced injury, particularly for younger animals without previous exposure to overflights. Under such conditions, avoidance of caribou is prudent and, except during migration, relatively easy. The size of the group's wintering area can be delienated by a high level (300 m) survey by light aircraft and subsequently avoided entirely, if localized, or flown over at a minimum altitude of 300 m.

Within the Red Wine range, the Red Wine Mountains have been an important late-winter area even in those years when alternate areas are also in use. In addition, many Red Wine caribou use the mountains, particularly the steep flanks, during summer, presumably for relief from insect harassment. For these reasons, the Mountains should be restricted year-round to flying at altitudes under 300 m.

Within the George River range in LLT 1, a small area of upland tundra (Harp Lake) once supported limited calving by the George River population, but has been adandoned since the late 1970's (Dalton and Luttich, 1986). This area should be avoided during late winter. Following the calving period (late-June), or whenever surveys indicate no caribou are present, this area can be reopened to low-level flying.

Monitoring the impacts of low-level flying. Avoiding George River caribou, and winter concentrations of Red Wine caribou, would best be accomplished through satellite telemetry. Once the satellite radiocollars are deployed, periodic location and activity updates are obtained without the necessity for costly, time-consuming, harassing (to caribou) and inefficient aerial surveys. Aerial surveys can be reserved for exceptional situations, when more detailed information on distribution or population parameters is required. For the Red Wine population, sufficient PTT's to monitor all subgroups of the population are necessary, with 20 as the recommended minimum. These should be deployed in late-winter when the Red Wine caribou are concentrated into subgroups, with a minimum of two PTT's per subgroup. The PTT's should be programmed to provide updates on location every 2-4 days, in order to obtain the shortest interval between transmission-days while still ensuring two years of operation. Whatever the chosen transmission cycle, activity data should be obtained for the entire period between transmissions, and should reflect a daily, or finer, temporal scale. PTT's will need to be replaced every two years. A comparable sample of 20 should be collared in the Mealy Mountain population, to provide a baseline against which to measure effects through the research program outline below.

The same recommendations hold for the George River population. Because of its larger size and unknown group structure, a strategy for equitably distributing PTT's among subpopulations must be developed before PTT's are deployed. The animals currently tagged with VI-IF transmitters may be useful in identifying these groupings. At least five-times as many PTT's as are on the Red Wine caribou would be needed to adequately monitor the George River population. The exact number should be determined empirically, once the subpopulation structure is better known. The data obtained from the PTT's will not only allow avoidance measures to be immediate and non-obtrusive, but will also build a database useful in improving mitigation measures in the future, as suggested below.

Research recommendations. Two areas of research are recommended. First, data on movements and habitat use are needed for both woodland and barren-ground caribou. Second, more information is needed on the population dynamics of the woodland caribou, as data gathered during the present study, as well as the continuing lack of growth, suggest that calf survival and recruitment may be lessened as a result of exposure to high levels of overflights. This monitoring should be implemented immediately and continued throughout the next decade, so that changes in behaviour and population dynamics can be tied to changes in low-level flying activity as the number of overflights triples and new programs are instituted (Shank, 1979). The research on woodland caribou should involve both the Red Wine Mountain and the Mealy Mountain populations, in order that valid comparisons between disturbed and undisturbed animals can be made (Geist, 1978). This research should be carried out by or on behalf of the provincial wildlife offices responsible for management of the caribou populations involved.

Research on movements and habitat can follow directly from the use of satellite telemetry for avoiding caribou. As in the monitoring program, a minimum of 20 animals should be outfitted with satellite collars in each woodland population. Because the subpopulation structure and dynamics of the George River population is unknown, neither a minimum nor optimal number of satellite collars can be determined at present. It is recommended that a minimum of 50 satellite collars be deployed during the first year. In subsequent years, this number should be increased so that eventually, each major subpopulation will support a well-distributed sample of about 15 satellite collars. The data collected from the Red Wine animals will indicate whether their habitat and home range use patterns change as a result of increasing exposure to low-level flying activity. In the second case, these data will indicate which areas, or types of areas, are preferred by the Red Wine and George River caribou at particular times of year. In the latter case, vegetation/habitat inventories and topographic information can be combined with this location data to determine the relative importance of LLT 1 habitats for caribou. The data necessary to do this work will be largely at hand.

Research on population parameters will need to be more extensive, as this provides the primary mechanism for quant"itatively determining any negative impacts from low-level flying disturbance (Shank, 1979). Again, the satellite-collared caribou will provide much of the necessary data. First, indices of exposure must be determined for each female, based on her locations and the flight tracks of sorties in LLT 1. It is for this reason that all flight tracks should be recorded and in as much detail as possible. Second, a measure of calf survival for the radiocollared females should be obtained through two or three helicopter surveys at progressively lengthened intervals. The number of surveys should be kept to a minimum, and the quietest aircraft, best pilot and most skilled telemetry technician should be used in order to avoid undue disturbance. Too often, the activities of the wildlife researcher constitute the greatest disturbance factor faced by an animal, and for this reason, traditional calf survival methods employing radio-collared calves are vigorously recommended against. Third, the last survey should be conducted during early winter once the animals begin to congregate and snow makes tracking easy. At this time, classification data should be collected. Finally, in order to detect changes in population size, population estimates should be obtained through intensive aerial surveys every three years, using the stratified random block design (Siniff and Skoog, 1964) . The satellite-collared caribou in the Mealy Mountain population will act as the comparison population for all the above data. If these data indicate that poorer calf survival is correlated to exposure level, or that the Red Wine population as a whole suffers higher calf mortality than the Mealy Mountain population, then further research to identify the causal agents for this higher mortality may be required.

Management Recommendations - Low-level Flying (Component 2)

Component 2 involves the establishment of a NATO Tactical Fighter Centre. Besides some enlargement of LLT 1, and changes to the types of training involved, a number of ground-based additions will be made to both training areas, including both live and inert weapons ranges. Also, a ground facility to house 20 personnel is planned for LLT 1. The total increase in sorties expected to be flown in both training areas under Component 2 is 21 000, more than double that of Component 1 at its maximum. About 15 000 of these would be using the weapons ranges (Anonymous, 1989).

Mitigation. The data gathered during the present study focused on the effects of overflights as now being conducted under Component 1, operating at one-third **its** maximum. Compared **to** the present situation, Component 2 will include (1) six times as many low-level sorties, some in missions of up to 90 aircraft, (2) nearly as many high altitude (>1500 m) "dog fights", **some** involving supersonic speed, (3) three to four times as many helicopter sorties, (4) establishing weapons ranges in LLT 1, (5) creating a permanent field station **in** LLT 1, (6) the dispersal of 3.5 metric tonnes of aluminum **"chaff"** per year, (7) four to five times as many emergency fuel dumps and external tank jettisons, (8) increased probability of wildfire from aircraft crashes or weapons accidents and (9) a doubling of human population in the Goose Bay area. The present study can only address the first three issues. The correlation between overflights and 24-h activity level in **1987,** when specific animals were being sought out, suggest that high levels of exposure, but at lower levels than might be expected in 2001, will increase energy expenditure. The negative correlation between overflights and calf survival suggest that population growth may be reduced at some point in the future. To minimize these potential effects, exposure to overflights must be monitored, and mitigation measures must be developed, refined and followed, using the approach outlined under Component 1. The other issues noted above **were not** addressed directly by the present study, and may be of greater impact on the population dynamics of the caribou than periodic exposure to a low flying jet.

The major permanent threat to caribou populations is loss of habitat (Bergerud, et al., 1984b). Ground-based development in or near sensitive areas thus could adversely affect caribou. The weapons ranges projected for Component 2 are relatively small (325 km^2 each), and must be situated in areas of minimal impact. The potential impact should be evaluated prior to any actual development, based on data obtained from research of the characteristics of habitat presently being utilized by caribou of the George River population, year-round. That is, habitat preferences from all areas visited by the caribou on the Ungava Peninsula should be evaluated so that the relative suitability of habitats in LLT 1 can de determined. It is necessary to look at habitat needs on this year-round basis, as the visitation patterns of George River caribou in LLT 1 may change as the population experiences future changes in numbers. Basing decisions about permanent ground-based development on the animals' current needs, as they are primarily those of late-winter, will present an incomplete picture and may result in the removal of habitat that might be crucial at another stage in their population cycle. For this reason, ground-based developments should not proceed until a full evaluation of caribou habitat requirements, and the ability of LLT 1 to support these, are complete. The same recommendations hold for the siting of the field station. The impacts of noise and activity at these sites needs to be fully explored.

The impacts of chaff, minute (10-80 mm long) strips of aluminum or aluminized fibreglass released to foil radar, are not known for free-ranging caribou. Concentrations are expected to be

50 fibres per m^2 (Anonymous, 1989) . In domestic herbivores, visible chaff was rejected by all species studied (Mackay, 1971; CRESSA, 1978: as cited in Anonymous, 1989), suggesting that caribou may also find vegetation associated with chaff less palatable, resulting in movement to other areas. Consumption of chaff did not harm domestic species, but the effect on nutritionally-stressed lactating female caribou under the burden of insect harassment, or of animals enduring severe winter weather conditions, cannot be simply extrapolated from well-fed domestic animals. Finally, the effects of weather on fibreglass-based chaff need to be documented, as smaller fibres produced through weathering may be more irritating or harmful than the larger fibres released from the jets. Further research is certainly warranted.

Extensive wildfires may also have adverse effects on caribou populations through habitat loss. An estimated 5-6 aircraft accidents per year are expected under Component 2 (Anonymous, 1989) . In addition, fires ignited by weapons, either on the weapons range or elsewhere following accidental discharge, may occur. Although most would be minor, and perhaps ultimately beneficial, a major fire in Red Wine Mountain caribou range could have a significant negative impact because of the population's low numbers. Therefore, fire hazard conditions should be monitored and during critical fire-danger periods, jets should be directed away from or over crucial habitat or areas. In addition, fire fighting capability should be enhanced to deal quickly with any potential situation.

Increased accessibility of caribou habitat to humans is another significant threat to caribou populations (Bergerud, et al., 1984b), as it typically brings increased hunting pressure, both legal and illegal. This threat is greatest for the Red Wine population, not only because that population is small and unproductive, but also because these animals have occasionally shared winter range with George River caribou. Under those circumstances, legal hunting of George River caribou has resulted in losses to the Red Wine population. In one particular instance, 24 Red Wine caribou may have been lost in one case of mistaken identity (M. Berger, pers. comm. 1988). Thus it is crucial that in areas where mixing of populations is known to occur (between 54-55° N in LLT 1), special care be taken to avoid such situations. Because this is likely to be the area where the field station will be located, hunting by any individual, military or otherwise, from a military field facility, should be prohibited.

Finally, the doubling of the human population in Goose Bay within the decade will more than double the present level of hunting pressure, as many of these individuals will be transient construction and military personnel, most of whom are male (Anonymous, 1989). The military personnel and many of the others will be immediately eligible for game licences under Newfoundland and Labrador hunting regulations. The impact of this hunting pressure, both legal and illegal, on the woodland and barren-ground populations could have significant impacts on population dynamics and cause the extirpation of local segments of the caribou population. Although this impact is not directly attributable to low-level jet training activity, it is certainly a consequence of an increase in low-level flight training activities at Goose Bay and is likely to be the most profound, long-term influence on the future of caribou populations in Labrador.

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