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# Short-Term Impacts of Low-Level Jet Fighter Training on Caribou in Labrador

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ABSTRACT. The short-term 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 an initial startle response but otherwise brief overt reaction by woodland caribou on late-winter alpine tundra habitat. Between 1986 and 1988, daily effects of jet overflights were monitored on 10 caribou equipped with satellite-tracked radiocollars, which provided daily indices of activity and movement. Half the animals were exposed to jet overflights; the other 5 caribou were avoided during training exercises and therefore served as control animals. In 1988, the control caribou were from a population that had never been overflown. Level of exposure to low-level flying within the exposed population did not significantly affect daily activity levels or distance travelled, although comparison with the unexposed population did suggest potential effects. The results indicate that significant impacts of low-level overflights can be minimized through a program of avoidance.

Key words: caribou (*Rangifer tarandus*), low-level flying, jet aircraft, helicopters, disturbance, activity, movements, Labrador

RÉSUMÉ. Durant les mois de la saison d'entraînement (d'avril à octobre), de 1986 à 1988, on a étudié les retombées à court terme sur le caribou (*Rangifer tarandus*) de l'entraînement à basse altitude des avions de combat à la base des Forces Armées canadiennes de Goose Bay au Labrador. Des observations visuelles du vol des avions à réaction à basse altitude (à 30 m du sol) ont indiqué que, vers la fin de l'hiver, dans son habitat de toundra alpine, le caribou des bois avait une réaction initiale de surprise, nettement perceptible mais qui ne durait pas. Entre 1986 et 1988, on a surveillé les effets quotidiens du vol des avions sur 10 caribous équipés de colliers-radios suivis par satellite, qui fournissaient quotidiennement des indices de l'activité et du déplacement des animaux. La moitié de ces derniers étaient exposés au vol des avions, les cinq autres étant évités à dessein au cours de l'entraînement pour pouvoir servir d'animaux témoins. En 1988, les caribous témoins provenaient d'un groupe qui n'avait jamais été survolé. Le niveau d'exposition aux vols à basse altitude n'a pas affecté de façon significative le niveau d'activité ou la distance parcourue quotidiennement par la population exposée aux vols, bien qu'une comparaison avec la population non exposée aux vols ait laissé entrevoir des effets potentiels. Les résultats indiquent que des retombées significatives de vols à basse altitude peuvent être minimisées si l'on adopte un programme visant à éviter les animaux.

Mots clés: caribou (*Rangifer tarandus*), vol à basse altitude, avion à réaction, hélicoptères, perturbation, activité, déplacement, Labrador.

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## INTRODUCTION

The continuation and expansion of military low-level flight training activities in northern Canada have increased concern regarding their impact on caribou (*Rangifer tarandus*). Northwest of Goose Bay, Labrador, NATO forces stationed at Canadian Forces Base (CFB) Goose Bay started the present era of low-level jet fighter training in 1981. 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.

The potential effects of this training can be conveniently divided into two classes: short-term behavioural 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 overflights on population demographics and habitat use. The impacts of jet aircraft 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.

The present study was designed to investigate the potential short-term effects of low-level flying activity by fighter-type jet aircraft on caribou. It was hypothesized that disturbance due to low-level flying would be reflected in increased activity levels and by greater daily distances travelled, as animals engaged in escape-related behaviours (running, walking) more frequently following overflights. These effects were measured by watching the behavioural 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 levels, remotely monitored by satellite telemetry. Our adoption of satellite telemetry — a relatively new technology in wildlife studies (Fancy *et al.*, 1988) — is one of its first applications to remotely monitor caribou behaviour and movements.

## STUDY AREA

Within the two areas currently used for low-level training (Fig. 1), flights to within 30 m above ground level (agl) are permitted. Training exercises consist of navigation, evasion and simulated attacks on ground targets, using terrain features to provide cover from radar. Flight speeds are subsonic (typically 775-825 $km \cdot h^{-1}$). The two training areas and CFB Goose Bay are connected by transit corridors, where minimum altitudes of 80 m agl are permitted. The exposure of different sites to low-level flying activity varies substantially within the training areas, ranging from up to 250 flights per month in the southeastern section of the northern low-level training area (LLT1) to fewer than 10 sorties per month in the outer two units.

Our study area included the ranges of three woodland caribou (*R.t.* caribou) populations (Fig. 1). Two small, sedentary populations inhabit the southern portion of the study area. The Red Wine Mountain (RWM) population of about 700 animals inhabits a 23 000 $km^2$ area, which includes the heavily overflown southern portion of LLT1, as well as range to the south. During winter, most members of the population can be found within LLT1, whereas a portion of the population migrates out of LLT1 prior to calving and remains to the south or west of

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the training area until after the fall rut. The Mealy Mountain (MM) population of about 2000 animals inhabits a 22 000 $km^2$ area east of Goose Bay, which is far from both training areas. Topography, climate, vegetation and other range characteristics are similar for both populations. Both ranges have rounded, barren hills supporting alpine tundra, which provide for late-winter forage when deep snow in the surrounding heavily forested plateau limits foraging opportunities and impedes travel (Brown, 1986).

The George River (GR) population of more than 500 000 caribou uses the northern and northwestern sections of LLT1 on a periodic basis, usually during the post-calving period between June and August. Since 1984, the calving grounds have expanded to the south-southwest. Thus, the southernmost 5-10% of the calving ground is now within the northwest corner of LLT1.

## METHODS

### *Study Design*

Two criteria constrained the methods chosen. First, the caribou's exposure to low-level flying (number of overflights) had to be manipulated reliably, as low-level flying over any individual animal was expected to be unpredictable and sporadic in nature. Second, the methods for measuring exposure and response had to be unobtrusive, as disturbance from monitoring overflights and responses could be greater 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.

Visual observation of directed overflights allowed us to record the type and level of response by caribou and to test the

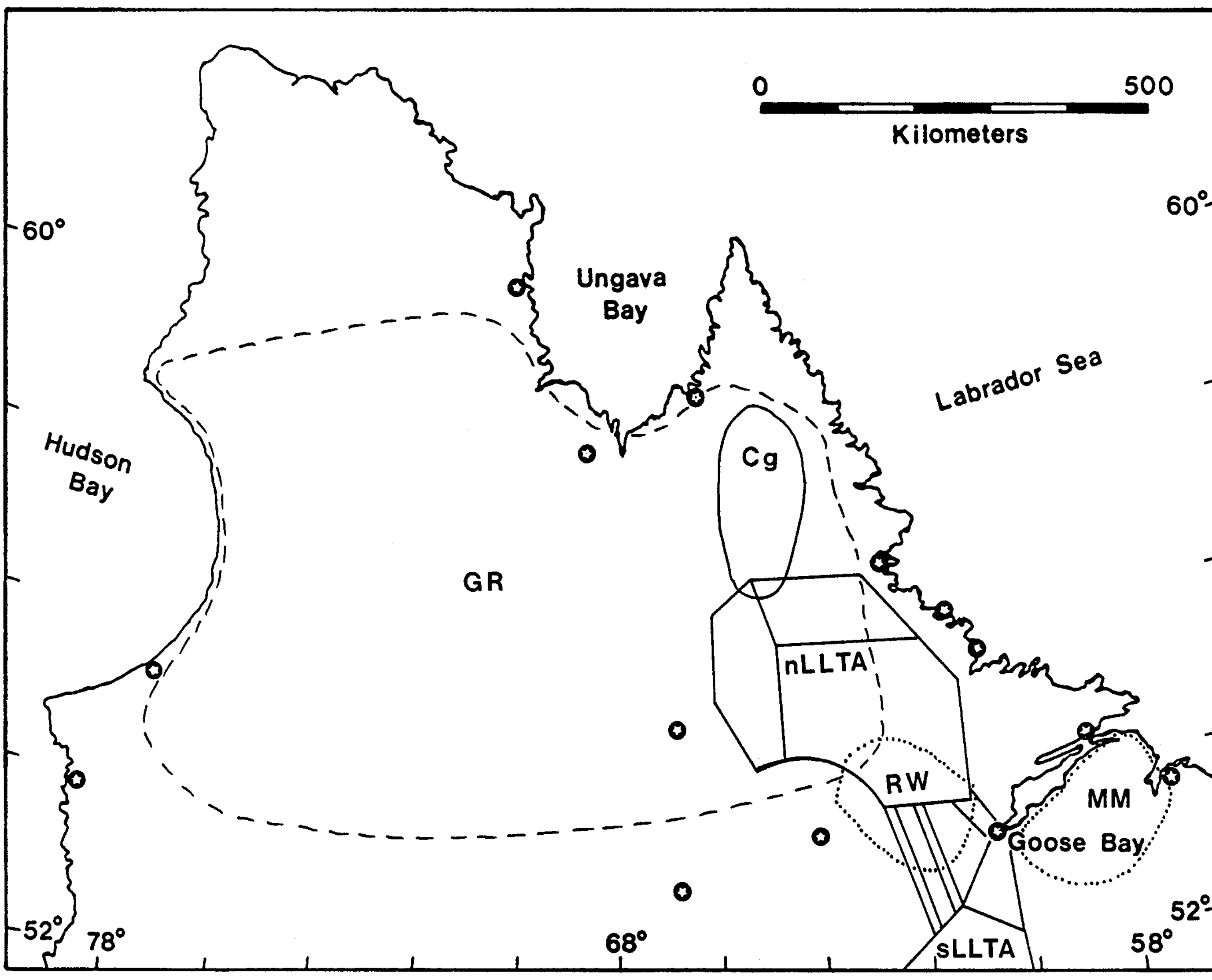


FIG. 1. Map of the study area and approximate ranges of three caribou populations in Labrador and northern Quebec. The George River (GR) population range is indicated by the dashed line. Cg = calving grounds of the GR population. The ranges of woodland caribou are denoted by dotted lines: RWM = Red Wine Mountain population; MM = Mealy Mountain population; nLLTA = the northern low-level training area (LLT1); 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 LLTAs and CFB Goose Bay. Permanent communities are indicated by circled stars.

feasibility of directing overflights remotely over specific caribou. The use of satellite telemetry permitted us to remotely direct aircraft to specific caribou and non-intrusively monitor their responses on a daily basis, which could be compared to a control group consisting of caribou deliberately avoided by aircraft or individuals from a herd not exposed to overflights.

*Observational Approach — Directed Overflights:* Visual observations were attempted in late winter, when caribou were in open habitat where they could be observed without influencing their behaviour. Jets (F-4, F-5, F-16, F-18 and Tornado aircraft) were deliberately directed to fly over the caribou. The field crew, including a forward air controller from CFB Goose Bay, flew by helicopter to the observation area, where they located a suitable group of caribou and vantage point. When a jet neared the rendezvous point, the forward air controller guided the pilot to fly directly over the caribou at normal operational speed (775-825 $km \cdot h^{-1}$) and at minimum altitude (30 m·agl). Usually several jets arrived together and flew over the animals at intervals of less than one to 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). A spotter kept the camera operators appraised of the jet's approach and recorded the moment of overpass, altitude and distance of the jet to the animals, type and air force of jet, and other pertinent data. Caribou responses to overpasses by helicopters also were observed for comparative purposes. These were done before departing the observation site after the last jet overpassed. Helicopter overflights were conducted at typical cruising speed (150 $km \cdot h^{-1}$) and altitudes of 30-150 m.

Videotapes were analyzed using a Panasonic AG-1830 VCR. For the RWM caribou, the time of first response relative to the moment of overpass was determined. Initial responses included: standing (for lying caribou); head-up (for lying or feeding caribou); and changes in movement (for feeding, standing or walking caribou). If the animals moved or accelerated their movements, the duration and distance of movement were measured until movement either stopped or returned to pre-overflight levels. Distances were estimated in body lengths (BL = 1.5-2.0 m), as an independent measure was not available. Duration and distance data were log-transformed before multiple regression analyses were performed. Group identity, composition (cows plus 11-month-old calves only, bulls only and mixed sex/age groups), size and behaviour prior to overflight were used as independent variables. For the GR caribou, distances (BL) moved by randomly selected samples of 20-40 caribou were determined for each 5 s period, beginning 5-20 s before and ending up to 20 s after the overpass. For each period, half the animals were taken from a 100 m wide strip under the jet's flight path, while the other half came from beyond this region.

*Remote Monitoring of Overflights:* We used satellite telemetry (Fancy *et al.*, 1988) to manipulate and measure the daily level of exposure and responses to low-level flying of each study animal. Satellite telemetry remotely provided daily relocations and an index of the animal's total activity level during the preceding day. Using the locations, we could remotely direct jet aircraft either toward or away from an animal's location. By manipulating exposure levels among animals, we could then evaluate the relationship between exposure to aircraft and a caribou's subsequent daily movement and activity level.

The satellite platform transmitter terminals (PTT) (Telonics, Inc., Generation ST-2 and ST-3) broadcast a brief (250 ms) digital signal once each minute. These signals are received by polar-orbiting satellites whenever the PTT is within view and relayed to Service Argos processing centres. To conserve battery power, our PTTs broadcast for 8 h each day.

Locations provided by Service Argos, although precise to 0.001° for both latitude and longitude (roughly 100 and 65 m respectively), vary in accuracy. Three levels of "guaranteed" locations average within 1 km of the true location (Harrington *et al.*, 1987; Fancy *et al.*, 1988). In 1988, a fourth "non-guaranteed" location index was added. These non-guaranteed locations are sometimes accurate but other times err by tens to hundreds of kilometres. To minimize locational errors, we used only the best daily location, chosen first on the basis of the quality index assigned by Service 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, generated by a mercury switch within the PTT (Fancy *et al.*, 1988), discriminates well among running, walking and lying/feeding (S. Fancy, pers. comm. 1989). Although variation in the installation angle of the switch may cause systematic differences in the index among individuals (S. Fancy, pers. comm. 1989; M. Ferguson, pers. comm. 1989; A. Gunn, pers. comm. 1989), the long-term activity index does provide a reliable index of relative activity for each individual caribou.

Satellite collars were deployed in April or May and were retrieved in December, at the beginning and end of the low-level flying season respectively. Adult female caribou were captured from helicopters using a $CO_2$ darting pistol. Either etorphine (1986) or carfentanil (1987-88) combined with xylazine or acepromazine were used as immobilants; these were reversed with diphrenorphine or naloxone. In May 1986, we attempted to recapture RWM caribou originally collared in 1982-83 (Brown, 1986), both to expedite locating animals already dispersed in the lowlands and to capitalize on their known histories. In April 1987 and 1988, we attempted to recapture RWM animals that had utilized suitable areas in past years. In 1988, we recaptured MM caribou that had been initially outfitted with VHF collars in 1985.

In 1986 and 1987, the 10 satellite collared caribou were divided into exposure and control groups. Each day, the most current location was obtained for the collared caribou and relayed to each NATO air force as either "target" (exposure group) or "avoidance" (control group) coordinates. We requested as many overflights for each target coordinate as possible. Conversely, jets were requested to stay at least 9.2 km away from avoidance coordinates. Following a sortie, the pilot reported the time, speed and altitude of all target coordinates flown. Field-truthing exercises, in which observers were stationed at either target or avoidance sites, were conducted in 1986 and 1987 to measure the reliability of directing overflights toward or away from the study animals.

In 1988, the design was changed and flights were not regulated throughout LLT1, so that a "normal" distribution of exposure to low-level flying could be obtained. The number of jets passing within 1 km of each caribou was estimated from the records of all flight tracks flown in the low-level training areas during 1988. The flight tracks were derived from the aircraft's turn coordinates, which were generated either by onboard computers or were recorded by hand from topographic maps. All animals in LLT1 would be considered exposure animals but would differ in their level of exposure to low-level flying primarily due to geographical differences in low-level flying activity.

We chose the control caribou in 1988 from the MM 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 and 3) under the 1988 study procedures, it was not 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 present and historical range of low-level flying aircraft.

### *Data Analyses*

*Exposure to Overflights:* The primary independent variable was the measure of the caribou's daily exposure to low-level flying. In 1986 and 1987, this was simply the total number of reported overflights each day. In 1988, an overflight was defined as a jet within 1 km of the caribou's location. This radius was chosen to account for the inherent error in our estimate of the caribou's location, any movement that occurred since that location had been fixed, navigational error on the part of the pilot and because 1 km is similar to the accuracy of reported overflights in 1986 and 1987.

Although military jets vary in their noise output, we did not control for this variation because 94% of all sorties are flown by aircraft similar in noise output (Department of National Defence, 1989). In a study of low-level overflights conducted near CFB-Goose Bay, F-4s (41% of all sorties) and Tornadoes (30%) did not differ significantly in peak noise level (Canadian Public Health Association, 1987). Two other jets flown at CFB-Goose Bay are similar to either the F-4 (F-18: 3% of sorties) or the Tornado (F-16: 20% of sorties) in noise output (Department of National Defence, 1989). The smaller and quieter Alpha-jet accounted for only 6% of all sorties flown. Uncontrolled variation in altitude, attitude, air speed, engine power, masking noise and topographic features, as well as distance to the caribou, are expected to have a greater influence on sound level than is aircraft type for the present study.

*Response to Overflights:* The two variables used to estimate the effects of exposure of a study caribou to low-level flying activity were daily activity level and daily distance travelled. The PTT 24 h activity index is suitable to compare daily variation in activity for an individual caribou. Daily distance travelled was the distance between the two highest quality locations on successive days. Daily distance was not normally distributed and was log-transformed for all statistical analyses. Seasonal variables modifying caribou activity and movements included Julian day, month and season. The variable season comprised the pre-calving, calving, insect and fall periods. The pre-calving period ran from the date of capture in April or May to 22 May and included time on the late-wintering areas in the Red Wine or Mealy mountains, as well as spring dispersal into the surrounding lowlands. The calving period was from the date of earliest suspected calving (23 May) to 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). The insect period was from the last day with sub-freezing temperatures in the spring to the first day with sub-freezing temperatures in the late summer. The fall period followed the insect period and continued until low-level flying activity ceased. Temperature data were from Environment Canada in Goose Bay, Churchill Falls and Cartwright.

Other variables were the identity of the female and the presence of a calf. Calf survival was determined by periodic aerial surveys starting in mid-June in 1987 and 1988. Each female was located by helicopter every 3-4 weeks and briefly driven from cover (if necessary) so her 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. The 12 weather variables for each caribou population are highly correlated and redundant. Therefore, a Principal Components Analysis using a varimax rotation was conducted for the RWM population using all April-October weather data collected in 1986-88 (N=642 days) and only the 1988 data for the MM population. The analysis isolated three principal components for each set of data (Harrington and Veitch, 1990): factor 1 (temperature) was an indicator of temperature; factor 2 (precipitation) was a combination of precipitation, barometric pressure and hours of sun; and factor 3 (wind) largely comprised wind speed and atmospheric pressure. These three normalized weather factors were used to examine the relationship of weather to activity and movements.

*Regression Analysis:* The daily influence of low-level flying activity was examined using regression analysis on the set of variables. 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 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.

### *Overflight Stimulus*

To characterize the sound of a low-level overpass, audio recordings of overpasses were collected on two days in 1986 using a Nagra Model 4.2 reel-to-reel tape recorder at 38 $cm \cdot s^{-1}$ and 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. Peak sound pressure levels were measured by a Bach-Simpson Model 886 Sound Level Meter, using the fast setting on the C scale.

## RESULTS

### *Overflight Observations*

*Red Wine Mountain Caribou:* Observations of overflights were conducted in the Red Wine Mountains on 13 April 1987 and 28 and 29 April and 5 May 1988. The terrain of heavily glaciated hills with only low boulders and alpine tundra gave little protective cover. Most caribou were observed at distances of 500-750 m, and visibility was several kilometres.

A total of 40 overpasses were flown over eight groups of caribou (Table 1). High (300 m agl) or wide (>75 m) overpasses caused detectable responses only 38% of the time (N=16 overflights). Direct overflights (30 m agl and within 50 m of the animals), on the other hand, resulted in overt responses significantly more often (88% of the time [N=24]; G-test, P<0.001). The median time to react (0 s) was presumably in response to the most intense sound of the overpass. Eleven of 21 direct overflights began with startle responses, in which caribou suddenly scrambled to their feet and/or bolted several body lengths away, coincident with the jet's overpass. Eight of 10 responses that began prior to the jet's pass occurred when caribou sighted the jet at a distance.

Although caribou usually began to run after their initial response (22 of 27 overflights), they began slowing almost immediately. The median time from beginning to end of movement was 9 s, with the last half of this period done at a slow walk. If animals had been feeding, standing or walking prior to the overpass, they resumed similar behaviour within the next minute (13 of 15 overflights). Animals that had been lying before the overpass usually continued to stand for at least a minute following the overpass (10 of 12 overflights). However, during the next several minutes, animals either began to feed or lay down again, and by 5-10 min after the last overpass, behaviour had returned to pre-overflight level.

A multiple regression analysis, using data from direct overflights (N=24), indicated that only behaviour prior to the overpass was significantly correlated with the level of response (Table 2). When caribou were walking prior to the overflight, they reacted sooner (P<0.05) and ran longer (P< 0.05) and farther (P<0.01) than did caribou that were feeding/standing or lying prior to the overpass. Group identity (P>0.7), composition (P>0.6) and size (P>0.1) were not systematically related to any response variable.

One series of seven overpasses by a Bell 206L helicopter was flown at 30 m agl over a group of eight adult male caribou in 1987: the group had not been overflown by jets earlier that day. These animals were travelling at a walk prior to the overpasses. In 1988, three helicopter overpasses were flown 15 min after the last of eight jet overpasses over a group of eight bulls. Prior to the helicopter overflights, the animals were either bedded or feeding. In all cases, every caribou reacted prior to the helicopter's passing (Table 1). The animals sighted the helicopter and trotted or galloped directly away from its path. They continued to gallop hard until the helicopter passed overhead, when they turned to the side and slowed their pace. The animals continued to move for another 8-27 s after the helicopter passed and moved a total of 22-180 body lengths.

The group overflown on the same day by both jet and helicopter aircraft responded significantly sooner to the helicopter and ran significantly longer and farther than it did in response to the jets (Mann-Whitney U: P<0.05).

*George River Caribou:* Observations of jet overflights of a group of approximately 500 GR caribou on upland tundra were videotaped on 13 May 1988. A steep ridge provided us with a panoramic view of the caribou in a relatively flat valley 30 m below. Hard, crusted snow covered 70-80% of the ground. Three independent surveys (total caribou = 276) indicated an average composition of 58% cows; 19% 11-month-old calves; 23% bulls.

Between 1250 and 1302 h, six series of a total of 13 overflights by F-16 aircraft were observed (Table 3). The jets arrived in the area in groups of two and three and were directed individually over the centre of the caribou group at intervals of 6-22 s. During the first three series, when many caribou (30%) were still lying, only 15% (N=60) reacted before the initial overpass of each series. During the last three series, when all animals were standing, feeding or walking, an average of 50% (N=115) reacted prior to the overpass. However, the absolute level of this reaction was low; the maximum distance moved prior to a series of overflights was 10 BL (15-20 m) and the mean was 2 BL (3-4 m).

Most caribou (70%; N=260; 13 overflights) reacted suddenly, scrambling to their feet and bolting forward as the jet passed. Although 90-95% of the caribou began to run, most began slowing shortly after the overpass. Fifty-five percent stopped moving within 5 s, and 65% had stopped within 10 s of the overpass, unless another jet passed over in the meanwhile. Total median distance moved during a single overpass was 8 BL (12-16 m), ranging to a maximum of 34 BL (50-68 m) for the second overpass in a series of two.

Caribou within 50 m of the jet's flight track moved a greater distance in response to an overpass than those farther away (9.9±1.8 m vs. 4.2±2.3 m; 9 overflights/360 caribou; Two-way Anova: P<0.001). All caribou within 50 m of the flight track ran, but 7% (N=180) of those animals 50-100 m from the flight track did not run.

Five overpasses were flown by an A-Star 300D helicopter one hour after the last set of jet overpasses. Most (90%) caribou on snow-free ground were feeding, while those on snow were either standing or walking. The caribou began to run 10-20 s prior to an overpass and the median animal had moved a

TABLE 1. Summary of response parameters of Red Wine Mountain caribou to low-level jet and helicopter overflights in the Red Wine Mountains in 1987 and 1988 (raw data in Harrington and Veitch, 1990)

| | Group data | | Responses to direct overflights[a] | | | | Responses to high or wide overpasses[b] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Aircraft | Size | N | Latency[c] | Duration[d] | Distance[e] | R/TO[f] | Latency | Duration | Distance | R/TO |
| Jet | 4-33 | 8 | 0 | 10 | 12 | 21/24 | 0 | 4 | 6 | 6/16 |
| Helicopter | 8 | 2 | –8 | 19 | 85 | 8/8 | –4 | 19 | 31 | 2/2 |

[a]Direct overflights: 30 m altitude and ≤ 50 m to side.
[b]High and wide overflights: > 50 m altitude and/or > 50 m to side.
[c]Median latency (s) is measured relative to the overpass ( 0 s = overhead).
[d]Median duration of movement in seconds.
[e]Median distance moved is expressed in caribou body lengths (1.5-2.0 m).
[f]R/TO = number of overflights with overt responses/total number of overflights.

distance of 83 BL (125-150 m) before the helicopter passed overhead (Table 3). After the helicopter passed, the animals turned and ran back opposite their initial direction. Although they now ran at a slower pace, the median animal still moved another 36 BL (55-70 m) over the next 20 s.

GR caribou ran longer and farther in response to helicopter overpasses than to jet overpasses (N=18 overflights; Anova: P<0.001). The greatest total median distance moved in response to a jet was 34 BL (50-68 m). This was exceeded by every helicopter overpass by a factor of two or more. Caribou also ran harder from the helicopter. The maximum rate of movement per 5 s period during an overpass was more than 45 BL (68-90 m) for the helicopter, but only 28 BL (42-56 m) for the jets, while the median maximal rates of movement were 39 and 6 BL respectively. Seventy percent of the response to the helicopter occurred prior to the overpass, whereas nearly all the response to jets occurred after the overpass.

*Field-Truthing of Directed Overflights*

Observers placed at five dummy target sites in 1986 recorded a total of 59 jets. Mean distance of jets from the target coordinates was 225±262 m (N=33 jets). Forty-two percent passed within 50 m of the target. Only 54% of observed overflights were reported by pilots, indicating that exposure of target caribou to overflights in 1986 may be underestimated by half due to underreporting by pilots. However, an analysis of jet flight track data, caribou locations and overflight reports indicated that overflight report data and flight track data were highly correlated (r=0.89; P<0.01). Therefore, overflight reports do provide a reliable index of relative exposure to low-level aircraft activity.

In 1987, 56 jets were observed at 7 target sites. Mean distance from target was 170±263 m (N=52) and 60% of jets were within 50 m of the target. Significantly more overflights were reported in 1987 (82%) than in 1986 (G-test; P<0.01), following a more rigorous procedure for reporting instituted in 1987. Virtually all (40 of 42) reported overflights were observed by us in the field.

Observers stationed near four avoidance sites recorded a total of six jets (out of a possible 64) within the surrounding 9.2 km control zone. Their mean distance from the avoidance coordinates was 3.6±1.3 km, and no jet passed within 2 km of the avoidance site, indicating that control caribou locations were being avoided successfully.

TABLE 2. Relationship between level of response to low-level jet overpasses and behaviour of caribou prior to the overflights

| Behaviour prior to overflight | N[a] | Latency (s) Median | (range) | Duration (s) Median | (range) | Distance (BL) Median | (range) |
|---|---|---|---|---|---|---|---|
| Lying | 10 | 0 | (–4,+6) | 5 | (0-23) | 4 | (0-30) |
| Feeding/standing | 8 | 0 | (–2,0) | 7 | (0-25) | 8 | (0-62) |
| Walking | 6 | –4 | (–7,–1) | 18 | (15-24) | 51 | (23-80) |

[a]N = number of overflights.

*Remote Monitoring of Overflights*

A total of 18 RWM and 4 MM caribou were captured, equipped with PTTs, and monitored between 1986 and 1988 (Table 4). 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 travelled for 74% of days. Activity indices were obtained on 97% of possible days.

*1986 and 1987 Low-Level Flying Seasons:* In 1986 and 1987, both daily activity levels and distances moved varied nearly twofold among the animals (Tables 5 and 6). The variation in exposure to overflights was similar in 1986 and 1987, ranging from none to 4.5 per day among the caribou. The two caribou exposed to the greatest number of overflights had intermediate values for both daily activity and distance travelled in 1986. The two most overflown animals in 1987 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 travelled.

*1988 Low-Level Flying Season:* Flight track data from 83% of the sorties flown during 1988 indicated that exposure levels varied more than tenfold among the RWM caribou (Table 7). Two animals had an average of one jet or more per day within 1 km of their location, whereas the other three were exposed only once every 2.5-10 days. Mean activity indices and daily distances travelled for RWM animals were similar to previous years (Anova: df=2,22; P>0.8 and 0.1 respectively), and neither variable was correlated with an animal's exposure to overflights (Anova: df=2,22; P>0.4 and 0.9 respectively). For MM caribou, mean activity indices and daily distance travelled were less than those obtained for the RWM animals in 1988 (Table 7) but were similar to RWM animals in previous years (activity in 1987; daily distance in 1986). Overall, MM caribou moved less on a daily basis in 1988 than did RWM caribou over the three years they were followed (Anova: df=1,27; P=0.049), but the two population samples did not differ significantly in mean daily activity level (Anova: df=1,27; P>0.3).

TABLE 3. Median distance moved by George River caribou during overflights by jet and helicopter aircraft on 13 May 1988 (summarized from Harrington and Veitch, 1990)

| | | Interval in relation to overflight[a] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Aircraft | N[b] | –20 s | –15 s | –10 s | –5 s | +5 s | +10 s | +15 s |
| Jet[c] | 13 | — | — | — | 0[d] (0-13) | 6 (0-15) | 0 (0-10) | 0 (0-4) |
| Helicopter[e] | 5 | 15 (0-23) | 12 (1-27) | 18 (15-30) | 38 (14-45) | 23 (2-38) | 8 (0-39) | 2 (0-17) |

[a]Negative intervals immediately preceded the overpass; positive intervals followed the overpass.
[b]N = number of overflights.
[c]Altitude of jet overflights varied between 25 and 60 m (median = 30 m).
[d]Median distances moved are measured in caribou body lengths (1.5-2.0 m), with the range in parentheses. Each individual overflight median is based on sample of 20-40 caribou (jets) or 8-24 caribou (helicopter).
[e]Altitude of helicopter overflights varied between 30 and 150 m (median = 90 m).

*Regression Analyses of Activity and Daily Distance Travelled:* The 24 h activity index and daily distance travelled are correlated variables, as directional movement is one component contributing to the total activity index. Thus daily distance was one of the predictor variables used in the regression analysis for the 24 h activity index (but not *vice versa*).

Few variables were significantly related to the daily distance travelled by the animals (Table 8). In general, daily distance was lowest during the calving period, highest in the insect and fall periods, and also increased after a female had lost her calf. When the RWM and MM data sets 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 travelled each day.

For the 24 h activity index, daily distance travelled accounted for about 15% of the variance (Table 8). Temperature, a weather component, accounted for another 5%, while season, individual and calf survival together accounted for an additional 5%. The activity index was positively correlated to temperature and was 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. The index was lowest during the calving period and was lower for females accompanied by calves. MM caribou had lower 24 h activity indices, even when their shorter daily travel rates were taken into account. In all, these variables accounted for 20-32% of the variance in the 24 h index.

TABLE 4. Red Wine and Mealy Mountain caribou followed with satellite telemetry between 1986 and 1988

| Caribou[a] | Age[b] | Initial capture[c] | # recaptures | PTT-years[d] | Comments[e] |
|---|---|---|---|---|---|
| RWF013 | 9 | 03/19/82 | 6 | 3 | PTT-F (88/296) |
| RWF016 | 8 | 03/20/82 | 3 | 2 | PTT-F (87/114) |
| RWF035 | 7 | 03/27/83 | 2 | 1 | |
| RWF037 | 7 | 03/26/83 | 5 | 2 | PTT-F (88/250) |
| RWF039 | 12 | 05/09/86 | 2 | 2 | |
| RWF040 | 12 | 05/09/86 | 1 | 1 | |
| RWF041 | 9 | 05/09/86 | 0 | 1 | Mort. (86/235) |
| RWF043 | 14 | 05/09/86 | 1 | 1 | |
| RWF044 | 14 | 05/12/86 | 3 | 2 | PTT-F (87/273) |
| RWF045 | 12 | 05/15/86 | 1 | 1 | PTT-F (86/177) |
| RWF046 | 10 | 04/04/87 | 1 | 1 | |
| RWF047 | 3 | 04/05/87 | 1 | 1 | |
| RWF048 | 5 | 04/05/87 | 1 | 1 | |
| RWF050 | 6 | 04/10/87 | 1 | 1 | |
| RWF051 | 9 | 04/05/87 | 1 | 1 | |
| RWF052 | 3 | 04/05/87 | 3 | 2 | |
| RWF053 | 2 | 04/07/88 | 1 | 1 | PTT-F (88/279) |
| RWF055 | 1 | 07/04/88 | 1 | 1 | |
| MMF001 | 8 | 04/10/85 | 1 | 1 | Mort. (88/224) |
| MMF002 | 6 | 04/02/85 | 2 | 1 | |
| MMF003 | 12 | 04/10/85 | 2 | 1 | |
| MMF004 | 3 | 04/20/85 | 3 | 1 | PTT-F (88/106) |

[a]Caribou: RWF = Red Wine Mountain female; MMF = Mealy Mountain female.
[b]Age calculated as of assumed birthdate in 1986.
[c]Caribou captured prior to 1986 were initially outfitted with VHF collars.
[d]PTT-years = number of low-level flying seasons wearing PTT.
[e]PTT-F = PTT failure; Mort. = Mortality. Year and Julian day of death are given in parentheses.

TABLE 5. Summary of daily data collected for satellite-collared Red Wine caribou during the 1986 study season

| Caribou | Activity index | Distance travelled (km) | Overflights reported |
|---|---|---|---|
| RWF013 | 141±56[1] (171) | 2.8±2.2 (101) | 3.4±5.3 (165) |
| RWF016 | 208±68 (170) | 3.4±2.5 (87) | 0.1±0.6 (165) |
| RWF035 | 122±47 (153) | 3.0±2.3 (74) | 0.1±1.3 (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±73 (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) |

[1]Mean ± sd (number of days).

TABLE 6. Summary of daily data collected for satellite-collared Red Wine caribou during the 1987 study season

| Caribou | Activity index | Distance travelled (km) | Overflights reported |
|---|---|---|---|
| RWF013 | 98±46[1] (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) |

[1]Mean ± sd (number of days).

TABLE 7. Summary of daily data for satellite-collared Red Wine and Mealy Mountain caribou during the 1988 study season

| Caribou | Activity index | Distance travelled (km) | Overflights (# jets < 1 km) |
|---|---|---|---|
| Red Wine Caribou | | | |
| RWF013 | 138±62[1] (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) | 0.3±1.8 (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) | — |

[1]Mean ± sd (number of days).

TABLE 8. Contribution of predictor variables to the variance in the daily distance travelled and the 24 h activity index, as determined by multiple regression

| Predictor variable | 1986 season % explained | 1986 season P[a] | 1987 season % explained | 1987 season P | 1988 Red Wine % explained | 1988 Red Wine P | 1988 Mealy Mountain % explained | 1988 Mealy Mountain P |
|---|---|---|---|---|---|---|---|---|
| Dependent variable = daily distance travelled | | | | | | | | |
| Individual | — | | 0.9% | 0.002 | 2.1% | <0.001 | — | |
| Calf survival | — | | 0.4% | 0.013 | — | | — | |
| Julian day | 4.1% | <0.001 | — | | — | | — | |
| Month | 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[b] | | 0.3% | 0.033 | 1.0% | <0.001 | — | |
| Overflights | — | | 3.5% | <0.001 | — | | na | |

[a]Only those values significant at p < 0.05 are shown.
[b]na = not applicable.

Overflight exposure was significantly correlated with activity level only in 1987.

*Overflight Stimulus*

Regression analysis of 52 low-level overpasses, using altitude, horizontal distance and aircraft type as independent variables, indicated that noise level decreased 6.9 dB every 100 m from the jet's flight path (r=–0.817; P<0.001) (Fig. 2). Sound level also decreased at the rate of 5.9 dB per 100 m altitude. Aircraft (F4 and Tornado jets only) did not differ significantly in noise level (P>0.1). The maximum noise level recorded was 131 dB for a direct overpass at 30 m agl, and mean noise level for close overpasses (within ±30 m of flight track) was 115±8 dB.

Noise level increased rapidly as a jet approached, rising from ambient levels to a maximum in about 1 s. Sound level dropped immediately after the jet passed over but did not return to ambient levels for another 10 s or more. The noise was broadband, with peak amplitudes between 1 and 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 it was overhead, but on windy days, especially when surrounded by trees, we had little warning of an overpass.

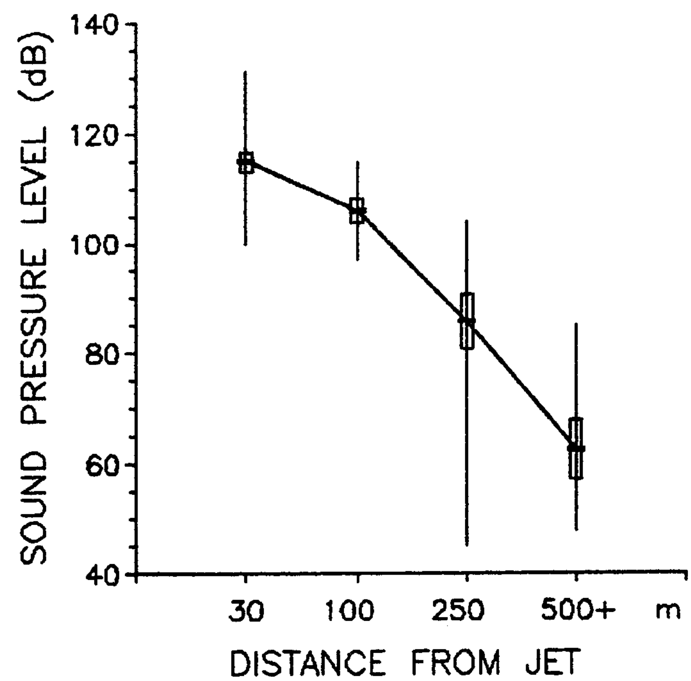


FIG. 2. Mean sound pressure level (dBc) of F4 and Tornado jet overpasses are shown as a function of mean distance from flight track. Vertical bars connect minima and maxima; boxes enclose standard errors of the mean; horizontal dashes indicate the mean.

DISCUSSION

*Behavioural Response to Overflights*

Our observations indicate that the initial response of caribou to a low-level jet aircraft is caused by the sound of the overpass, not the sight of the jet. The usual response to a sudden, intense noise is the "startle reflex," with its concurrent activation of the sympathetic nervous system (Moller, 1978). Direct overpasses will produce sounds with the most rapid rise times and highest peak levels and thus should cause the most intense startle reactions. In addition, due to the reflex nature of the response, habituation to such stimuli is not likely. Overpasses displaced from the animals have both slower rise times and lower peak levels, and consequently would be less startling.

Startle responses may be especially detrimental to caribou during calving, causing problems such as stillbirths, cow-calf separations or injuries to newborn calves (Banfield, 1974; Cowan, 1974; Miller and Broughton, 1974; Miller *et al.*, 1988). Panicked cows and calves during thaw could result in calves mired in wet snow. Startle responses may have more subtle effects, such as reduced milk production (Ely and Peterson, 1941) and calf thyroid function (Ames, 1971). Possibly, calves exposed to frequent overflights may grow slower and could consequently suffer higher mortality from increased predation, inability to cope with inclement weather or the energetic demands of summer movements and insect harassment.

Startle reactions may also be detrimental where sudden movements can result in injury because of rugged topography, especially when ice cover reduces traction. Injuries are also possible when animals are congregated in groups, especially when constrained by deep snow, river crossings or icy ridges.

Following the initial startle, the animals' responses followed a time course 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, which suggests that the visual image of the jet becomes an important focus after the initial startle. Within the first minute following an overpass, most animals appeared to relax their vigilance (e.g., lie down or lower head and feed) and resumed former activities within several minutes of the overpass. On those occasions when caribou could watch an approaching jet, the animals reacted before the pass, thereby running a longer period. These more prolonged responses are to be expected in open habitat, as caribou in forested habitats are unlikely to see jets, except briefly as they recede.

The slower air speed of the helicopter gave advance warning of its approach and thus reduced the startle impact. The caribou began to run sooner and ran significantly longer than during jet overpasses. Following a single helicopter overpass, the animals were displaced farther than for jet overpasses. The longer overpass time and the visual stimulus of a helicopter suggests that they may cause greater avoidance responses in caribou 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 (e.g., capturing/collaring, classification surveys). Caribou that are pursued by helicopters may learn to associate helicopters with the threat posed by predators, intensifying the response with the reinforcement of periodic exposure.

*Impact of Low-Level Flying on Energy Expenditure*

The 24 h activity index appears to be the most valid of our two daily measures of impact. First, this index was significantly and consistently correlated to a number of biologically relevant variables. Second, it is an absolute measure of head movement that is related in predictable ways to standard measures of activity (running, walking, feeding/resting). The other dependent variable, daily distance travelled, has a significant amount of error (20-40%) on the scale of movements made daily by woodland caribou (2-4 km·day$^{-1}$). Also, when movements are not strongly directional, daily distance will underestimate actual distance travelled. The location data are better suited to analyze home range use, which is a more valid indication of long-term disturbance (Harrington and Veitch, 1990).

Neither the 24 h activity index nor the daily distance travelled was 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.

Heart rate telemetry, however, shows that heart rate often stays elevated after any initial overt response has ended (Kanwisher *et al.*, 1978; Moen *et al.*, 1978; MacArthur *et al.*, 1979). 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. However, the energy expenditure associated with an elevated heart rate, in the absence of an overt behavioural response, is equivalent to moving only a few body lengths (Floyd *et al.*, 1988). The one significant correlation between exposure to overflights and daily 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 percentage points in overall activity level may occur, consistent with Geist's (1971) calculations on the costs of harassment in caribou.

*Overall Impacts of Low-Level Jet Overflights*

Our results indicate that the greatest impact of low-level flying jet aircraft will be due to the startle reactions caused by the loud and sudden noise of low, direct overflights. 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 (7 dB/100 m) as distance from the flight track and jet altitude increased. Beyond 250 m from the jet's flight path, the mean sound pressure level for jet overpasses was under 90 dB, which is less aversive in domestic and wild mammals (Manci *et al.*, 1988). Thus, the "disturbance footprint" of an overpass is probably confined to a width of less than 500 m. As most low-level training flights are at 30-150 m agl (Department of National Defence, 1989), however, every jet still has the potential to disturb caribou within this 500 m corridor.

Data collected in 1988 on satellite-collared caribou and jet flight tracks indicate that overflights close enough to elicit startle responses by caribou are infrequent under present levels of flying. The animal designated as 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 500 m wide "disturbance corridor" once every eight days, on average. For other caribou, the frequency of such overflights was much less. However, it is possible that under the higher levels of low-level flying activity expected by 1996, some caribou may be exposed to an unacceptedly high number of overflights during sensitive periods. Any potentially adverse impacts could be minimized by monitoring jet flight paths through the Red Wine population range, so that excessive exposure of specific areas can be avoided, particularly during the calving period.

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