

PRELIMINARY EVALUATION OF GPS COLLARS FOR ANALYSIS OF HABITAT USE AND ACTIVITY PATTERNS OF BLACK BEARS

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Abstract: Prototype radiocollars incorporating global positioning system (GPS) receivers were attached to 8 adult female black bears (*Ursus americanus*) in March (5) and June–July (3) of 1994 in northern Ontario, Canada. Collars contained a 6-channel GPS receiver, an independent very high frequency (VHF) tracking beacon, an activity sensor, and a computer–memory module. The total package weighed 1.3 kg. The GPS receiver accessed the coarse/acquisition (C/A) code, so accuracy of system horizontal position was expected to be 100 m (i.e., 95% of fixes will be within 100 m of true position). To test the accuracy of location estimates, an additional collar was placed at a reference location during the study period. Units were set to acquire GPS fixes at 3-hour intervals and stored latitude, longitude, time, date, fix quality (horizontal dilution of precision, [HDOP]), fix status (no fix, 2-dimensional [2D], or 3-dimensional [3D] fix), and activity count information in a memory module. Projected life of the unit was 4.5 months with storage capacity for a minimum of 1,000 records. One collar malfunctioned, 1 collar was not recovered, and 2 bears died of natural causes before significant data were acquired, but 4 collars successfully acquired data from 15 June to 13 August 1994. Two collars were recovered from live-trapped bears in September 1994, and 2 were recovered during routine den visits in March 1995. There were no detectable collar-induced injuries, nor any detectable difference in behavior compared to bears with conventional radiocollars. Three of the females successfully raised cubs to the yearling stage by March 1995; the fourth female had a normal litter of cubs-of-the-year in March 1995. The reference collar acquired fixes 99% of the time with 95% confidence intervals for the locations of 73 m on the east–west axis and 103 m on the north–south axis, with no bias away from the reference location. Collars on 3 bears in open habitat (recent burns, young forest stands) acquired fixes 50%, 50%, and 65% of the time, whereas the collar on the bear under more closed canopy acquired fixes only 32% of the time. However, the fine-grained analysis of fixes and satellite-derived landcover did not show a significant difference between the fixes obtained by GPS and conventional radiotelemetry under different landcover types.

Ursus 10:209–217

Key words: black bear, global positioning system, GPS, habitat, Ontario, radio telemetry, *Ursus americanus*, wildlife tracking.

The pattern of extensive movements of black bears to seasonally abundant food sources throughout the species' range requires that we manage black bear habitat at the landscape scale (Schoen 1990). Although black bears appear to move across the landscape in a coarse-grained manner, they likely sample locally abundant, high-quality food resources in a fine-grained way. Thus, researchers investigating habitat use by black bears should do so at multiple temporal and spatial scales.

Patterns of habitat use by black bears have been investigated for more than 25 years across almost the entire range of the species from Florida (Maehr and Brady 1984, Mykytka and Pelton 1990) to Alaska (Schwartz et al. 1987). This is because habitat quality has a major influence on population growth through the correlation between condition of females and their reproductive success (Bunnell and Tait 1981, Rogers 1987, Elowe and Dodge 1989). Most recent studies of habitat selection by black bears have relied on information obtained from radiocollared bears and have mainly examined first- and second-order habitat selection (Johnson 1980). Study of third-order selection, the use of habitats within the home range, is complicated by the size of the error polygons relative to the size of the resource patches the animal is

selecting. The ability to detect habitat selection through conventional radiotelemetry locations is limited by increasing habitat complexity, decreasing precision of triangulation bearings, and decreasing sampling effort (White and Garrott 1986; Nams 1989; Clark et al. 1993, 1994).

Estimates of location obtained by radiotelemetry using vehicle-mounted antenna systems usually have large error areas associated with them (White and Garrott 1986, Nams 1989, Nams and Boutin 1991). In heterogeneous fine-grained environments, error areas may include many habitat elements; this confounds interpretation of results. Aerial tracking from fixed-wing aircraft is often used when animals move large distances over short periods, but sampling frequency is generally reduced by budgetary constraints, availability of aircraft, and poor weather. In addition, in densely forested areas where visual sightings of radiocollared animals are rare when aerial tracking, errors >0.5 km can be expected (White and Garrott 1990, M.E. Obbard unpubl. data). Satellite tracking systems such as the Argos system (Service Argos Inc., Landover, Md.) (Fancy et al. 1988, Harris et al. 1990, Keating et al. 1991) could be used to monitor long-distance movements of black bears. However, the accuracy

of the Argos system (Keating et al. 1991) may be inadequate for correlating location data with fine-scale habitat features (<250 m diameter). Thus, it seems unlikely that either conventional radiotelemetry or the Argos system can be used to fully investigate the habitat associations of black bears at multiple scales. In contrast, the Navstar global positioning system developed by the United States Department of Defense is expected to provide accuracy of 100 m for coarse/acquisition code data that have not been differentially corrected (U.S. Dep. Defense 1984, Wells 1986, Lotek Eng. Inc. 1993). Thus, GPS technology has the potential to provide data both for analysis of fine-grained habitat use and for monitoring long-distance movements.

We evaluated prototype radiocollars (Lotek Engineering Inc., Newmarket, Ont., Can.) that incorporated GPS receivers and which originally were developed for moose (*Alces alces*) and caribou (*Rangifer tarandus*) (Rodgers and Anson 1994, Rodgers et al. 1996) to determine whether they would be suitable for smaller animals such as black bears. We also assessed the usefulness of GPS collars for evaluating habitat use patterns at multiple scales. The black bear version did not contain the radio-modem used in the moose-caribou version for wireless downloading of data. This required that we recover the collars from the bears and download the data using a serial communications connection to a personal computer.

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STUDY AREA

This study was conducted in and adjacent to the eastern part of the Chapleau Crown Game Preserve (CCGP), Ontario (48°N, 83°W). The area lies within the Missinaibi-Cabonga Forest Section of the southern Boreal Forest Region (Rowe 1972). Almost pure stands of jack pine (*Pinus banksiana*) predominate on sandy outwash plains or areas of coarse lacustrine deposits. Poorly drained areas are occupied by stands of black spruce (*Picea mariana*), sometimes with larch (*Larix laricina*) and eastern white cedar (*Thuja occidentalis*). Mixed stands of trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white birch (*Betula*

papyrifera), balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), and black spruce are found on higher, better-drained sites (Rowe 1972). The terrain is rolling to hilly with elevations from 195 m to 630 m above sea level. The surface geology is dominated by glacial features such as ground moraines, end moraines, and eskers. The CCGP lies within the Height-of-Land climatic region of northern Ontario (Chapman and Thomas 1968). Here, the continental climate is modified by Lake Superior resulting in cooler summers and heavier snowfall in winter (Chapman and Thomas 1968). Mean air temperatures are -15.8°C in January and 16.7°C in July; mean annual precipitation is 79 cm with mean annual snowfall of 284 cm (Chapman and Thomas 1968). The study area has been greatly influenced by both fire and timber harvesting in this century (Ont. Minist. Nat. Resour. 1984), resulting in a complex mosaic of different-aged forest stands.

MATERIALS AND METHODS

Animal Handling and Telemetry

Prototype GPS collars were attached to adult female black bears during routine den visits (5) in March 1994 or when bears were captured in barrel traps (3) in June-July 1994. Bears were immobilized with a combination of ketamine hydrochloride and xylazine hydrochloride (Addison and Kolenosky 1979). Conventional VHF radiocollars were exchanged for GPS collars if bears weighed >70 kg.

The GPS collars contained a 6-channel GPS receiver, an independent VHF tracking beacon, activity sensor, and a computer-memory module. The GPS receivers accessed the C/A code, so system horizontal positional accuracy was expected to be 100 m (i.e., 95% of fixes will be within 100 m of true position; U.S. Dep. Defense 1984, Lotek Eng. Inc. 1993) for non-differentially corrected data. Units were set to acquire GPS fixes at 3-hour intervals and to store latitude, longitude, time, date, fix quality (HDOP), fix status (no fix, 2D or 3D fix), and activity count information in a memory module. Projected life of the unit was 4.5 months (the GPS receiver was set to begin operation 15 Jun) with storage capacity for a minimum of 1,000 records. GPS collars weighed 1.35 kg, and the lower package measured 12.5 x 8 x 9 cm.

We attempted to locate radiocollared bears daily using the collar's VHF beacon to enable us to compare the GPS and VHF systems. VHF locations were determined by triangulation using 5-element Yagi antennas mounted atop vehicles (Wildlife Materials Inc., Carbondale, Ill.).

We used a minimum of 3 bearings obtained within 20 minutes to estimate each location. Data were entered into Locate II (Pacer 1990), and locations were estimated using length maximum likelihood estimators (Pacer 1990, Nams and Boutin 1991).

GPS collars were recovered from live-trapped animals in fall 1994 or during routine den visits in March 1995. Data were downloaded from the collars to a computer for analysis.

Sampling Frequency and Accuracy

The GPS tracking system in the collars was set to record data every 3 hours and stored 2 measures of fix quality: fix status and horizontal dilution of precision. Fix status indicates the number of satellites from which the system received signals long enough to calculate a position. If the GPS received data from <3 satellites, the fix acquisition attempt fails and no location is calculated. With signals from 3 satellites it is possible to calculate a 2D fix; if the collar receives data from 4 or more satellites, it calculates a 3D fix. Dilution of precision is a measure based on geometrical characteristics of triangulation from the satellites. It indexes the precision of a fix based on the locations of the satellites used in calculating the position of the collar. As with triangulation in conventional radiotelemetry, if the known locations (the satellites) are clustered together relative to the location of the unknown position (the collar), the expected precision is low giving high values for HDOP. Conversely, if the satellites are spread across the sky, the precision of the location calculated will be greater and the HDOP values lower. We summarize these data as the fix acquisition rate (the number of successful fixes as a proportion of all fix attempts), the ratio of 2D to 3D fixes, and the mean and standard deviation of the HDOP for each bear and for the stationary collar. The fix acquisition rate corresponds to the observation rate reported by Rempel et al. (1995) and the sampling frequency of location data used by Keating et al. (1991).

To examine the distribution of GPS fix acquisition by time of day, we tabulated successful fixes by fix time for each bear. A chi-squared (χ^2) test determined whether the sample distribution deviated from the expected uniform distribution for time of day.

The expected horizontal position accuracy of the locations from the GPS collars, without differential correction, was expected to be 100 m; 95% of fixes will be within 100 m of true position (U.S. Dep. Defense 1984, Lotek Eng. Inc. 1993). To test the positional accuracy, 1 collar remained at a known location with a clear view of the sky during the 54-day study period. The location

of this stationary collar was estimated with a GPS roving unit (Garmin SRVY II, Garmin Int., Lenexa, Kans.), which averaged the locational fixes taken every second for two 10-hour periods during 2 consecutive nights. The data were not differentially corrected to adjust for selective availability (random errors intentionally introduced to the GPS signal for military security; U.S. Dep. Defense 1984) as base station data were not available; however, by averaging frequently acquired fixes for a 10-hour period this error was reduced to <15 m (Garmin Int. 1993). The location estimate obtained by averaging the 2 average fixes from the Garmin roving unit on consecutive days we called the reference location of the stationary collar.

The latitude and longitude coordinates collected by the stationary collar were converted to universal transverse mercator (UTM) coordinates (North American Datum 1927). The distance between the reference location and the mean of the stationary collar fix coordinates was calculated, as was the 95% confidence interval for the easting and northing values. The mean, standard deviation, and 95th percentile of the distances between the reference location and the fixes taken by the stationary collar were calculated. Since the stationary collar was operating under known and optimal conditions (i.e., not moving and with a continuous clear view of the sky), the fix acquisition rate, the proportion of fixes by fix status, and the average HDOP calculated for this collar served as benchmarks with which to compare data from the collars placed on the bears.

We attempted to obtain VHF fixes for GPS-collared bears close to the time that a GPS fix was scheduled to be made to compare the location estimates from the 2 systems. Time of the VHF fix was assigned as the midpoint between the time of the first and third bearings (maximum 20 minutes elapsed time allowed to acquire all 3 bearings). Any pairs of GPS and VHF fixes for a given bear which were within 10 minutes of each other were matched and the distance between the 2 locations calculated. We report the minimum, maximum, and average of the distances between VHF- and GPS-derived locations, and the number of fixes for which the average error ellipses did not overlap. The error overlap was assessed by comparing the distance between matched pairs of fixes with the sum of the 95% confidence radii for the GPS and VHF methods. For GPS we used the expected precision of 100 m as the radius; for VHF telemetry we used a radius of 342 m, based on accuracy and precision assessments from the study area (Schenk 1994). If the distance between pairs of fixes was <442 m, the error ellipses were considered to have overlapped.

Effects of Topography and Landcover

Since conventional radiotracking methods use the VHF radio frequency band, they are limited approximately to line-of-sight signal reception, ignoring signal reflection and refraction. This can result in some silent regions in the study area from which VHF fixes cannot be acquired by hand-held or vehicle-mounted antennas. This results from landforms that block the collar's signal from reaching a receiver's antenna locations, which were confined to timber access roads in our study. Since the GPS required line-of-sight reception between the collar and the sky rather than over the land surface, we expected that generally topography would not affect GPS fix acquisition unless an animal was close to a hill or cliff that obscured a part of the sky. Elevation data for the study area and a geographic information system (GIS) were used to compare the effect of topographic relief on the GPS and VHF animal location techniques. The digital elevation model was assembled from U.S. Defense Mapping Agency digital terrain elevation data, which were derived from contours, spot heights on ridges, and shorelines on 1:250,000 topographic maps. The data were stored for 100 m x 100 m pixels with an elevation interval of 1 meter (Spectranalysis Inc. 1994). The IDRISI GIS (Eastman 1992*a,b*) was used to delineate the viewshed (the land surface visible) from 3 m above the road—the height at which the antennas for the VHF tracking system were located. This analysis identified areas which were hidden from the view of our conventional VHF radiotracking system. We compared the distribution of GPS fixes and VHF fixes located in the viewshed and in the obscured areas identified by the viewshed analysis using a 2 x 2 cross-tabulation and a χ^2 statistic.

The vegetative canopy over a GPS collar can affect signal reception from the satellites, which could bias against habitats with tall, dense overhead vegetation. To examine the effects of cover type in a coarse-grained manner, we compared the fix acquisition rates and fix status ratios by individual bear and the predominant cover types in their respective home ranges. The difference in fix acquisition rates among the bears was tested with a χ^2 statistic of a 2 x 4 cross-tabulation of fix attempts (successful or unsuccessful) by bear.

To examine these effects at a finer spatial scale, the daytime GPS and VHF fixes were overlaid on a landcover dataset using the GIS. Forest and landcover types for the study area were classified from 1990 digital image data recorded by the multi-spectral thematic mapper sensor carried on Landsat remote-sensing satellites. This sensor measures visible and infra-red light reflectance for pixels approximately 30 m x 30 m. These image data were

resampled to a 25-m pixel size and interpreted using a supervised classification technique. The classification was augmented with aerial photo interpretation to differentiate forest cover types by tree species. The resulting classification was comprised of 10 forest types and 6 other cover types (i.e., water, recent clearcut or burn, exposed bedrock, wetland, poorly vegetated or shrub, and agriculture, built-up, and mine tailings; Spectranalysis Inc. 1993). The distribution of fixes by cover type from GPS and VHF telemetry were compared using a χ^2 analysis of a 2-dimensional cross tabulation. To achieve the required number of expected observations in the table, the number of landcover classes was reduced from 16 to 7 by aggregating similar cover types and by eliminating landcover classes in which there were no fixes.

The fix acquisition rate for GPS fixes by landcover type cannot be computed, since the cover type for cases where no fix could be obtained is unknown. However, the proportion of 2D and 3D fixes in each cover type indicated the effect of cover on satellite visibility, which was the primary reason for a collar failing to compute a position. A cross tabulation of the distribution of 2D and 3D fixes by the 7 landcover classes was assessed using the χ^2 statistic.

RESULTS

GPS Collars

One collar malfunctioned at initiation (June 15), the VHF beacon of 1 collar stopped transmitting in early September (the collar was not recovered), and 2 bears died of natural causes before significant data were acquired, but 4 collars successfully acquired data from 15 June to mid-August. Two of these collars were recovered from live-trapped bears in September 1994, and 2 were recovered from bears in their dens in March 1995. There were no collar-induced injuries nor any detectable difference in behavior compared to bears with conventional radio-collars. There was no evidence that the collars affected reproductive success; 3 females successfully raised cubs to the yearling stage by March 1995 and the fourth female was accompanied by a normal litter of 3 cubs-of-the-year in March 1995. The latter female was the heaviest (91 kg) we handled during 6 years of den visits in our study area (M. E. Obbard unpubl. data).

Sampling Frequency and Accuracy

The collars, including the stationary collar located at the camp, collected data from 15 June 1994 to approximately 13 August, when all units failed. The 4 collars on

live bears acquired 780 fixes in 1,673 attempts, for a fix acquisition rate of 46%. In contrast, the stationary collar acquired 423 fixes in 426 attempts for a 99% fix acquisition rate (Table 1). The overall mean HDOP of all successful fixes for collars on bears was 3.763 ($n = 780$, $SD = 1.99$). For 2D fixes the mean HDOP was 3.647 ($n = 665$, $SD = 2.108$), and for 3D fixes the mean HDOP was 4.434 ($n = 115$, $SD = 0.953$).

Successful fixes for all bears were not uniformly distributed throughout the day ($\chi^2 = 41.8$, 21 df, $P < 0.005$; Fig. 1). The deviation from a uniform distribution of the number of fixes acquired by bear 085 contributed 52% of the value of the χ^2 statistic with fewer than expected fixes at 1100, 1400, 1700, and 2000 hours. An additional 28% of the value of the χ^2 statistic was contributed by bear 122 with fewer than expected fixes at 1400, 1700, and 2000 hours.

The GPS unit used to accurately determine coordinates for the stationary collar calculated 2 coordinate pairs 3.61 m apart horizontally. These coordinates were based on 34,509 and 32,597 fixes collected in each of the two 10-hour periods. The 2 locations were averaged to provide a reference location for comparison with the location computed from the stationary GPS collar. The mean of the 423 positions collected by the stationary collar was 2.0 m from the reference location.

The error for any single fix, expressed as the horizontal distance between a fix for the stationary collar and the reference location, had a mean of 46.2 m (range = 1–348 m, $SD = 44.8$); the 95th percentile of these distances was 105 m. The 95% confidence interval for the northing coordinates was 103.0 m and for the eastings it was 72.9 m (Fig. 2). Neither the mean of the eastings nor the mean of the northings was significantly different from the reference eastings ($t = -0.23$, 422 df, $P = 0.41$) and northings ($t = 0.77$, 422 df, $P = 0.28$).

There were 6 fixes for which there were both GPS and conventional VHF radiotelemetry fixes obtained within 10 minutes of each other. The distances between these pairs of locations ranged from 174 m to 762 m with a mean of 499 m. For 4 of the 6 pairs of fixes, the error ellipses did not overlap.

Effects of Topography and Landcover

The viewshed analysis indicated that 25.3% of the study area within 3,500 m of the road was obscured from the road by topographic relief. However, the distribution of fixes within and outside of the viewshed was not significantly different between the GPS fixes ($n = 268$) and the VHF fixes ($n = 56$) when the VHF beacon of the GPS collars was operating (i.e., 0900–1800 hours daily; $\chi^2 = 2.39$, 1 df, $P = 0.122$).

The difference among bears in fix acquisition rate was highly significant ($\chi^2 = 76.64$, 3 df, $P < 0.001$; Table 1). Bear 85, whose home range was mainly in dense cover, had fewer successful fix acquisitions than expected. In contrast, bear 142, whose home range was mainly in early successional habitat, had more successful fix acquisitions than expected. The comparison of the distribution of fixes by landcover classes derived from satellite imagery demonstrated no difference between the GPS and the VHF telemetry ($\chi^2 = 11.58$, 6 df, $P = 0.07$; Table 2). The effect of land cover on the quality of GPS fixes (2D vs. 3D fixes) was not significant ($\chi^2 = 3.84$, 6 df, $P = 0.70$).

DISCUSSION

Despite being about 3 times the weight and volume of conventional VHF radiocollars, the GPS collars had no detectable effect on reproductive success or behavior. Bears with GPS collars were seen climbing trees with no apparent difficulty, were captured in barrel traps, raised

Table 1. GPS fix status and HDOP (horizontal dilution of precision) for 4 individual black bears in northern Ontario, Canada, Jun–Aug 1994.

Bear	Home range cover	Fix attempts	Fix acquisition rate	2D:3D ratio	HDOP mean (SD) (N)
68	recent burn area, low shrub	475	50%	5.8:1	3.588 (1.875) (237)
85	dense deciduous and conifer cover	513	32%	7.7:1	3.792 (2.207) (166)
122	mixed deciduous and sparse coniferous	474	50%	4.8:1	3.863 (2.063) (239)
142	shrub and recent successional stages	211	65%	5.9:1	3.854 (1.826) (138)
Stationary collar	Open, no movement	426	99%	0.6:1	3.372 (1.477) (423)

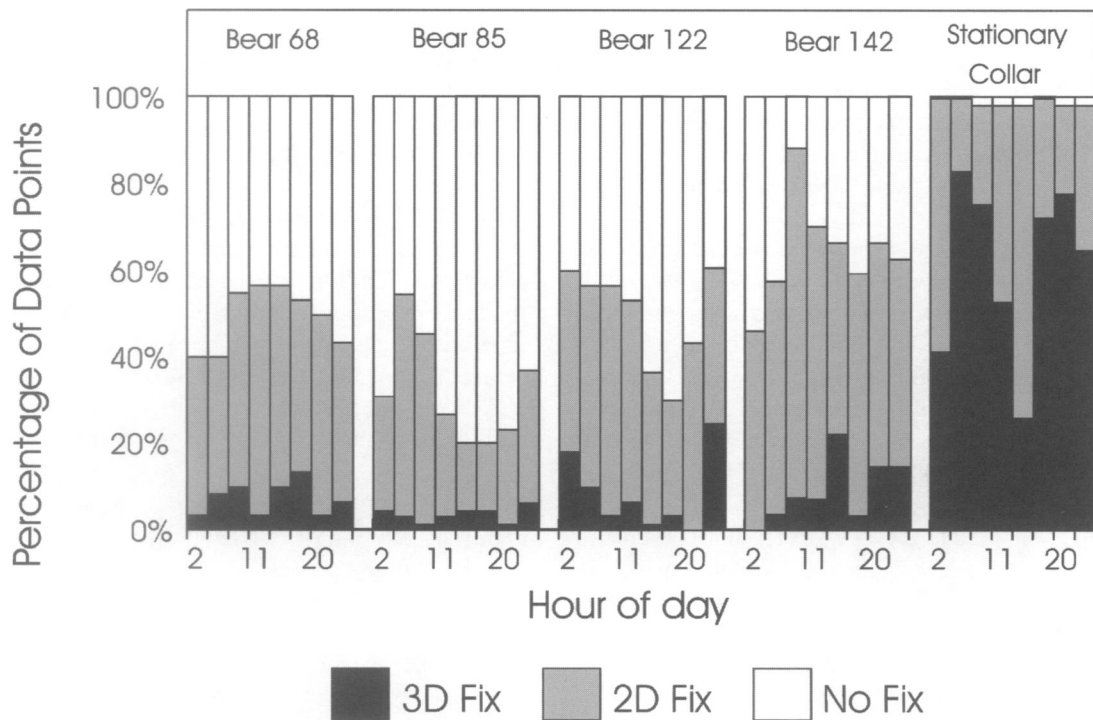


Fig. 1. GPS fix status (3- [3D], 2-dimensional [2D], and no fix) for each black bear and the stationary collar for northern Ontario, Canada, Jun–Aug 1994.

cubs to yearling stage, excavated dens, and had normal litters of cubs.

The overall fix acquisition rate of 46% for the GPS collars on live bears is superior to the 8% reported for the Argos satellite system on test animals in mountainous terrain (Keating et al. 1991). However, it is generally lower than the rates obtained by Rempel et al. (1995) for stationary GPS collars in a controlled experimental setting where they calculated rates ranging from 54% to 97% for all canopy types tested except for a very dense red pine (*Pinus resinosa*) plantation where the rate was 10%. This difference may be due to movement of the collar during the fix acquisition attempt as the bear travels and feeds or to the collar's view of the sky being obscured if the animal is lying down. The fact that the stationary bear collar was capable of acquiring fixes 99% of the time supports this hypothesis, but we have no evidence from direct observation or from activity measurements to test this supposition. Also, Moen et al. (1996) found that the proportion of failed fixes increased significantly when a moose carrying a GPS collar bedded down and the collar was oriented horizontally. In contrast, Moen et al. (1996) reported no significant difference in the proportion of 2D

locations, 3D locations, or failed attempts whether the moose was moving or stationary.

The mean of the positions collected by the stationary collar indicated no bias away from the reference location. The scatter of GPS fixes around the reference location is a measure of the accuracy of a single GPS fix. The 95% confidence intervals on the eastings and northings and the 95th percentile of the distribution of error distances support the declared accuracy of approximately 100 m for non-differentially corrected GPS fixes. This far exceeds a comparable measure of accuracy of the Argos system of about 3,104 m (Keating et al. 1991) and exceeds the accuracy for conventional VHF telemetry in our study area of 342 m (Schenk 1994).

When the GPS fixes were matched and compared with VHF fixes, the discrepancy was surprising (the error ellipses did not overlap for 4 of 6 matched fixes). The short wave length, long signal path, and the binary characteristics of the GPS satellite transmissions mitigate against signal interference having an effect on positional error (i.e., multi-pathing should not be a problem). If there is significant signal interference (i.e., the signal is blocked by a physical obstruction), the GPS will not be able to

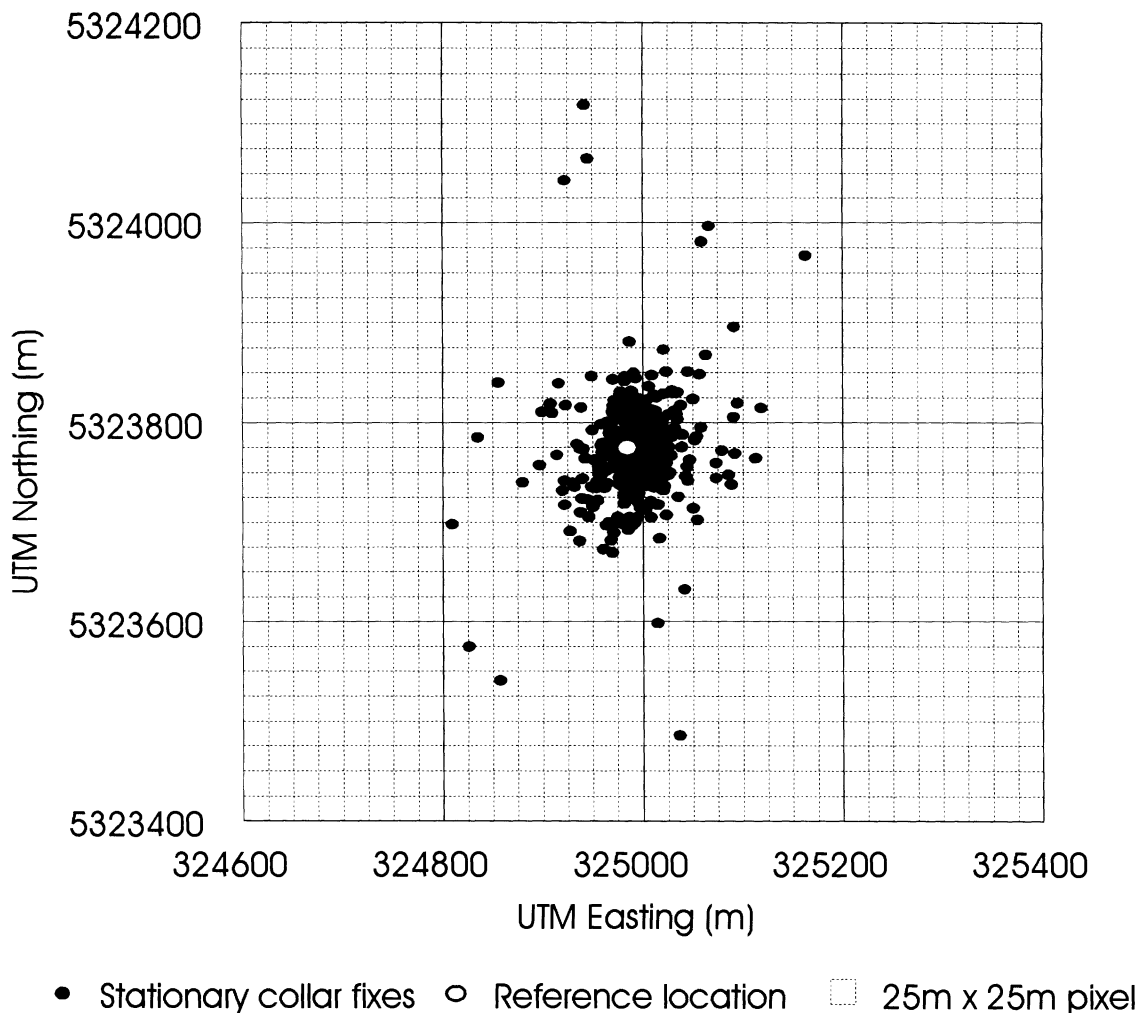


Fig. 2. Distribution of fix locations from the stationary GPS collar in northern Ontario, Canada, Jun–Aug 1994.

calculate a position; if a position is calculated it will have the declared accuracy characteristics (Rempel et al. 1995). It seems reasonable to assume that the lack of overlap of error ellipses is due to errors in the VHF telemetry system and that we have underestimated the error radius for VHF fixes.

The exploration of the effect of topography on the VHF performance relative to the GPS demonstrated that for that particular portion of our study area inhabited by the 4 GPS-collared bears, there was no effect of topography in biasing the VHF system against locating animals in hidden areas. However, we expect that for bears in some parts of the study area the topographic effect on VHF reception and error may be significant. The viewshed analysis indicates where there may be problems and where there are likely advantages in using GPS collars over conventional VHF methods.

The coarse-grained analysis of the effect of general habitat type indicated that GPS fixes were the least successful for bear 85 in habitat with the densest vegetation and the most closed canopy. GPS fixes were the most successful on bear 142 in the most open habitat. The time of day analysis also showed that the fix acquisition rates for bears 85 and 122 were lower when they were more likely to be actively foraging. In contrast, for bears 68 and 142 in more open habitat, there was no bias in time of day for successful fixes. This suggests that there is a bias against obtaining GPS fixes in more heavily vegetated habitats, particularly when the bears are active (Fig. 1).

The conclusion of the coarse-grained analysis regarding the bias introduced by cover type is not supported by the fine-grained analysis of fixes on satellite-derived landcover types. However, the failure to detect this bias

Table 2. Frequencies and percent of fixes by landcover, tracking system, and GPS fix status for radiocollared black bears in northern Ontario, Canada, Jun–Aug 1994.

Landcover class	Tracking system ^a			GPS fix status ^b		
	VHF (%)	GPS (%)	Total	2D (%)	3D (%)	Total
Water and wetland	3 (5%)	10 (4%)	13	14 (2%)	6 (5%)	20
Mixed conifer	7 (13%)	14 (5%)	21	63 (9%)	12 (10%)	75
Sparse conifer	17 (30%)	58 (22%)	75	138 (21%)	23 (20%)	161
Mixed deciduous	8 (14%)	30 (11%)	38	94 (14%)	11 (10%)	105
Sparse deciduous	10 (18%)	63 (24%)	73	160 (24%)	26 (23%)	186
Shrub	9 (16%)	53 (20%)	62	112 (17%)	21 (18%)	133
Cut or burn	2 (4%)	40 (15%)	42	84 (13%)	16 (14%)	100
Total	56	268	324	665	115	780

^a Between 0900 hours and 1800 hours only.

^b All GPS fixes.

in the fine-grained analysis may be due to the small sample size or to the locational error in the GPS and VHF fixes relative to the spatial resolution of the landcover data. Further fine-grained analysis is required either with substantially increased sample size or increased fix resolution.

The bias against fix acquisition in dense cover is important particularly in habitat analyses, and measures to overcome it are required. If the bias can be measured and it is relatively constant within a particular landcover type, then the proportion of fixes in each cover type can be adjusted. Another solution would be to increase the frequency with which fixes are attempted and estimate with greater temporal resolution the animal's trajectory across the landscape. This would permit inferring the cover types through which the animal passes and thus improve the estimates of the proportion of time spent in each cover type. With advances in the collar design which would either permit downloading data without recapture, as is done with the moose and caribou version of the collar (Rodgers and Anson 1994), or increasing the memory capacity to enable more frequent fixes, this strategy for overcoming bias may be feasible.

The large size and weight of the current GPS collar makes it impractical for animals smaller than black bears. The bear version is further limited by its data storage capacity and by the need to recover the collars to download the stored data. This limits the collar's usefulness for species undergoing extensive migrations. In addition, these prototype collars had a shorter than expected operational life—acquiring fixes for only 2 months of an expected 4.5 months. Nevertheless, GPS collars have several advantages over conventional VHF collars or satellite collars:

1. GPS collars offer greater sampling frequency than conventional collars where sampling is limited by either availability of personnel, increased errors from radiotracking at night, or budget or weather constraints when using aircraft.

2. GPS collars offer greater sampling frequency than the Argos system because the duty cycle can be shorter than the Argos satellite overpass interval and the successful fix acquisition rate is substantially higher than with the Argos system (Keating et al. 1991).

3. GPS collars offer higher spatial accuracy than either conventional telemetry or satellite telemetry, providing a better match for landcover data derived from satellites and for forest inventory maps from aerial photographs.

4. GPS collars offer the possibility of evaluating habitat at multiple scales enabling one to examine coarse-grained movements while at the same time examining fine-grained features along an animal's trajectory across the landscape.

Future enhancements of the GPS–GIS analysis system will involve storing appropriate satellite information to achieve 10-m horizontal positional accuracy through differential post-processing of data, reducing the size of the collar package, and adding a temperature sensor with memory capability to record temperature at the time of the GPS fix.

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