Uncontrolled field performance of Televilt GPS-Simplex™ collars on grizzly bears in western and northern Canada

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Abstract Commercially available telemetry collars for wildlife that employ Global Positioning System (GPS) devices generally have the ability to gather a large volume of precise location data. We appraised the performance of 12-channel Televilt GPS-Simplex™ collars (Televilt/TVP Positioning AB, Lindesberg, Sweden) deployed across western and northern Canada on grizzly bears (*Ursus arctos*). Of 71 collar deployments between 2000 and 2002, 38 were retrieved and performed according to their programmed schedule, 20 were retrieved and had some degree of failure, and 13 experienced catastrophic failures and were not retrieved. In addition to these deployments, 10 collars failed predeployment. GPS collar fix success rates were greater for the retrieved collars from the Northwest Territories than for the 4 study areas in British Columbia and Alberta ($F_{4,50}$= 10.82, P<0.001); thus, the latter areas were grouped for further analyses. Collar fix success rates in the British Columbia and Alberta study areas differed between the retrieved collars that functioned normally ($\bar{x}$=65%, SE=2.3, n=28) and collars retrieved with failure events ($\bar{x}$=56%, SE=4.3, n=17; t_{43}=2.09, P=0.043). Fix success rates were lower the longer collars were in the field (r_s=-0.35, n=45, P=0.020). Locations from the GPS collars had a mean dilution of precision of <4 for 2D and 3D locations and thus had a good degree of precision. We were satisfied with the volume and quality of the location data; however, we advise other researchers that significant time and money may be lost troubleshooting problems with the Televilt Simplex system. Other recommendations for future and current users are considered.

Key words GPS collars, grizzly bear, location data, movements, telemetry, Televilt, *Ursus arctos*

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Global Positioning System (GPS) collars gather a large volume of precise locations relative to aerial or ground-based very high frequency (VHF) radiotelemetry and Argos satellite-based methods. Known-time locations on the ground are determined by commercially available GPS receivers integrated into collars that detect the United States military Global Navstar constellation of satellites in high earth orbit (about 20,000 km). Receivers measure locations when they accurately interpret and record signals that determine satellite position, time at which signals leave the satellites, and distance of the receiver from the satellite (Douglas-Hamilton 1998).

Although some reports have pointed out benefits and limitations of GPS collars (Moen et al. 1996, Dussault et al. 1999, Bowman et al. 2000, D'Eon et al. 2002) and related performance issues of GPS collars in the field (Rodgers and Gallerani Lawson 1997, Johnson et al. 2002, Di Orio et al. 2003), relatively few technical reports involve GPS telemetry and bears (Obbard et al. 1998, Schwartz and Arthur 1999). We felt we could provide insights to other users on the performance of a specific commercially available GPS collar under uncontrolled field conditions to better evaluate the utility of this method for bears. We employed the Televilt GPS-Simplex™ system (Televilt/TVP Positioning AB, Lindesberg, Sweden) on grizzly bears (*Ursus arctos*) in the Northwest Territories, central and northern British Columbia, and Alberta's Canmore and Crowsnest Pass regions, central mountain and foothills areas, and the Rocky Mountain East Slopes area near Banff.

Since 2000 Televilt has used the same 12-channel Motorola platform in its GPS-Simplex collars. We had a unique opportunity to assess the performance of this system relative to bears because our studies encompassed a variety of terrain features and climates across western and northern Canada. We appraised GPS collar fix success rates, compared data retrieved directly from the collar versus the remotely obtained VHF data-encoded downloads, and reviewed performance issues.

Study areas

We collected data from alpine, valley, foothill, and tundra regions in Alberta, British Columbia, and the Northwest Territories (Figure 1).

Alberta

The East Slopes grizzly bear project study area encompassed the Bow River Watershed from its source to approximately where it met the prairie. The 2,060-km^2 area was located west of the town of Banff in mountainous terrain. Topographic features included rugged mountain slopes, steep-sided ravines, and flat valley bottoms. The landscape consisted of montane (1,300–1,600 m above sea level), subalpine (1,600–2,300 m above sea level), and alpine (>2,300 m above sea level) ecoregions. The alpine and subalpine regions occupied the high-elevation lands in the Front Range. The alpine region was characterized by a mosaic of low shrubs and herbs. Subalpine areas were forested with mature stands of pine (*Pinus* spp.), spruce (*Picea* spp.), fir (*Abies* spp.), and larch (*Larix* spp.) interspersed with areas of wetland shrub. The montane region occupied valley bottom and foothill lands and was characterized by pine, fir, spruce, and aspen (*Populus* spp.) forests with dry grasslands and wet spruce–shrub plant communities.

The study area for the Foothills Model Forest grizzly bear research program in the northeast Alberta Rocky Mountain slopes region was 9,752-km^2. There was a strong human presence within this mountainous and foothill area. Activities included hunting, tourism, forestry, mining, oil and gas development and exploration, transportation corridors, trapping, commercial outfitting, and public recreational use. The mountains of Jasper National Park, Cardinal Divide, and Redcap Range areas contained a variety of landforms including glaciers, mountains, alpine and subalpine meadows, wet meadow complexes, and lower foothills to the east, with forests varying from primarily deciduous species to mixed-wood stands. The higher-elevation features (ranging to 3,000 m above sea level) generally occurred in a southeast–northwest direction.

Two other study areas in Alberta encompassed a combined 170-km^2 area in the Canmore and Crowsnest Pass regions in southwest Alberta. The Canmore landscape in the Bow River Valley included the 4-lane Trans-Canada Highway, a 2-lane parkway, railroad, a residential and resort complex, and lands adjacent to the communities of Banff, Canmore, Deadman's Flats, and Exshaw. The Canmore region of the Bow Valley provided a linkage between Banff National Park and protected areas in Kananaskis Country. The Crowsnest Pass study area included the Crowsnest River Valley and contained private and crown land with large ranches, forestry, and recreation areas adjacent to the communities of Blairmore, Bellevue, Frank, and

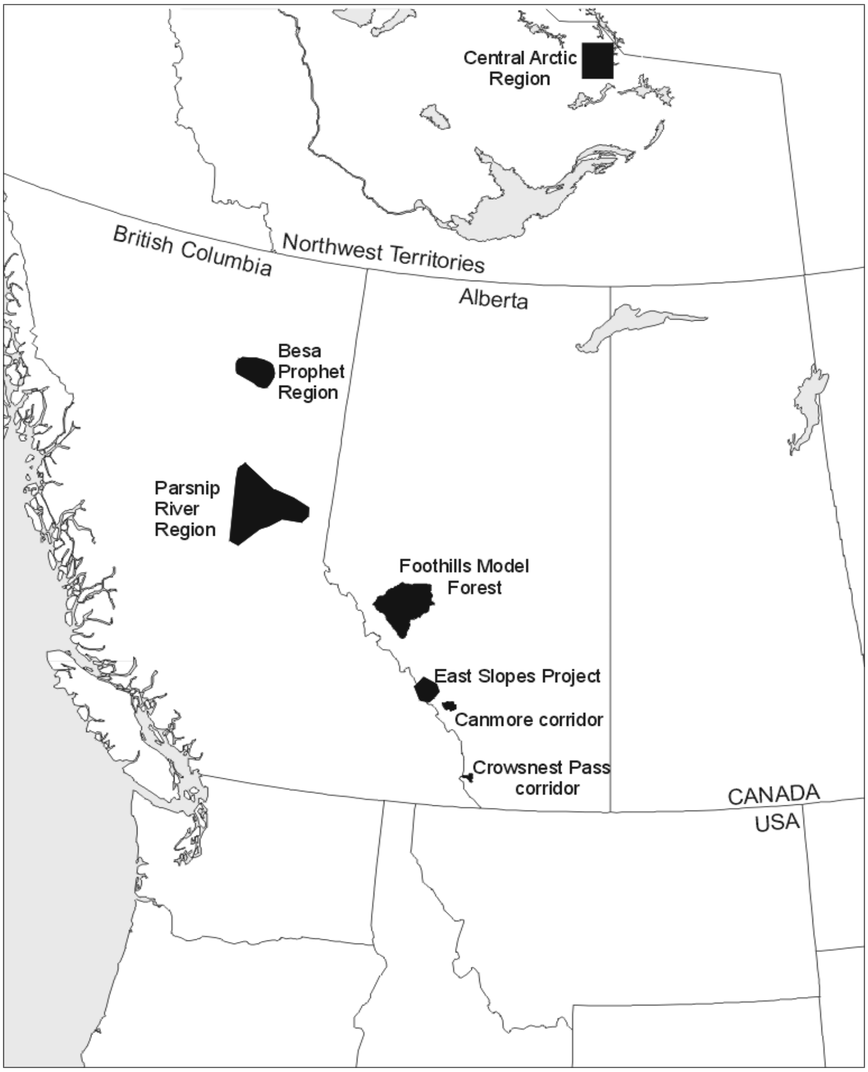

Figure 1. Shaded areas represent the Televilt GPS-Simplex™ collar deployment areas in British Columbia, Alberta, and the Northwest Territories between 2000–2002.

Coleman, with montane, subalpine foothills parkland, and foothills fescue (*Festuca* spp.) grasslands.

British Columbia

The 17,400-km^2 Parsnip study area in central British Columbia encompassed the movements of grizzly bears primarily within the Prince George Forest District and extended north and northeast. It surrounded the Parsnip River and its tributaries and had 2 distinct topographical areas: a plateau (rolling hills and flat valleys) and the Hart Ranges of the Rocky Mountains (with steep-sided bowls, avalanche chutes, and upper-elevation valleys). The old-growth forests of the plateau were comprised of spruce and fir, with pine on poorly drained upland sites. Bogs and wetland areas were primarily spruce, and drier sites had pine-dominated forests. Elevations ranged from 586–1,662 m. In the mountains, lower-elevation forests were dominated by spruce–subalpine fir stands, but the proportion of subalpine fir became progressively greater with increasing elevation and dominated upper-elevation stands. Moderate to steep-sided bowls of upper-elevation grasslands, extremely wide avalanche chutes, and largely open upper-elevation valleys were common. These subalpine areas and avalanche chutes supported lush shrub–forb meadows, whereas higher-elevation alpine areas were composed of alpine tundra communities, barren rock, and snow and ice above 1,550 m. Elevations ranged from 724 m in the valley bottoms to the highest peak at 2,560 m. Forestry was the predominant resource-extraction industry, and the area contained a major highway (British Columbia Highway 97), the British Columbia railway line, and a network of forestry roads.

The Besa-Prophet study area encompassed approximately 4,800 km^2 in the southeastern portion of Muskwa-Kechika Management Area of northern British Columbia. There were 3 primary biogeoclimatic zones. The boreal spruce zone at lower elevations (<1,100 m) included valleys vegetated by spruce, aspen, and willow (*Salix* spp.)–birch (*Betula* spp.) communities. The spruce–willow–birch zone at mid-elevations (1,100–1,600 m) had an abundance of willow and scrub birch as well as some spruce and fir. Above 1,600 m, the alpine tundra zone included barren rock with mat vegetation, snowfields, and rounded peaks and plateaus dominated by alpine grasses, lichens, and trees in krummholz form. The area in general was distinguished by a repeating network of east–west drainages and south-facing slopes.

Northwest Territories

We also deployed collars in a 5,000-km^2 area of tundra in the central Arctic of the Northwest Territories. This region was an open, rocky upland of the Canadian Precambrian Shield dominated by rounded, rocky hills and boulder fields along with shallow rivers, stream areas, and numerous lakes. The rock outcrops and glaciofluvial features such as eskers, kames, drumlins, and raised beaches often were the only major relief features. Drainages supported willow and birch shrubs as tall as 3 m, birch shrublands dominated the uplands, and a mix of low shrubs along with various grass and berry species permeated throughout the study area. We chose the area because it surrounded a 40-km-radius area around the all-weather roads, infrastructure, and 4 open pits belonging to the Ekati™ and Diavik™ Diamond Mines, Inc.

Materials and methods

We tranquillized bears by darting from a helicopter or using leg snares or culvert traps during the 2000–2002 field seasons. We examined, marked, and fitted each bear with a Televilt GPS-Simplex collar. The GPS antenna was aligned to the dorsal line of the bear's back ±15%.

The user-defined location-acquisition rates for our GPS-Simplex collars varied among study areas. However, the collar configuration remained the same, and we used a standard 2-minute GPS positioning time. We analyzed data only from GPS units constructed since 2000, with the 12-channel Motorola GPS platform. A successful GPS fix stored the collar identification, latitude and longitude using the World Geodetic System 1984, 2D or 3D location quality, dilution of precision, date, and time to the second. Each unit also had a VHF transmitter, which was both a traditional locating beacon and a radio link for transfer of the GPS data to a remote VHF receiver (Televilt RX-900C).

Each 1,200-g collar had sufficient memory to store 12,000 records. All collars were made with flexible, strong, ultraviolet-proof belting material. Edges were rounded to provide a comfortable fit for the bear. All electronic components were encased in a fiberglass–resin composite material to prevent water penetration. We used only lithium batteries because they provide the best ratio of energy output to weight and have reliable performance in cold temperatures (Televilt 2001). Battery packs were user-replaceable, and life expectancy depended on the programmed GPS fix acquisition rate.

To reduce the risk of losing data stored on board each collar, collars can be programmed to periodically transfer a copy of stored GPS locations over a VHF frequency to the RX-900C receiver. We approached to within 1–2 km of bears at a preprogrammed time, and used a mix of helicopters, fixed-wing aircraft, and ground telemetry in the various study areas to retrieve GPS locations recorded since the last preprogrammed contact. Collars deployed in 2000 and 2001 took 7 seconds to download 1 GPS location. After a manufacturer's collar modification in 2002, each location took 2.5 seconds to download.

Some of our deployed collars remained on bears through their denning period, so we tabulated GPS collar fix successes (i.e., number of locations stored in the collar's memory divided by the number of GPS location acquisition attempts made) only for the period outside denning activity. Using the Statistical Package for the Social Sciences (SPSS; Norusis 1993), we conducted analysis of variance (ANOVA) with a post-hoc Tukey's test to determine differences in collar fix success between study areas. We used *t*-tests to determine differences in collar fix success rates between retrieved collars that functioned normally and those with failures and evaluated relations between fix success rates and length of deployment via Spearman's rank correlation coefficients. We presented means ± standard error and considered values of $P<0.05$ as significant. We analyzed data based on 5 groupings. We combined data from the retrieved collars in Alberta's East Slopes area with data from the nearby Foothills Model Forest area due to a small sample size and because terrain was similar. Likewise, we grouped data from the Canmore corridor and Crowsnest Pass corridor (see Figure 1).

Results

We deployed 71 Televilt GPS-Simplex collars on grizzly bears between 2000 and 2002 and were able to retrieve 58. Other than some hair loss and matting of the pelage, we did not witness any other adverse effects of the Televilt GPS-Simplex collars on the bears. Thirty-eight deployments performed according to their programmed schedule, 20 had some degree of failure, and we experienced 13 outright failures after deployment on collars we likely will never retrieve unless we opportunistically reencounter the individual. An additional 10 collars failed predeployment (problems with programming, the GPS antenna or the unit itself, or VHF failure). All collars that failed predeployment were returned to Televilt for repair (although there was local technical support, via Telemetry Solutions, Concord, Calif., all collar repairs were done by the manufacturer in Sweden).

The loss of data from a nonretrieved GPS collar can be expensive, given the costs for aircraft use, fuel, and personnel time. To offset this potential risk, we retrieved data stored on board 25 of the GPS-Simplex units through periodic preset VHF downloads. However, we only had a mean 57% (SE =5.1) recovery rate of the total data available to us stored in the collars. Download times generally ranged from 15 minutes to 1.5 hours.

Between 2000 and 2002, our retrieved collars attempted 95,244 location fixes. Fix acquisition success by the GPS was significantly higher for the Northwest Territories collars (mean=87%, SE=2.4, n=10) compared to the 4 other locations ($F_{4,50}$= 10.82, P<0.001). In British Columbia collar fix success rates in the Parsnip River region had a mean of 54% (SE=4.2, n=17), and it was 70% (SE=4.2, n= 10) in the Besa-Prophet region. In Alberta collar fix success rates in the combined Foothills Model Forest–East Slopes regions had a mean of 65% (SE= 2.4, n=13), and it was 61% (SE=6.4, n=5) in the Canmore and Crowsnest Pass corridors. These data from British Columbia and Alberta areas were pooled for subsequent analyses.

In the British Columbia and Alberta study areas, GPS collar fix success differed between the retrieved collars that functioned normally (mean= 65%, SE=2.3, n=28) and the retrieved collars that had some degree of failure (mean=56%, SE=4.3, n =17; t_{43}=2.09, P=0.043). The range of values for collar fix successes was 41–88% for collars that functioned normally, 15–76% for collars retrieved with failures, and 71–96% for collars retrieved from the Northwest Territories. For the collars outside the Northwest Territories, a significant negative relationship existed between the rate of GPS collar fix success and length of time a collar remained on the bear (r_s=-0.35, n=45, P=0.020); fix success rate diminished the longer a collar was in the field.

Mean 3D locations' position dilution of precision (PDOP) were 3.0 (SE = 0.08, n = 10) for the Northwest Territories collars, 3.5 (SE=0.03, n=28) for collars that functioned normally in British Columbia and Alberta, and 3.5 (SE=0.05, n=17) for collars that had some degree of failure. Mean 2D horizontal dilution of precision (HDOP) was 3.3 (SE=0.07, n=10) for the Northwest Territories collars, 3.6 (SE=0.06, n=28) for collars that functioned normally in British Columbia and Alberta, and 3.6 (SE=0.06, n=17) for collars with failures. Lower DOP values generally provide more precise locations (Janeau et al. 2001), although the use of DOP in measuring location precision has been questioned (Moen et al. 1996, D'Eon et al. 2002).

Discussion

GPS technology is a relatively new tool and offers several advantages for monitoring movements and activities of large terrestrial mammals (Johnson et al. 2002). Also, the precision is vastly improved compared to other telemetry methods since the United States government in May 2000 turned off Selective Availability (SA), the intentional timing error introduced to the GPS system. Because of its accuracy, researchers may be tempted to fit this new technology into their study designs. However, collars do not always perform as advertised by the manufacturers (Johnson et al. 2002).

Location precision is affected by the number and geometry of satellites, animal movement, and collar-antenna orientation (Rempel et al. 1995, Edenius 1997, Obbard et al. 1998, Schwartz and Arthur 1999, Bowman et al. 2000, D'Eon 2003). Additionally, topography and canopy coverage, basal area, and tree height reduce the likelihood of a GPS collar acquiring satellite signals (Moen et al. 1996, Dussault et al. 1999, Licoppe and Lievens 2001, D'Eon et al. 2002, Di Orio et al. 2003). The differences in terrain and canopy coverage between areas were presumed to be the primary factors influencing the GPS collar fix success rates we observed. However, any or all of the above explanations likely influenced the collar fix success rate differences we encountered between the Northwest Territories and the southern study areas. Regardless, the mean fix success rates we reported are higher than the mean rates reported for grizzly bears using the Telonics GPS-Argos and GPS stored-on-board systems (Schwartz and Arthur 1999), and for black bears (*Ursus americanus*) using the Lotek GPS system (Obbard et al. 1998).

Our collaboration is the first uncontrolled field-performance account of the Televilt GPS-Simplex system on grizzly bears. In general, the volume of data we collected was much greater than that for our previous studies (e.g., McLoughlin et al.'s [1999] once-every-48-hours fix from an Argos satellite collar on grizzly bear G592 from May 1995 to September 1996 yielded 45 locations, compared to 2,567 hourly Televilt GPS-Simplex locations from the same individual from June to October 2000). However only 38 of the retrieved 71 collar deployments performed to Televilt's advertised expectations. Even though we experienced a high degree of failure, the volume of data we recovered exceeds multi-year, intensive VHF or satellite-based Argos studies for bears. Indeed, the precision and large volume of location acquisitions in a relatively short time period were major factors in why we chose the Simplex system.

The principal limitation with the collars was outright failures involving the VHF signal. In these cases the whereabouts of the bear remained unknown and the collar was not retrieved. Causal factors for the 13 collars that failed post-deployment remain unknown. Prefailure symptoms ranged from a shift to emergency battery mode, weakening or malfunctioning VHF beacon, and internal GPS clock or timing shifts to total failure. Another major malfunction was associated with the collar's failure to gather fixes while all other properties of the collar appeared to be working (e.g., shutting off on the hour to obtain a fix, not in emergency mode, switching beats per minute when the bear was active or inactive).

The negative relationship between the rate of fix success and the length of time a collar remained on the bear was significant. We suggest that performance and reliability may become suspect as length of time in the field increases. Schwartz and Arthur (1999) reported similar findings for grizzly bears using the Telonics GPS system on Alaska's Kenai Mountain range. For optimal collar performance, we recommend retrieving collars after each field season and before bears hibernate. Individual researchers will have to determine the cost-effectiveness of this approach on a project-by-project basis.

Our average 57% data retrieval rate from the VHF downloads was adversely influenced by weather (low cloud cover, reduced visibility), poor signal strengths (i.e., too far away), animal movements during downloads, improper receiver settings (operator error), and aircraft interference (VHF static or the wing-tip dipping during a turn and thus blocking out the signal); these factors reduced the number of locations we were able to receive. It was not possible to quantitatively compare VHF data-collection methods because they varied either between types for the duration of time the collar was on the bear or even between types as a download session was occurring (i.e., landing a helicopter mid-download). Because the data transfer uses a VHF signal, the method providing the most unobstructed line-of-sight path to the collar (i.e., a hovering helicopter) generally had the highest degree of success. Download times were dependent upon the collar's program, and specifically the frequency of attempts as well as the regularity of downloads. Once a download window had ended, those data were no longer available for future remote downloads and were stored on board the collar for later retrieval. Other users should realize that even under the best field conditions, an entire dataset likely would not be recovered until collars were retrieved.

To keep water out of the collar electronics, a rubber O-ring was used to fill the gap between the electronic housing and the battery pack. In 2000 and 2001, the O-ring was on the collar housing. Newer batteries now have the O-ring on the battery pack. Regardless of placement, the O-ring between the battery pack and the collar mechanism was found to have slipped on some of the failed collars that were retrieved. This slippage likely allowed water into the battery pack and resulted in battery failure. The recovered collars did not show extensive damage from wear or bear chewing or clawing. Unexpected battery failures led to perplexing collar activities including a download that was supposed to last 60 minutes but was abandoned after 190 minutes, and total collar shutdown.

We recommend that a perchloroethylene putty (i.e., Automotive Goop, Eclectic Products, Pineville, La.) be used to block the gap between the electronic housing and the battery pack, enhancing the rubber O-ring seal. This resin sealant was applied to all collars deployed in the Northwest Territories. We believe terrain and canopy coverage were not the only factors influencing GPS fix success rates because the open landscape of the alpine Parsnip region had some similarities to the open tundra of the Northwest Territories study area. Although the influence of number and geometry of satellites between areas was not tabulated, we believe the putty applied to the Northwest Territories collars contributed to the higher collar fix success rates experienced there. Other users are cautioned that if they decide to alter the Televilt collar, the manufacturer may not recommend such action. However, with user-replaceable battery packs, the onus is on the user to ensure adequate waterproofing of the collar before deployment.

Ear-tag or small button-tag transmitters (i.e., Advanced Telemetry Systems, Isanti, Minn.) attached directly to the Televilt collar may help relocate a bear whose collar has failed. However, these tag transmitters, though they add minimal weight to the collar, have limited range and reliability (personal observation; Costello et al. 2001), so they may be only a short-term option viable for animals with relatively small home ranges.

The memory capacity of the RX-900C receiver was sometimes limiting. With collars downloading at 7 seconds per location, there is only enough memory for about 3.25 hours worth of data transfer. Although more memory becomes available with the newer collars (2.5 seconds per location transfer rate), collar refurbishment is not an option and users must incur a significant expenditure to replace and deploy newer collars.

The manufacturer indicates that the user has 6 months from the time a collar goes on emergency mode to the time it fails completely. However, 8 of the 9 collars that went into emergency mode failed within 1–4 weeks. To avoid a complete loss of data, we recommend that future users promptly recover the collar once the emergency mode is enabled.

We are generally satisfied with the volume and quality of the location data collected from our GPS-Simplex collars to date. Coping with collar failures, however, caused a significant unexpected increase in research costs and time to troubleshoot problems and significantly reduced the volume of location data we were able to collect. We also commonly faced animal-welfare and ethical issues when recapturing grizzly bears with failed collars. Johnson et al. (2002) warned that the complexity of GPS collars and the extreme conditions under which they are forced to operate would result in failure of some units. Regardless, at least over the short term, some of us will continue to use the Televilt system because a significant amount of time and money has been invested in acquiring and learning the products and accessories. However, we expect that unforeseen technical problems and recapture costs for failed collars will continue to be a drain on our resources. Future researchers should factor into their budget recapture costs for failed collars.

As GPS and collaring technology and performance continue to improve, more applications will become available in the future to wildlife managers and scientists. Starting in 2003, GPS-Simplex units became available with remote-control start of reporting and remote-control release mechanisms. In Europe, Televilt currently has a GPS collar system that uses the cellular–mobile phone network to automatically transmit locations to a secure website. In 2004 a commercial satellite system for Televilt GPS collars in North America now allows bi-directional communication so that data retrieval and reprogramming, even with the collar on the animal, can be done from any computer, anywhere, anytime. However, new technology passed to end-users is relatively unproven for field use. Additionally, no amount of predeployment testing can guarantee that a collar will work once it is applied to a grizzly bear. If other researchers are interested in the latest models of the Televilt line of products for bears, we recommend patience (problems may be resolved by other users) or acceptance that significant time and money may be lost. However, given the rapid pace of technological advancement since the first GPS collars were tested (Rempel et al. 1995), it likely will not be long before a faster, smaller, or longer-lasting model becomes available.

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Literature cited

BOWMAN, J. L., C. O. KOCHANNY, S. DEMARAIS, AND B. D. LEOPOLD. 2000. Evaluation of a GPS collar for white-tailed deer. Wildlife Society Bulletin 28:141–145.

COSTELLO, C. M., R. M. INMAN, K. L. HIGGINS, D. E. JONES, H. B. QUIGLEY, S. L. SIMEK. 2001. Comparison of an expandable radiocollar and an eartag transmitter for monitoring juvenile black bears. Western Black Bear Workshop 7:17.

D'EON, R. G. 2003. Effects of a stationary GPS fix-rate bias on habitat-selection analyses. Journal of Wildlife Management 67:858–863.

D'EON, R. G., R. SERROUYA, G. SMITH, AND C. O. KOCHANNY. 2002. GPS radiotelemetry error and bias in mountainous terrain. Wildlife Society Bulletin 30:430–439.

DI ORIO, A. P., R. CALLAS, AND R. J. SCHAEFER. 2003. Performance of two GPS telemetry collars under different habitat conditions. Wildlife Society Bulletin 31:372–379.

DOUGLAS-HAMILTON, I. 1998. Tracking African elephants with a global positioning system (GPS) radio collar. Pachyderm 25: 81–92.

DUSSAULT, C., R. COURTOIS, J-P. OUELLET, AND J. HUOT. 1999. Evaluation of GPS telemetry collar performance for habitat studies in the boreal forest. Wildlife Society Bulletin 27: 965–972.

EDENIUS, L. 1997. Field test of a GPS location system for moose *Alces alces* under Scandinavian boreal conditions. Wildlife Biology 3:39–43.

JANEAU, G., A. CHRISTOPHE, AND I. GIRARD. 2001. Is it still necessary to use GPS in differential mode since the elimination of selective availability? Pages 73–75 *in* Proceedings of tracking animals with GPS: an international conference. The Macaulay Land Use Research Institute, 12–13 March 2001, Aberdeen, Scotland.

JOHNSON, C. J., D. C. HEARD, AND K. L. PARKER. 2002. Expectations and realities of GPS animal location collars: results of three years in the field. Wildlife Biology 8:153–159.

LICOPPE, A. M., AND J. LIEVENS. 2001. The first tracking results from a female free-ranging red deer (*Cervus elaphus l.*) fitted with a GPS collar in Ardenne, Belgium. Pages 25–27 *in* Proceedings of tracking animals with GPS: an international conference. The Macaulay Land Use Research Institute, 12–13 March 2001, Aberdeen, Scotland.

MCLOUGHLIN, P. D., R. L. CASE, R. J. GAU, S. FERGUSON, AND F. MESSIER. 1999. Annual and seasonal movement patterns of barren-ground grizzly bears in the central Northwest Territories. Ursus 11:79–86.

MOEN, R., J. PASTOR, Y. COHEN, AND C. C. SCHWARTZ. 1996. Effects of moose movement and habitat use on GPS collar performance. Journal of Wildlife Management 60:659–668.

NORUSIS, M. J. 1993. SPSS for windows: base system user's guide, release 6.0. SPSS Inc., Chicago, Illinois, USA.

OBBARD, M. E., B. A. POND, AND A. PERERA. 1998. Preliminary evaluation of GPS collars for analysis of habitat use and activity patterns of black bears. Ursus 10:209–217.

REMPEL, R. S., A. R. RODGERS, AND K. F. ABRAHAM. 1995. Performance of a GPS animal location system under boreal forest canopy. Journal of Wildlife Management 59:543–551.

RODGERS, A. R., AND E. J. GALLERANI LAWSON. 1997. Field Trials of the Lotek GPS collar on moose. Page 58 *in* Forum on Wildlife Telemetry: innovations, evaluations, and research needs. United States Geological Survey and The Wildlife Society, 21–23 September 1997, Snowmass Village, Colorado, USA.

SCHWARTZ, C. C., AND S. M. ARTHUR. 1999. Radio-tracking large wilderness mammals: integration of GPS and Argos technology. Ursus 11:261–274.

TELEVILT/TVP POSITIONING AB. 2001. Discover the full power of GPS with Televilt GPS collars. Tracking animals with GPS: an international conference. Pages 107–109 *in* Proceedings of tracking animals with GPS: an international conference. The Macaulay Land Use Research Institute, 12–13 March 2001, Aberdeen, Scotland.

Rob Gau (photo) and ***Robert Mulders*** have worked together since 1999 on barren-ground grizzly bear research in the central Arctic of the Northwest Territories and Nunavut. Rob is a wildlife technician for the Government of the Northwest Territories' Wildlife and Fisheries Division Carnivore Program and has been involved with barren-ground grizzly bear research since 1991. He received his M.S. from the University of Saskatchewan and B.S. from the University of Alberta, and his areas of expertise include grizzly bear nutritional ecology and large-carnivore biology. Robert Mulders is currently the carnivore/furbearer biologist with the Government of the Northwest Territories. He obtained his B.S. at the University of Alberta and an M.S. from Laurentian University, and was previously involved with research on caribou, muskox, polar bears, and wolves in the eastern Arctic. Rob and Robert are currently involved with a number of projects involving grizzly bears, wolverines, lynx, marten, and cougars. For the last 12 years ***Lana Ciarniello*** has worked on a variety of field-based research projects with black and grizzly bears in the Northwest Territories and northern Ontario, and the Parsnip Grizzly Bear Project in British Columbia. Her B.S. is from the University of Victoria and M.S. from the University of Calgary. Lana is currently a Ph.D. candidate at the University of Alberta. ***Doug Heard*** received his B.S. in biology from the University of Waterloo and his M.S. in zoology from the University of British Columbia. He is currently a regional wildlife specialist with the Province of British Columbia's Ministry of Water, Land and Air Protection and adjunct professor in the Ecosystem Science and Management Program at the University of Northern British Columbia. His professional interests focus on predator–prey relationships between ungulates and carnivores. ***Cheryl Chetkiewicz*** received her B.S. from the University of Alberta, M.S. from the University of Alaska Fairbanks, and is currently a Ph.D. candidate at the University of Alberta. Previously she managed the Jaguar Conservation Program at New York's

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