Elizabeth A. Jozwiak,[1] Kenai National Wildlife Refuge, U.S. Fish and Wildlife Service, P.O. Box 2139, Soldotna, Alaska 99669,

William F. Andelt, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, Colorado 80523

and

Theodore N. Bailey,[2] Kenai National Wildlife Refuge, U.S. Fish and Wildlife Service, P.O. Box 2139, Soldotna, Alaska 99669

Accuracy of GPS and Map-plotted Aerial Telemetry Locations on the Kenai Peninsula, Alaska

Abstract

We compared the accuracy of aerial telemetry locations obtained with an aircraft mounted Global Positioning System (GPS) and the same locations independently determined by the observer from maximum VHF signal hand-plotted on a map. We located 12 radio collars (six visible from aircraft) in three habitats on each of six occasions on the Kenai National Wildlife Refuge, Alaska. Accuracy of GPS ($\bar{x}$ = 139.1 m, SE = 9.65) and map-plotted ($\bar{x}$ = 168.4 m, SE = 21.9) locations did not differ. Accuracy did not differ among habitat types or by visibility of the collar. Accuracy of the GPS method improved with successive trials (contrast $F_{1,5}$ = 20.57; P < 0.001). The pilot activated the GPS unit 1-2 sec, and an average of 81.4 m (SE = 7.63), before passing over reference points indicating that test flights should be conducted before data collection to determine the optimal time to activate the GPS unit. Coordinates estimated from topographic maps and a ground-based GPS unit varied by an average of 70.5 m (range = 23.1-157.4 m), and increased with latitude (r = 0.81, $F_{1,4}$ = 7.62; P = 0.051). Considering our results, we recommend using GPS over map-plotting of aerial telemetry locations for analysis of large-scale animal movement patterns because of ease of use and ability to download data directly to a computer for analysis.

Introduction

Radiotelemetry has been employed from the ground (Heezen and Tester 1967; Springer 1979) and aircraft (Hoskinson 1976; Gilmer et al. 1981) for locating wildlife. Error in ground based triangulation has been reported (Hupp and Ratti 1983; Lee et al. 1985; Garrott et al. 1986; White and Garrott 1990; Nams and Boutin 1991), but the extent of error in aerial based telemetry is not well documented. Locations of radio-marked animals have been recorded from aircraft by a variety of methods, but map-plotting (ground location plotted by the airborne observer onto a map when the maximum VHF signal is obtained) primarily had been used at the time of our study. Sources of aerial telemetry error include the quality of maps or aerial photos, presence of landmarks, investigator's ability to locate the animal's position on a map or aerial photo, observer fatigue, search procedures, and aircraft speed and elevation (White and Garrott 1990).

With advances in satellite technology, aircraft GPS receivers are being used to collect geographic positions of VHF radio-marked animals. This method does not rely on an observer's ability to pinpoint an animal's location onto a map. Rather, a GPS receiver calculates a 2-dimensional position (latitude and longitude) based on signals received from $\geq$ three of 24 orbiting satellites. A 3-dimensional position (latitude, longitude, and altitude) is computed when signals from $\geq$ four satellites are received simultaneously. During the 1990's, the most significant source of error in GPS data was attributable to selective availability, which introduced unpredictable sources of error into satellite transmissions for reasons of national security, and reduced accuracy to within 100 m 95% of the time (Hurn 1989). Selective availability was eliminated by the United States Department of Defense in May 2000. Prior to May 2000, this error could be reduced, by differential correction, to 2-5 m of the true location (Bobbe 1992) using post processing techniques. Our GPS locations along with those of other wildlife studies

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[1]Author to whom correspondence should be addressed. E-mail: Elizabeth_Jozwiak@fws.gov

[2]Current address: 36915 Hakala Drive, Soldotna, Alaska 99669

(Dussault et al. 2001, Hulbert and French 2001, Adrados et al. 2002) were collected prior to the removal of selective availability.

The accuracy of GPS-collected and map-plotted location data have been reported (Carrel et al. 1997), but little is known about the relative accuracy of locating radio-collared animals in different habitat types. Several studies compared the accuracy of GPS and LORAN-C, but assumed map locations to be without error (Butler et al. 1995), or did not determine map error for their locality and assumed a +/- 20 m (Leptich et al. 1994) or +/- 12.5 m (Carrel et al. 1997) error between the observed location and the mapped location. Mapped locations can be ≥340 m from the actual location (Brew et al. 1993). When aerial telemetry is used to estimate the location of radio-collared animals, accuracy of the technique should be estimated. Our objectives were to compare the accuracy of aerial GPS locations to hand-plotting aerial locations on a map, and to determine if accuracy was affected by habitat type and visibility of collars, while taking into account map error in our study area.

Study Area

The study was conducted in the northwestern lowlands of the Kenai National Wildlife Refuge, Kenai Peninsula, Alaska (Figure 1). This area was chosen primarily because of the availability of road access to three habitats where we studied radio-collared wolves (*Canis lupus*). The three habitats included: 1) a 1947 burn area consisting of dense white and black lowland spruce (*Picea glauca* and *P. mariana*) with a 5-6 m high canopy, 2) a 1969 burn area composed of young 3-4 m tall paper birch (*Betula papyrifera*) and aspen (*Populus tremuloides*) in a relatively open stand with little canopy cover, and 3) a mature hardwood habitat containing large stands of >40 year old paper birch, aspen, and a few white and black spruce with relatively little open ground vegetation and a thick 15-20 m tall canopy cover.

Methods

Aerial GPS and Aerial Map-Plotted Locations

We conducted six trials in summer between 13 July 1993 and 16 August 1994 to test the accuracy

Figure 1. Aerial view of the Kenai Peninsula lowlands.

of aerial telemetry locations obtained using the GPS and the map-plotting technique. During each trial, we randomly distributed 12 (164-167 MHz) wolf radio collars (Telonics, Mesa, Arizona) in the three habitat types. We placed collars at random locations selected from a set of 160 map points accessible by foot or canoe in each habitat type. We determined the distance and direction to the collar location from a road or lake shore using an aerial photo and compass. Collars were placed in an area of approximately 1000 km^2 and all collars were >25 m apart, and <3 km from the road. After collar locations were chosen, two of four collars in each habitat type were chosen randomly as "visual" collars. Visual collars simulated the occurrence of an animal being observed from the air. A 1.5 m x 1.5 m orange tarp was centered on the ground under the "visual" collar which could be seen from the aircraft. All collars were placed 60 cm above ground and fitted around a plastic bottle filled with saline solution to simulate signal absorption by an animal's body (Hupp and Ratti 1983).

We used a Cessna 206 fixed wing airplane with strut mounted, 2-element directional antennas and the same pilot and observer in all six trials. The pilot had >3 yr, and observer >15 yr of aerial telemetry experience. Collars were located using a standard search protocol (Gilmer et al. 1981). Flight altitude ranged from 210 to 270 m, airspeed ranged from 130 to 157 km/hr, and wind velocity varied from 7 to 17 km/hr. After a radio collar was located (either visually or by signal strength), the observer marked the position on a 1:63,360 topographic quadrangle map, and the pilot recorded the position when the aircraft passed over the collar with a Trimble TNL 2000 in-dash GPS Navigator receiver (Trimble Navigation Limited, Sunnyvale, California). Accuracy trials were flown when position dilution of precision was relatively low, and the number of satellites was highest based upon daily ephemeris information obtained from a local surveyor. Locations of collars were not known to the observer and pilot prior to telemetry flights.

Ground Estimates of "True" Locations

We estimated the "true" ground position of radio collars in the two trials in 1993 by averaging locations collected with a Garmin GPS 100 Survey II receiver (Garmin International, Inc., Olathe, Kansas) with an external antenna mounted to a 4.5 m pole, but locations were not differentially corrected (i.e. uncorrected). The "true" ground position of each radio collar for the four trials in 1994 was estimated by differential correction using the same Garmin field receiver and antenna, and a Garmin GPS 100 Survey II base unit, operated <50 km from the study area, at the Killey AZ benchmark which was re-surveyed in 1988 with B order accuracy (Federal Geodetic Control Subcommittee 1984). To assess our accuracy in estimating the "true" ground position of collars, we placed the GPS field receiver on top of the GPS base unit at the Killey AZ benchmark and measured accuracy of uncorrected and differentially corrected locations. We also obtained and compared uncorrected and differentially corrected locations of collars in trial 4. We further calculated GPS error by placing the GPS base unit on the Killey AZ benchmark and the GPS field unit on two 1st order accuracy benchmarks (Audrey and Kirt; Federal Geodetic Control Subcommittee 1984) and estimated their locations using differential correction.

We collected and averaged GPS locations at the "true location" for 20 min if locations were logged in 3-dimensional mode, or >20 min when positions fluctuated between 2-dimensional and 3-dimensional mode. The Garmin GPS 100 Survey II receiver updated its location once per second (Garmin GPS 100 SRVY II Personal Surveyor™ Owner's Manual, Garmin International, Inc., Olathe, Kansas), thus we speculate that the unit obtained and averaged about 1,200 locations in each 20-minute period. In 1994, data were downloaded to an IBM computer for differential post processing using GARMIN PC100S2 software. Locations recorded with a position dilution of precision >4, and 2-dimensional locations were automatically eliminated by the software program

We estimated map error in the study area by locating five road intersections on topographic maps, determined their *x,y* coordinates with a digitizer, and then compared the digitized locations to the same positions estimated in the field with a GPS unit and differential correction. To determine how the radiotracking technique contributed to location error, the location of the five road intersections was estimated using the aircraft GPS receiver during four aerial flights.

Transforming Coordinates and Statistical Analyses

We transformed aircraft and ground GPS locations from latitude and longitude to UTM coordinates (North American Datum [NAD] 83) using ARC/INFO Software (ESRI, Redlands, California, version 7.0). The aerial locations of collars plotted on quadrangle maps, and the map reference points were digitized in decimal degrees (ARC EDIT; ARC/INFO), and converted from NAD 27 to NAD 83 and into the UTM projection for comparison with GPS-collected locations. Error distance was calculated as the Euclidean distance between the observed aerial GPS or map hand-plotted location and the true location estimated from the ground.

We used analysis of variance (PROC GLM; SAS Institute 1993) with a mixed effects model to compare error of the two data collection methods and test the effects of collar visibility, habitat, and trial number on location error. A linear contrast was used to test the effect of trial number on accuracy of trials. Linear regression (PROC REG; SAS Institute 1993) was used to determine the effect of latitude on map error. The significance levels for all analyses were set at $P = 0.05$.

Results

Aerial GPS and Aerial Map-Plotted Locations

Error of telemetry locations did not differ between the aircraft GPS ($\bar{x}$ = 139.1 m, SE = 9.65) and map-plotting ($\bar{x}$ = 168.4 m, SE = 21.9) methods ($F_{1,36} = 2.39$; $P = 0.131$), among habitats ($F_{2,36} = 1.01$; $P = 0.373$), or between visible and hidden collars ($F_{1,36} = 2.91$; $P = 0.097$) (Table 1). Accuracy varied among trials ($F_{5,36} = 3.71$; $P = 0.008$), and the interaction between trial and method was significant ($F_{5,36} = 2.90$; $P < 0.026$), with the GPS technique improving in subsequent trials (contrast $F_{1,5} = 20.57$; $P < 0.001$). All visual collars were successfully observed from the aircraft.

The difference between 17 road reference points estimated with GPS from the ground and air averaged 81.4 m (SE = 7.63, range = 17.3-133.0 m). When both points were plotted relative to the heading of the aircraft, all aerial-estimated locations were positioned an average of 67.1 m (n = 17, SE = 7.95, range = 16.5-123.5 m) before the "true" reference point perpendicular to the line of flight. Eleven of the 17 aerial-estimated points were an average of 16° (SE = 3.50, range = 0-31°) of the same heading as the aircraft. Based upon flights over road reference points at an airspeed of 130-157 km/hr (36-44 m/sec), the observer/pilot team activated the aircraft GPS receiver an average of 1.5-1.9 sec before passing directly over the road intersection.

Ground Estimates of "True" Locations

The difference between the surveyed and estimated "true" locations of the Killey AZ benchmark averaged 5.0 m (n = 9, SE = 1.47) with differential correction, and 7.0 m (n = 10, SE = 1.22) without differential correction. GPS error averaged 0.6 m (n = 2) when the base unit was placed at the Killey AZ benchmark and the locations of two 1st order benchmarks were estimated with differential correction. The difference between ground-based collar locations estimated with and without dif-

TABLE 1. Telemetry error (m) estimated for an aerial Global Positioning System (GPS) and map-plotted aerial locations in the northwestern lowlands, Kenai National Wildlife Refuge, Alaska during 1993-1994.

	Visual Collars[1]						Hidden Collars[1]					
	GPS			Map			GPS			Map		
Habitat[2]	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range
1947 Burn[3]	87.9	15.0	14-191	104.8	17.3	24-227	156.3	20.8	78-285	224.1	64.7	53-664
1969 Burn[4]	126.4	20.3	35-255	132.3	26.3	32-328	181.0	24.6	73-360	121.8	21.8	40-305
Mature Hardwood[5]	157.7	25.8	43-347	191.9	34.5	49-424	125.0	27.8	21-320	235.7	101.2	10-1,309

[1]36 visual and 36 hidden collars = 72 total locations: 12 locations (six visual and six hidden) per trial.

[2]12 visual and 12 hidden collars in each of three habitat types: four collars (two visual and two hidden) per habitat type per trial.

[3]Dense low canopy: (5-6 m high coniferous trees).

[4]Open low canopy: (3-4 m tall hardwood trees).

[5]Dense high canopy: (>40 yr-old 15-20 m tall mixedwood trees).

ferential correction averaged 8.1 m (n = 9, SE = 1.27, range = 1.1-12.8 m) at the Killey AZ base station and 21.9 m (n = 11, SE = 3.69, range = 4.2-48.9 m) during trial 4. We pooled the differentially corrected and uncorrected locations in our analyses because differences between the two techniques were small. The difference between six locations digitized from the topographic map and estimated with the GPS unit on the ground averaged 70.5 m (range = 23.1-157.4 m), and increased with latitude ($r = 0.81$, $F_{1,4} = 7.62$; $P = 0.051$).

Discussion

Our inability to detect a difference in accuracy between aircraft GPS and hand-plotted map radio-collar locations likely was influenced by our moderate sample size. Our results are similar to Carrel et al. (1997) who reported the map plotting technique was comparable with uncorrected and differentially post-processed GPS locations. We found locations obtained with the aircraft GPS contained error from several sources. Real-time differential GPS software for aerial surveying (Bobbe 1992; Anthony and Stehn 1994) was not available during this study, therefore aerial GPS positions were uncorrected, and included selective-availability error when active. Even with selective availability disabled, Hulbert and French (2001) report additional sources of error in GPS locations such as from the receiver itself, topographically induced errors, and ionospheric and tropospheric delays. The accuracy of the TNL Navigator GPS receiver is reported at <15 m (Trimble Navigation 1992) excluding error introduced by selective availability. The study area contained prominent landmarks such as roads and lakes which were easy to identify from the air and aided in plotting locations on a map, thus our map-plotting error may be less than would be expected in areas with fewer landmarks. Additionally, error from map-plotting can potentially be higher in the winter when the area is snow-covered, and fewer features are visible. Survey error caused by observer/pilot teams would likely decrease if slower-flying aircraft with increased safety and visibility are used. For example, to make visual contact with radio-equipped wildlife to assess numbers, color patterns, locate kills, and observe behavior, the observer/pilot team in this study normally used a Piper PA-18 Supercub.

We did not anticipate the added survey error from the observer/pilot team. They contributed to error by activating the aircraft GPS receiver before they were positioned directly over road reference points, and thus likely activated the GPS unit before flying over telemetry collars. Aerial GPS accuracy likely would increase if trials are conducted to determine the optimal time to activate the aircraft GPS receiver prior to data collection. Reducing this source of error could have increased the accuracy of our visually-observed radio collars by up to 67 m (SE = 7.95).

The observer/pilot team located hidden collars from the air as accurately as visible collars. We expected the location of visible collars to be estimated more accurately because the true location was observed, and not estimated with telemetry. We speculate that we did not find differences in accuracy due to collar visibility because observer/pilot error was moderate (error locating visible road reference points from the aircraft averaged 81.4 m) and probably obscured any differences.

Habitat type did not influence our accuracy for locating collars using the aerial map-plotting and GPS methods, nor our ability to acquire locations of collars. Although GPS collars are more accurate than the aerial telemetry techniques we report here, accuracy of GPS collars can be lower in habitats with closed compared to open canopies (Rempel et al. 1995, Moen et al. 1997, Rempel and Rodgers 1997, D'Eon et al. 2002). GPS collars also can underestimate the use of mature stands relative to other habitat types because rates of successful fixes have decreased with tree height and/or canopy cover (Rempel et al. 1995, Dussault et al. 1999, D'Eon et al. 2002, Frair et al. 2004, Janeau et al. 2004).

Map error should be determined for each study area if GPS accuracy flights are conducted on reference points estimated from map locations. Map error also should be evaluated particularly if animal locations are plotted on a map and subsequently entered into a Geographic Information System with other locations collected with GPS. We found map error exceeded horizontal map accuracy standards of +/- 32 m (Thompson 1987) for 1:63,360 topographic quadrangles which were last revised and field annotated in 1975 and 1980. Topographic map revisions in the future will likely bring published map locations into agreement with GPS determined locations.

We used one pilot and one observer in one geographical area with little change in elevation to compare accuracy of aerial telemetry. To determine external validity of our findings, additional pilot/observer teams should be tested at our study area and in other geographic areas. Our study and Gantz and Stoddart (1997) found that accuracy of pilot/observer teams increased with experience, thus experienced teams should be used for aerial telemetry. Caution should be used when extrapolating our aerial telemetry accuracy to radio-marked animals because observers often perform better when they know they are being tested (Mills and Knowlton 1989).

We recommend the use of aerial GPS over the map plotting technique for locating radio-marked wildlife even though error was similar for the two methods. The GPS method does not require converting map locations to a usable format which is labor intensive, and data can be easily downloaded into a Geographic Information System for analysis. However, it may be preferable to use the map-plotting technique when locating visible radio-marked animals in heterogeneous habitats where one would risk habitat misclassification with the error associated with the aerial GPS method. Accuracy of the map plotting technique also should improve in areas with more landmarks such as heterogeneous habitats. We also suggest that pilot/observer teams conduct accuracy surveys early in their study to 1) identify and reduce measurement error through modification of survey techniques, and 2) to determine the mean error when estimating locations of transmitter-equipped wildlife, particularly when conducting fine-scale habitat use studies.

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