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# Field test of a GPS location system for moose *Alces alces* under Scandinavian boreal conditions

**Lars Edenius**

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This paper reports on field tests of an animal-borne GPS telemetry system for moose *Alces alces* in northern Sweden. Tests involved accuracy of locations (standard mode GPS), percentage of successful location attempts under different canopy conditions, effect of movement, and performance of the GPS telemetry system on free-ranging moose. Locational accuracy was better than 92 and 183 m 95% of the time, and better than 42 and 74 m 50% of the time, respectively, dependent on whether the GPS receiver recorded a 2- or 3-dimensional location (3 or 4 satellites used to calculate the location). Percentage of successful location attempts ranged within 69-100%, and varied inversely with over-storey canopy cover and basal area of stems. Thick canopy cover and high stem basal area reduced locational accuracy and the percentage of successful location attempts. A backpack trial indicated that movement rate of 3-4 km/hour may reduce the percentage of successful location attempts under forest canopy. On moose, approximately 75% of attempts resulted in a location, the success rate being highest during winter/spring and lowest during fall. It is concluded that GPS has a great potential in wildlife telemetry studies, but effects of movement and habitat selection have to be addressed further.

*Key words: boreal conditions, GPS, moose, Sweden*

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As a result of recent technological development, radio collars with GPS (Global Positioning System) have become commercially available for wildlife telemetry studies. GPS technology has at least three potentially interesting features for location of animals: 1) high accuracy of GPS locations, 2) flexibility in sampling design, i.e. location attempts can be made at user specified intervals, and 3) low costs per GPS location (Rodgers & Anson 1994). However, before large-scale application the reliability of the technique must be determined by careful field testing. The GPS system was not designed to be used under forest canopy. Therefore, performance of GPS telemetry systems can be expected to be negatively affected by dense forest canopy cover and high stem density. Moreover, GPS performance on free-ranging animals may be adversely affected by collar movement.

Field tests of animal-borne GPS systems under different forest canopy conditions have been reported from Ontario, Canada (49°N) (Rempel, Rodgers & Abraham 1995), Minnesota, USA (48°N) (Moen, Pastor & Cohen 1997) and Alaska, USA (60°N) (Moen, Pastor, Cohen & Schwartz 1996). In this paper I report results of field tests of a GPS system for moose *Alces alces* in northern Sweden (64°N). I address locational accuracy and precision, effect of canopy conditions and collar movement on the percentage of successful location attempts, and performance of the GPS collar on free-ranging moose.

## Material and methods

For the tests I used two non-differential GPS collars (GPS_1000) from Lotek Engineering Inc., Ontario, Canada. The system consists of a 6-channel GPS receiving unit, a computer and data storage unit, a built-in activity sensor, a radio modem for external communication and retrieval of data, and a VHF tracking beacon (Rodgers & Anson 1994, Moen et al. 1996).

Locational accuracy was tested 13-19 February 1995 on primary stations in the Swedish national trilateration network. The collars were hung vertically under open sky or thin over-storey cover at three different stations located 8-20 km apart. GPS locations were made at 60-minute intervals, and at least 30 locations were attempted per collar and locality before cessation of the trial.

The effect of forest over-storey was tested 17-27 February 1995 across a wide range of canopy conditions. Within a 2,500 km$^2$ large moose population study area a steep streamside ravine with >20 m tall highly productive Norway spruce *Picea abies* forest was selected to provide the 'worst' possible combination of topographic relief, high canopy closure and high stem density. The GPS collars were either attached to a tripod at 1 m height between tree stems or hung directly on the trunk in the different trials. At each site over-storey canopy closure was estimated from black and white wide angle photographs facing upwards from the position of the collar antenna, and stem basal area was estimated with a relascope. On all sites, canopy cover was dominated by conifers.

To test the effect of movement on the likelihood of getting locations one collar was placed in a backpack and carried along an eight km forest trail at normal walking speed (appr. 3-4 km/hour) on 25 February 1995. The antenna was outside the backpack facing the sky at the level of the carrier's head. The collar attempted to take a GPS location every five minutes. Clocks were synchronised and under each satellite tracking session (<4 minutes), canopy closure was subjectively evaluated and classified into four categories: 1 = 0-10%, 2 = 11-30%, 3 = 31-50% and 4 = >50%.

The two collars were used on adult female moose in early March 1995. Both collars were scheduled to take one location every six hours (i.e. four times/day), and 12 locations during one hour every six hours one day/week. One collar performed 1,062 GPS location attempts until 27 July 1995 before power failure, and the other 3,011 attempts until 31 December 1995 before software failure. Home-range of both animals was <3,000 ha during the whole study period (90% convex polygon method).

The study was conducted in coastal northern Sweden (64°N, 20°E) in a predominantly forested area with scattered mires, open water and farmland. The boreal forest in this region consists of pine *Pinus sylvestris* and spruce and mixed stands of both species. Deciduous forest (predominantly *Betula* sp.) are found on more productive land. Luxuriant (dense) old Norway spruce forest covers <5% of the area. Due to intensive forestry the age distribution is distorted towards young and middle-aged forest with old (>80 years) forest covering approximately 40% of the land.

Latitude and longitude were transformed to the Swedish grid system in the RT90 map datum following Reit (1994). Locational error was calculated as Euclidian distance between locations and the position of the primary trilateration station. Two-dimensional (2-D) and three-dimensional (3-D) locations (using 3 and 4 satellites to calculate the position, respectively) were differentiated, and failed location attempts were recorded. A cut-off at DOP > 5 (dilution of precision) was employed to evaluate the role of satellite geometric configuration on locational accuracy (Rempel et al. 1995, Moen et al. 1997).

## Results

Frequency distribution of locational error was truncated (Fig. 1). In 3-D mode 50% of locations (N = 69) with DOP < 5 were less than 42 m from the true posi-

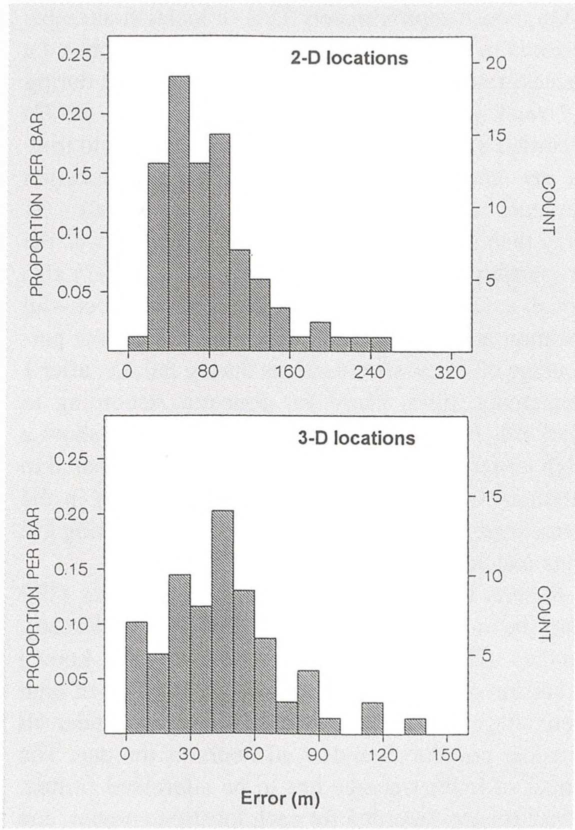


Figure 1. Frequency distribution of GPS locational error in 2-D and 3-D mode.

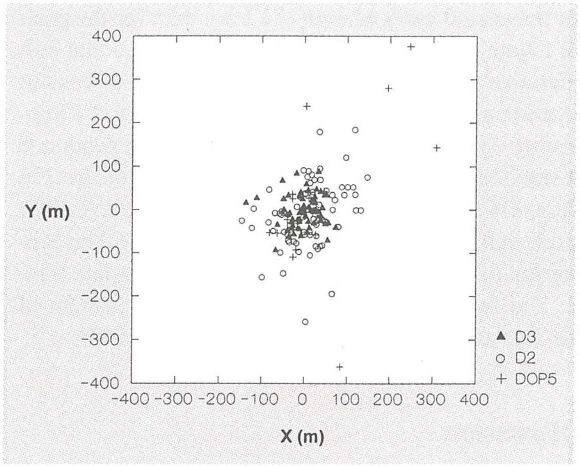


Figure 2. Spatial distribution of GPS locational error in relation to true position. D3 = 3-D locations, D2 = 2-D locations, and DOP5= 2-D and 3-D locations with DOP > 5.

tion, and 95% of locations fell within 92 m. The corresponding values for 2-D locations (N = 82) were 74 m and 183 m, respectively. For locations with DOP> 5 (N = 19) median error in 2-D mode was 356 m and 63 m in 3-D mode, the difference being significant (P = 0.003, U = 80.500, Mann-Whitney U-test).

Locational error was uniformly distributed around the true position both for 2-D and 3-D locations (Fig. 2; z = 2.72, P > 0.05 and z = 0.60, P » 0.05, respectively; Rayleigh's test for spatial uniformity (Zar 1996)).

Percentage of successful location attempts under different canopy conditions (11-63% canopy closure, corresponding to <5-20 $m^2$ basal area of stems) and placement of collars (trunk vs in the open) varied between 69% and 100%. When the collars were placed between stems the success rate was 94-100% at up to 45% canopy closure and 75% at 58% closure. When the collars were placed at the trunk of the tree the corresponding values were 69% at 58% closure. The proportion of 3-D locations varied inversely with canopy cover and stem basal area. The proportion of 3-D locations was 9-12% when collars were placed directly on the trunk of the tree compared to 48-63% when placed between stems.

Only 50% of location attempts in the backpack trial were successful. There was no relationship between the percentage of successful location attempts and canopy closure ($r_s$ = 0.06, P » 0.05, N = 24). The built-in activity sensor registered the maximum number of movements, i.e. 255 per 5-minute interval, in 67% of all location attempts.

Percentage of successful location attempts for collars used on moose was 76% and 73%, respectively, over the whole study period. Success rate was higher

Table 1. Performance of GPS collars on two free-ranging moose. Number of location attempts is given in parentheses.

| | Moose #1 | | Moose #2 | |
|---|---|---|---|---|
| Time period | % successful location attempts | % 3-D locations | % successful location attempts | % 3-D locations |
| March - 31 May | 80 (691) | 36 | 86 (829) | 46 |
| 1 June - 31 August | 70[1] (370) | 30 | 76 (1,209) | 32 |
| 1 September - 31 December | | | 57 (971) | 34 |

[1] Locations recorded until 27 July

for the period early March - 31 May than for the period 1 June - late July (both animals). For the collar still operative after 31 July the percentage of successful location attempts was lowest during the period 1 September - 31 December (Table 1). This collar produced at least one valid location per day for 277 of the 296 days. Of the successful locations 36% were in 3-D mode and 64% in 2-D mode (both animals). The proportion of 3-D locations was highest during late winter and spring (see Table 1). Seventy-five percent of the 3-D and 89% of the 2-D locations had DOP < 5.

## Discussion

Locational errors for both 2-D and 3-D locations were as expected for non-differentially corrected GPS (Rempel et al. 1995, Moen et al. 1997). The use of differentially corrected GPS may increase precision to <30 m 95% of the time (Moen et al. 1997). The DOP > 5 cut-off affected locational accuracy in 2-D mode but not in 3-D mode. Rempel et al. (1995) reported similar results. Thus, it might be advisable to exclude all 2-D locations with DOP > 5 to increase precision.

My results are concordant with earlier studies indicating that under open sky or under thin canopy cover 90-100% of attempts will result in GPS locations (Moen et al. 1996). Under increasing canopy closure the percentage of successful location attempts decreases. Rempel et al. (1995) recorded a stepwise effect of reduced satellite signal visibility, with the first effect being a reduction in the proportion of 3-D locations followed by an increased number of failed location attempts. They also found that stem density had a stronger impact than canopy closure *per se*, although in practice these factors could be expected to be interrelated.

With reservation for the small sample size, the backpack trial indicated that movement may negatively affect GPS collar performance. Moen et al. (1996) recorded no effect of moose movement (feeding, walking, and 'other') on a penned animal. This discrepancy may partly be explained by low movement speed and preference for habitats with thin canopy of this particular animal (R. Moen, pers. comm.). The activity registrator recorded a maximum number of movements for every second registration period during the walking trial (5-minute interval), which was much higher than on moose (L. Edenius, unpubl. data).

On moose approximately 75% of location attempts resulted in locations. Rempel et al. (1995) reported a success rate of 76% for different canopy types during a 2-week winter field trial, while Moen et al. (1997) recorded 82% during their March - August field trial. In my study the percentage of successful location attempts was higher during the period March - 31 May than during 1 June - 31 August, and so was the proportion of 3-D locations. Moen et al. (1997) also noted a reduction in the percentage of successful location attempts under canopy cover. The low percentage of successful locations during fall, i.e. after 1 September, gives cause for concern. According to Hjeljord, Hövik & Pedersen (1990), moose show a high preference for old forest during fall compared to summer in southeast Norway. The reduction in the percentage of successful location attempts during fall thus may reflect habitat choice.

Results are now accumulating to show that GPS may be a very valuable tool in wildlife telemetry studies. GPS provides a high accuracy and known precision of locations, and reliability in terms of high percentage of successful location attempts under all weather conditions and at all hours of the day. The effect of habitat choice has to be addressed further. Since time is recorded for each location attempt, one way to approach this problem may be to analyse movement vectors after integration of habitat data in a Geographical Information System (GIS) (Rempel et al. 1995).

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