REAL-TIME MOOSE TRACKING: AN INTERNET BASED MAPPING APPLICATION USING GPS/GSM-COLLARS IN SWEDEN

Holger Dettki[1], Göran Ericsson[2], and Lars Edenius[2]

[1]Department of Forest Resource Management and Geomatics, Swedish University of Agricultural Sciences (SLU), SE – 901 83 Umeå, Sweden; [2]Department of Animal Ecology, Swedish University of Agricultural Sciences (SLU), SE – 901 83 Umeå, Sweden

ABSTRACT: To date, moose (*Alces alces*) tracking has relied on techniques either based on 'Very High Frequency' (VHF) / 'Ultra High Frequency' (UHF) radio collars, or Global Positioning System (GPS) collars, often requiring significant effort in the field to collect data. Here we present a technique that automatically tracks and reports moose in almost real time, and presents moose positions and movement paths with an interactive web-based map service. We equipped 25 female moose with GPS/GSM collars in Västerbotten county, northern Sweden. The GPS receivers acquired a position every 30 minutes and transmitted them after 3.5 hours as a standard Short Messaging Service (SMS) message using the Global System for Mobile communications (GSM) cell phone network. The positions were automatically extracted from the receiving local GSM-modem and stored in a database. During 18 days in March 2003, 18,638 GPS positions were transmitted by 2,719 SMS messages. Of all positioning attempts 98.1% resulted in a valid position, whereof 99.7% were 3-dimensional positions. The real-time approach allows for many new research studies; e.g., small-scale migrational studies with adapted GPS schedules for different phases of migration. Further, public access to the moose data by a web-based map can be of fundamental importance for public acceptance when dealing with local concerns.

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A large fraction of the moose (*Alces alces*) population in Northern Sweden migrates between summer and winter home ranges (Ball et al. 2001), creating locally concentrated problems for forestry. Areas prone to extensive winter browsing by moose are often associated with extensive areas of economically valuable sapling stands of Scots pine (*Pinus sylvestris*). Access to accurate and up-to-date information is an important requisite for effective co-management of moose and forest resources. In order to mitigate and reduce conflicts arising because of strong browsing pressure in such winter concentration areas, improved knowledge about moose movement and ranging behaviour at the regional and landscape scale in relation to available winter browse is important. Such insights may greatly facilitate co-operation among hunters, foresters, and managers over management issues.

To date, ungulate tracking used to, for example, study migration and movements of large ungulates has relied either on techniques based on traditional radio-telemetry using 'Very High Frequency' (VHF)- or 'Ultra High Frequency' (UHF) radio collars (e.g., Heezen and Tester 1967, Hundertmark 1998, Ericsson et al. 2001) or in recent years more and more on Global Positioning System (GPS) telemetry (e.g., Rempel et al. 1995, Moen et al. 1996, Edenius 1997, Hundertmark 1998, Turner et al. 2000). GPS is a US based satellite-aided navigation system that allows the calculation of positions worldwide with about ± 10 m precision. Using a small handheld receiver a position can be calculated by triangulation when signals from at least 3 different of 21 available GPS-satellites are received. Extensive studies have been conducted to evaluate the performance of GPS collars under different environmental conditions (e.g., Moen et al. 1996, Edenius 1997, Moen et al. 1997, Struch et al. 2001). However, existing systems have the disadvantage that significant labour is required in the field for acquiring locations (VHF/UHF) or to extract on-board stored positional data from GPS collars via a local radio-link. The alternative, to download stored data after retrieval of a collar from an animal, always faces the risk of total data loss due to both mechanical collar failures or loss of the animal. Further, visualisation and spatial analysis of the data often require considerable investments in Geographic Information Systems (GIS) software and education. The aim of this paper is to describe a framework for tracking and displaying moose positions and movement paths in almost real-time with a web-based map service, which provides simple statistics on positions and movements.

STUDY AREA

The study area was located near Åsele in the county of Västerbotten, Sweden (64 °06'N 17°18'E; Fig. 1). The 2,200 km^2 area has a winter density of 1.3 moose/km^2 with local concentrations up to ≥12.5 moose/km^2 (Andersson 2002). The climate is predominantly continental with relatively short summers (1 June - 10 Sept.) and the length of the growing season is 150-160 days with an onset between 10 May and 20 May. Average annual temperature is 2-3°C. The onset of winter is normally the first week of November and lasts to mid-April. Annual precipitation ranges between 600 and 700 mm. The ground is usually snow-covered from the first week of November to the last week of April. Maximum snow depth peaks at 70-80 cm in late February. Climatic data were averaged from the period 1961-1990 (Raab and Vedin 1995).

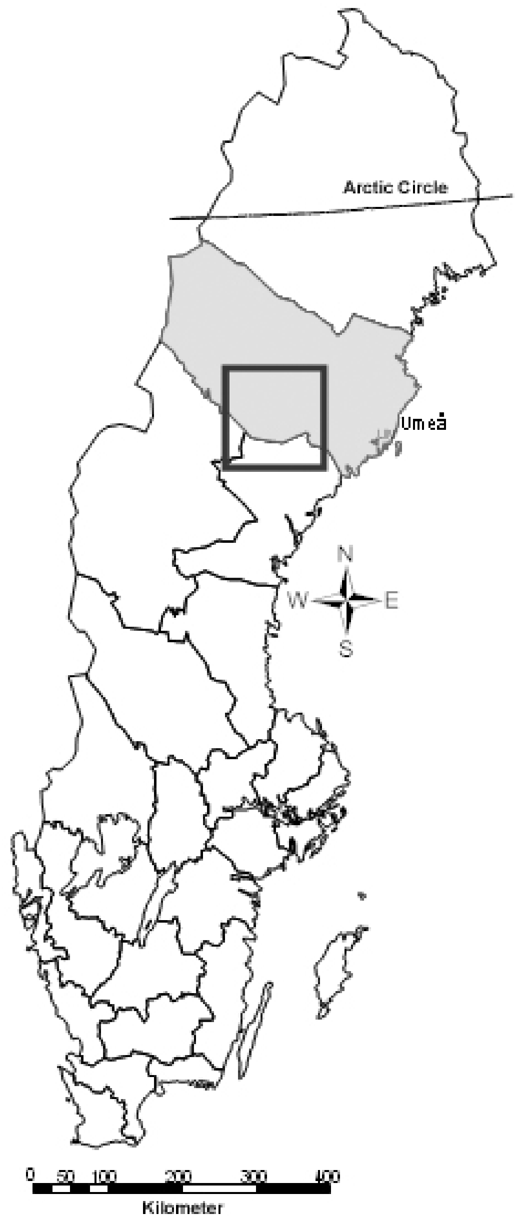

Fig. 1. The county of Västerbotten in Northern Sweden shown with the study area (rectangle), the city of Umeå, and the Arctic Circle indicated.

METHODS

GPS/GSM Collars

We equipped 25 female moose with GPS collars (GPS/GSM Plus 4D) from Vectronic Aerospace GmbH (Fielitz 2003) and uniquely numbered ear-tags during 1 - 5 March 2003. The collars weighed ca 1.1 kg and were designed for a battery lifetime of 1.5 years. We immobilised the moose from a helicopter using a dart gun injecting a mixture of anaesthetic and tranquillizer (ethorphine and xylazine; Sandegren et al. 1987). Moose were aged according to tooth wear (Ericsson and Wallin 2001), which is in agreement with the cementum annuli method ≤5 years of age (K. Wallin and G. Ericsson, unpublished data).

Twelve-channel GPS receivers mounted on the collars acquired a position every 30 minutes and stored them internally for later download. Each collar was equipped with a cell phone unit using the widely available Global System for Mobile communications (GSM) network in Europe, the second generation digital cell phone technology. The unit consisted of a 'dual band' module, i.e., it could use the common GSM frequencies in Europe of 900 MHz and 1,800 MHz. After 7 positioning attempts with a time interval of 0.5 hours, the GSM unit was programmed to send these 7 positions each 3.5 hours as a standard Short Messaging Service (SMS) text message to a GSM-modem located at the Swedish University of Agricultural Sciences (SLU) in Umeå, Sweden (63°49'N 20°16'E; Fig. 1). Despite the fact that the GSM technology does not require a free line of sight towards a GSM relay transmitter, the study area contains gaps with low or no coverage due to weak signals or partial signal blackouts in very remote or mountainous areas. Thus, not every SMS message could be transmitted immediately after the seventh position was acquired. Therefore the collars were programmed to always send a SMS message with the latest 7 positions first and then check for unsent positions stored in the collar when within an area with sufficient GSM coverage. If unsent positions were found, up to 10 SMS messages with a total of 70 positions were sent, starting with the latest unsent position. After sending, the GSM module went into a 'sleep' mode to preserve battery capacity and tried to send the next 7 positions and eventually the remaining unsent positions during the next sending opportunity (i.e., 3.5 hours later).

After the GSM-modem received a SMS message (Fig. 2), the positions were automatically extracted and the co-ordinates converted to the National Grid of Sweden and stored in a SQL-server database. Together with the positions, the exact date and time, altitude, dilution of position (DOP), type of position (2-dimensional or 3-dimensional), battery voltage, and the internal temperature of the collar were transmitted and stored in the database.

After one year, the collars will be retrieved manually by darting the moose. To locate a collar for retrieval in areas without GSM coverage, collars were additionally equipped with a permanent VHF transmitter. After retrieval, all data can be downloaded from the collars. Due to SMS message size limitations not all registered data (e.g., data from the built-in activity sensors for the animals X- and Y-axes) for each position are transmitted by SMS, but stored in the collars for later analysis.

Data Retrieval and Presentation

Digital topographical landcover maps (original scale 1:100,000) obtained from the Swedish National Land Survey were used as background maps. They were stored on a web server and accessed by the ArcIMS 4.0 engine (ESRI 2002) and the Internet Information server 5.0 (IIS 5.0; Microsoft Corporation 2000). A web application built with the Active Server Page technology

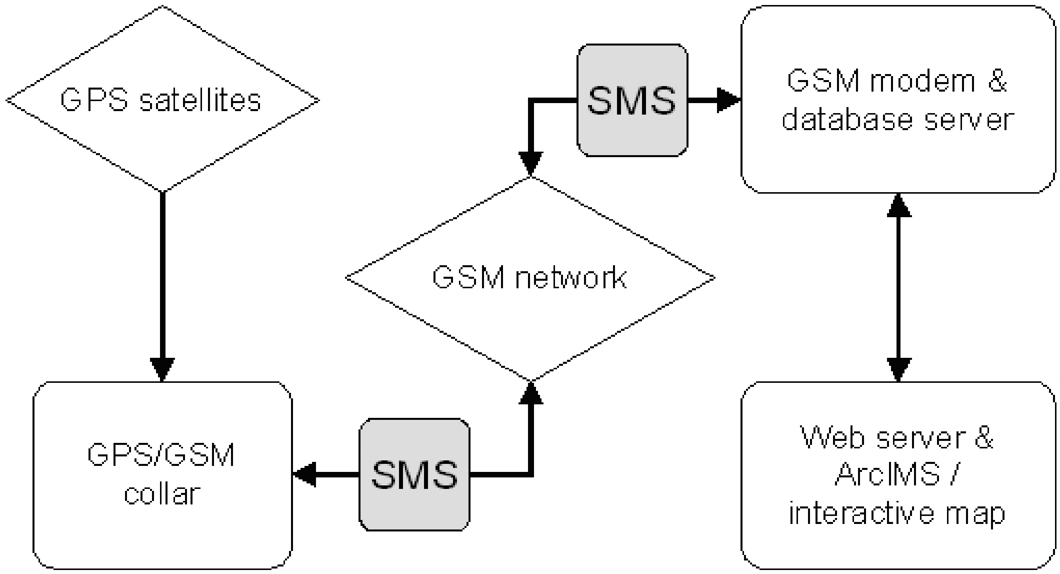

Fig. 2. Schematic description of the information flow: Positional information from the GPS-satellites is stored in the collar, and transmitted by the GSM network using SMS messages to a database server to be accessed as a map on the internet.

(ASP) and Visual Basic, both in the .NET environment (Richter 2002), extracted the positions for one or more moose and overlaid them on the background maps (Fig. 3a) using the ActiveX connector and ArcIMS (ESRI 2002) as positions or moving paths. Further, position co-ordinates for each recorded position (Fig. 3b) or simple statistics on path length or numbers of positions were shown as tables.

RESULTS AND DISCUSSION

GPS Positions and Data Transfer

Between 1 - 18 March 2003, 18,638 GPS positions were registered for the 25 moose in the database. Of all positioning attempts in the field, 98.1% were successful (Table 1), resulting in 99.7% 3-dimensional positions. The dilution of precision (DOP) value as a measure of positional precision (Moen et al. 1997) was < 2.0 for 75.1% of all positions. Based on these figures, the estimated number of valid positions will be ca 15,120 positions per moose and year.

All stored position data were transmitted by 2,719 SMS messages. Of all SMS messages 95.3% were successfully sent immediately after 7 positions were registered, while 4.7% were delayed because of the moose being outside an area with GSM coverage during the time of transmission (Table 2). Maximum delay time between two consecutive SMS transmissions for a

Table 1. Number of valid GPS-positions in the database during the first 18 days (1 - 18 March 2003). Data are given for 2-dimensional (2-D) and 3-dimensional (3-D) positions as well as positions with a dilution of position (DOP) <2.0. The number of attempts to obtain a position (fix) is also given for the same period.

	2-D	3-D	Total
Fix-attempts	—	—	19,004
Valid positions	64	18,574	18,638
DOP < 2.0	21	13,974	13,995

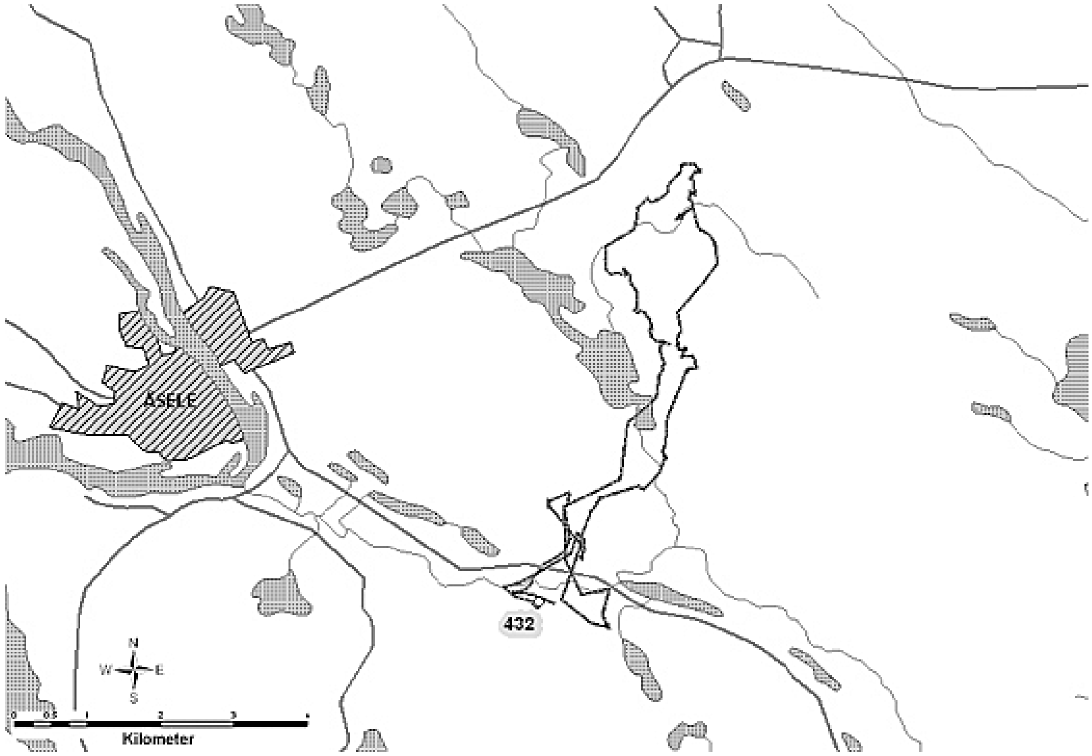

Fig. 3a. Example of a movement path for moose '432' on 18 March 2003 near Åsele in the county of Västerbotten, Sweden on the interactive web-site represented (a) as a map and (b) as a table of positions within the movement path. On the map, the circle at one end of the movement path (dashed line) indicated the last transmitted position. In the table the moose name or ID, the local date and time for each position, the northing, easting, and height above sea level ('RN North', 'RN East', and 'RN Height'; coordinates in the National Grid of Sweden, in meters), and the dilution of position (DOP) value were given. Further, it was noted in field 'Nav' whether the position was 3-dimensional (3D) or 2-dimensional (2D), and a temperature measure ('Temp', in degrees Celsius) was given.

Fig 3b.

Name	Date	Time	RN North	RH East	RN Height	DOP	Nav	Temp
432	2003-03-18	23:30:56	7115322	1580400	311.6	1.2	3D	6
432	2003-03-18	23:00:24	7115313	1580406	323.3	1.4	3D	6
432	2003-03-18	22:30:06	7115320	1580406	335.9	2	3D	6
432	2003-03-18	22:00:26	7115320	1580401	322.5	3.6	3D	6
432	2003-03-18	21:30:49	7115315	1580404	322.5	1.4	3D	5
432	2003-03-18	21:00:20	7115307	1580405	319.6	1.4	3D	5
432	2003-03-18	20:30:07	7115319	1580411	318.5	2	3D	5
432	2003-03-18	20:00:49	7115310	1580411	308.6	3.8	3D	5
432	2003-03-18	19:30:20	7115348	1580418	323.5	1.6	3D	2

single moose lasted 137.5 hours. We expect the percentage of delayed messages to increase during the year, as many of the collared moose may eventually migrate towards more remote, mountainous areas with a more fragmented GSM coverage. On the other hand, the GPS positioning success rate should remain quite constant, as the vegetation coverage, which is the main obstacle for the reception of the satellite signals for position calculation, is similar throughout the study area.

Data Access and Presentation

All moose data can be accessed by using a web page either as a map with positions and movement paths (Fig. 3a), or as a table of positions (Fig. 3b). Further, as the data are stored on a SQL-database server, the data are available on virtually any computer connected to the Internet. Hence, more sophisticated data analysis can be conducted locally using standard GIS packages.

The data were also made accessible to the public on an interactive web page showing moose locations and movement paths on a map (http://www-moosetrack.slu.se). Data access, however, was restricted to positions older than 2 weeks and no tables with positional data were given to avoid disturbance of the animals. The application is already heavily used by local residents, media, hunter associations, and forest companies for different reasons. Interest of local residents has so far been focused on comparing local knowledge on moose movement to actual movement as displayed data on maps on the Internet. Furthermore, several schools in Sweden have started to use the real-time information on the web site in education on wildlife ecology and management. We also anticipate an increased interest from the tourist industry, for example, by using the Internet interface to explore the charismatic value of moose to attract visitors, as a wild moose in many countries is recognized as a symbol for undisturbed wilderness. Moreover, we foresee that forest companies and hunter associations increasingly will use real-time information on moose activity to facilitate communication to help resolve conflict situations. Lastly, we expect to see an increased public interest channelled into projects such as 'adopting' a moose. Hence, public interest in real-time moose movement may deepen acceptance of moose populations in managed forest areas.

Pros and Cons

Monitoring of moose movement in almost real-time enables a quick reaction to possible problems with either animals or collars. For example, one of the collared moose stopped moving a few hours after darting and outfitting with a collar, and the collar temperature started to decrease over a period of 12 hours. It was possible to

Table 2. Number and percentage of SMS messages received during the first 18 days (1 - 18 March 2003) for different time intervals between SMS receptions.

Time (t)	#SMS received	Fraction at (t)
	2,719	100.0%
Directly (after 3.5 h)	2,590	95.3%
after 7.0 h	74	2.7%
after 10.5 h	13	0.5%
after 14.0 h	18	0.7%
after 17.5 h	16	0.6%
after 21.0 h	3	0.1%
> 24 h	5	0.2%

immediately revisit the animal to check on the health status of the moose. Though the moose was fine, technical problems with the collar were detected and corrected quickly with remote re-configuration to minimize data loss.

The major advantage of the technology used in this study is the ability to collect a large amount of data in almost real-time with minimal labour required. In a previous project conducted in the county of Västerbotten (Dettki et al. 2003), 15 moose were equipped with GPS collars over a period of 4 years, resulting in 17,036 valid positions. A varying GPS schedule was applied, resulting in 1 position per moose each hour, and up to 1 position per moose a day. The data were available first after the collars had been retrieved manually. In the current study, after only 18 days, 18,638 positions were recorded for 25 moose, applying a GPS schedule with 1 position per moose and 0.5 hours. While data handling in the previous study was done manually, in the current project it is necessary to use automated routines to handle the relatively large amount of data. Only basic supervision of the servers is required to handle the incoming data from the download of a SMS message from the GSM-modem, conversion of positions into local grid format, error check of both SMS and positional data, storage in the SQL-database and finally presentation on a map. This results in high efficiency in data retrieval and manipulation and very low costs per position, as the number of received positions is high and labour required is low.

However, some disadvantages with the technology exist. First, the amount of data transmitted by SMS is mainly constrained by the allowed size of each SMS, which is internationally standardized to a maximum of 160 characters per message. This prohibits transmission of additional data by SMS, such as activity and mortality data. Furthermore, SMS transmission drains battery power and is costly, so there are tradeoffs to be made. Even though the costs per position transmitted are small (approximately US $0.02 per position with 7 positions in each SMS message), during 1 year the costs for data transmission add up to approximately US $350.00 per collar with a position taken every 0.5 hours. Battery capacity continues to be a bottleneck of GPS/GSM-systems, especially for long-duration studies or small-sized animals. The same problems arise for transmitting data for differential post-processing, which would increase the amount of necessary SMS messages to be sent at least 3-fold. However, with a precision of ± 10 m with uncorrected positions, most applications likely do not have the need of differential real-time corrections.

The far greatest disadvantage is the limitation due to the fragmented or non-existing coverage of the GSM network in remote areas in many parts of the world. The Scandinavian countries differ in this respect from, for example, North America or Russia. In Sweden, about 75% of the land area is covered by at least one GSM network (TeliaSonera 2003). However, even though all bigger roads and settlements in northern Sweden have at least some degree of GSM coverage, coverage is poor in more remote areas. We tried to reduce this problem by programming the collars to deliver all stored positions at least once by SMS when the animal is within or re-enters into an area with sufficient GSM coverage. During the first 18 days, all positions stored on-board were also retrieved by SMS, even though some moose collars were out of contact with the GSM-network for up to 137.5 hours. It is important to note that SMS transmissions require less net coverage than is required for oral communication by cell phones or GSM data transfer. This means that the technique is applicable also in areas where it is not possible to use a cell phone for talking, due to fragmented GSM coverage.

Implications

The GPS/GSM-technique gives a new possibility to 'supervise' animals in almost real-time. For research this means one can see when, e.g., the migration starts, and then via SMS, change the GPS schedule scheme to acquire positions more frequently. It further opens up the possibility to determine in real-time when migration is over, i.e., when moose have reached their final destination. Wildlife managers then can use lethal or non-lethal methods to immediately break up concentrations of moose if they are in conflict with other forestry management goals in the area, for example, sapling stands of regenerating Scots pine. For researchers, the improved GPS/GSM-technique will mean less ad-hoc testing and less guess work in terms of what periods are interesting for data collection to test behavioral hypotheses. There is a great potential for time (habitat budget), disturbance studies, detailed movement, and habitat studies.

The notion that the GPM/GSM-technique is only possible to use in Europe or other densely populated areas is not necessarily true. The GSM-system is expanding in Canada and the US, and moose populations near some urban settlements are growing. We suggest that a few moose equipped with GPS/GSM collars which report to an interactive web-page will have fundamental importance; e.g., public acceptance when re-introducing moose. It will furthermore be of great help to make research more acceptable and stimulate public interest in wildlife management.

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