GPS COLLARS FOR MOOSE TELEMETRY STUDIES: A WORKSHOP[1]

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ABSTRACT: This paper provides outlines of presentations made during a special session devoted to GPS-based telemetry systems at the 32nd North American Moose Conference and Workshop, Banff, Alberta, April 20 - 24, 1996. The intent of this session was to provide an overview of GPS technology and to relate early experiences with GPS-based telemetry systems. Performance of these new systems under both controlled and field situations were discussed. Consideration was given to issues of data management and analysis, including estimation of home range characteristics using existing software packages and integration of GPS location data with remotely sensed digital habitat data in a Geographic Information System. Cost comparisons among telemetry systems used in moose studies were made. Future directions of GPS-based telemetry systems were also discussed.. This special session demonstrated that GPS-based animal location systems have the potential to set new standards for habitat-resource utilization studies of large animals over the next 5-10 years.

ALCES VOL. 33 (1997) pp.203-209

The need for an efficient, cost-effective way to collect large amounts of highly accurate location data from free-ranging animals has prompted the development of new telemetry devices based on the NAVSTAR Global Positioning System (GPS) (Rodgers *et al.* 1996). These novel animal location systems provide data 24-hours-per-day under all weather conditions and, most importantly, with an accuracy and precision that is at least two orders of magnitude improvement over previous methods. GPS collars are the most significant advance in wildlife telemetry in more than 20 years.

Given the potential significance of GPS telemetry for studies of moose and other large mammals, a special session devoted to this new technology was held at the 32nd North American Moose Conference and Workshop, Banff, Alberta, April 20 - 24, 1996. The primary objectives of this session were to provide an overview of GPS technology and to relate early experiences with GPS-based telemetry systems. Performance of these new systems under both controlled and field situations were discussed. Consideration was given to issues of data management and analysis, including estimation of home range characteristics using existing software packages and integration of GPS location data with remotely sensed digital habitat data in a Geographic Information System (GIS). Cost comparisons among telemetry systems used in moose studies were made. Future directions of GPS-based telemetry systems were also discussed. Outlines of conference presentations covering these topics are provided in the following sections. The author

[1]Order of authorship determined by the sequence of presentations at the 32nd North American Moose Conference and Workshop, Banff, Alberta, April 20-24, 1996.

responsible for each presentation is identified at the beginning of each section and may be contacted directly for more information related to the particular topic.

A GPS-based animal location system - Arthur R. Rodgers

To evaluate the "*Timber Management Guidelines for the Provision of Moose Habitat*" in Ontario, an efficient, cost-effective way to collect large amounts of highly accurate location data from free-ranging animals was required. In 1992, the Ontario Ministry of Natural Resources, several Canadian hydro-electric utilities, and the Canadian Electrical Association contracted Lotek Engineering Inc. (Newmarket, Ontario) to design and develop a new wildlife tracking system based on the NAVSTAR Global Positioning System (GPS) (Rodgers and Anson 1994). The Lotek GPS animal tracking system consists of remote units attached to the study animals and a command unit operating from a vehicle or aircraft. Two-way communication between an animal unit and the command unit is handled by UHF radio modems. The UHF modems have an operating range > 15 km (line-of-sight). An operator controls the command unit from an ordinary personal computer running the system software. The system software provides a menu-driven interface for user control of system parameters, communication services, and formatting and storage of received data. Data available from an animal unit consists of geographical coordinates, date, time, and optional sensor information. These data are stored cumulatively in a dedicated bank of non-volatile random access memory, allowing storage of up to 3,640 records. The standard 400-g lithium battery pack provides approximately 1 year of operation at 8 fixes/day (every 3 hr) with VHF beacon and modem functions operating 16 hours/day. A 700-g battery pack is available, which may provide 2 years of operation. With the standard battery pack attached, the total weight of the animal collar is approximately 1.8 kg. An overview of additional operating features of the Lotek GPS animal location system was provided in this introductory session.

Performance of GPS under boreal forest canopy - Robert S. Rempel

GPS technology has the ability to determine positions with accuracy ranging from millimetres to tens of meters. In this presentation I discussed some of the issues surrounding accuracy of various Global Positioning Systems, and then presented results of a controlled study on the effects of boreal forest canopy (tree spacing, height, and canopy closure) on GPS location accuracy and signal reception. The performance of nondifferentially corrected GPS collars was evaluated in an experimental forest with mature, evenly spaced trees (Rempel *et al.* 1995). Animal units were placed at ground-truthed positions in pure stands of black spruce (*Picea mariana*) planted at spacing densities of 1.8, 2.7, and 3.6 m, red pine (*Pinus resinosa*) at spacing densities of 1.8 and 3.6 m, jack pine (*P. banksiana*) with 1.8 m spacing, a mixed-wood stand, and an adjacent open field. Position accuracy was not affected by tree species, spacing, height, basal diameter, or canopy closure. However, mean observation rate (i.e., ratio of total possible fixes to actual fixes taken) generally declined with increasing tree density, height, and canopy closure. With the exception of a red pine stand (1.8 m) in which mean observation rate was 0.10, values ranged from 0.54 in a black spruce stand (1.8 m) to 0.92 in the jack pine stand. Mean observation rate in the open field was 0.97. Location error was greater if positions were based on 2-dimensional rather than 3-dimensional mode of operation (median errors of 65.5 and 45.5 m, respectively). When these experiments were repeated with differentially corrected GPS collars, median location error in 2-dimensional mode dropped to 6.7 m and in 3-dimensional mode to 3.6 m (Rempel and Rodgers 1997). However, implementation of differential correction may involve substantial costs, so effectiveness of this enhanced technology must be judged against study objectives and data requirements of the hypotheses being tested.

Evaluating the Lotek GPS collar: locational accuracy, effects of canopy cover, and moose behaviour - Ron Moen

We discussed 2 features of the Lotek GPS_1000 collar. An activity counter can be used to infer relative activity of collared animals between GPS location attempts (Moen *et al.* 1996a). Direct observations of a collared moose indicated that if activity counts were low then the moose was inactive. In contrast, if activity counts were high, there was a possibility that the animal was inactive. These high activity counts could have been due to software bugs or due to collar placement on the animal. When collars were placed on free-ranging moose in northern Minnesota, the activity counts showed expected daily patterns of feeding bouts and resting bouts of 1 to 2 hours duration when activity counts were not averaged. When activity counts were averaged (a scheme devised by the collar manufacturer because of memory and power limitations) then the patterns of activity and inactivity were less apparent. We also discussed the relative accuracy of GPS locations using post-processing software to calculate differential and uncorrected mode GPS locations from the same satellite pseudo-range and ephemeris data. We compared accuracy by calculating all possible combinations of 3, 4, 5, or 6 satellites when the GPS collar found 6 satellites in a location attempt while it was stationary in the open. Accuracy of differential mode positions increased as the number of satellites available to calculate a position increased. When 6 satellites were available then the calculated location was < 11 m 95% of the time. When 4 satellites were available then the calculated location was < 29 m 95% of the time. In uncorrected mode locations, the 95% distances were 109 m when 6 satellites were used, and 196 m when 4 satellites were used. 2-dimensional positions are calculated when only 3 satellites are available to calculate a position. They can be as accurate as 3-dimensional positions if the altitude of the GPS collar is known to within about 25 m. When the error in altitude is 150 m, the 95% distances are 187 m for differential mode locations and 276 m for uncorrected mode GPS locations. These different accuracies are important because on free-ranging moose about 25% of location attempts fail, 25% result in finding 3 satellites, and 4 or more satellites are found in 50% of the location attempts. Thus, the user of these collars must be aware of effects of animal movements and habitat choice when determining expected accuracy of GPS locations, rather than assume that accuracy will be as stated in normal GPS applications (Moen *et al.* 1996b).

Performance of a GPS animal location system in rugged mountainous terrain - John Paczkowski

Although GPS collars are being used more frequently in wildlife research, there is little information about the performance of GPS in mountainous terrain. We tested a Lotek non-differential GPS collar to investigate the effect that aperture of available sky has on location error and data acquisition. The GPS collar was placed at 25 surveyed bench marks throughout the Bow Valley and Kananaskis Country at locations of varied slope, aspect and elevation. The collar was programmed to store a location every 15 minutes, and was moved every 24 hours over a 30 day period. Mean location error was 186.6 m and 981.4 m for 3-dimensional and 2-dimensional locations respectively. A Geographic Information System (IDRISI;

Clark University, Worcester, Massachusetts) was used to calculate the aperture of available sky from each bench mark location. There was no significant relationship between the amount of available sky and the location error or rate of data acquisition.

Application of GPS technology to radio telemetry using an ARGOS up-link - Charles C. Schwartz

We tested the first prototype global positioning system radio transmitter ever deployed on a brown bear (*Ursus arctos*). The collar was fitted with a Trimble GPS receiver (Sunnyvale, California) and an ARGOS satellite uplink (Landover, Maryland). The collar was set to take 4 GPS fixes per day. Data were stored onboard the collar and retransmitted once per day to the ARGOS satellite. Data were then retransmitted from the satellite to a base station in Landover Maryland where we retrieved it via telephone modem. The prototype was tested 29 days on an adult female brown bear and an additional 36 days in various vegetation types while not on a bear. The GPS unit successfully obtained 95 of a potential 116 fixes (81.9%) and transmitted the data to the ARGOS satellite successfully 100% of the time. In addition, we obtained 24 of 29 ARGOS position fixes. When placed in various vegetation types, the GPS unit successfully obtained 100% of potential fixes when (1) open to the sky, (2) in mature aspen (*Populus tremuloides*) forest, and (3) regrowth hardwood forest less than 2 m high. Success declined to 97, 90, and 86% in mature paper birch (*Betula papyrifera*), regrowth white spruce (*Picea mariana*), and mature spruce forests, respectively. The GPS unit did not collect and retransmit data necessary to differentially correct locations, so accuracy was assumed to be similar to conventional non-corrected fixes (± 100m).

Field trials of the Lotek GPS collar on moose - Arthur R. Rodgers

To verify use of the Lotek GPS tracking system for the Moose Guidelines Evaluation Project (MGEP), a pilot study was undertaken in March, 1994 (Rodgers *et al.* 1995). The world's first commercially available GPS units were deployed on 8 adult cow moose in northwestern Ontario. Deployed animal units were downloaded for the first time at the end of March, 1994, and then bi-monthly thereafter. More than 5,700 records were downloaded from the eight collars during 1994. Downloaded data indicate that the animal units reliably attempted GPS location estimates every 3 hours as expected. The mean observation rate (i.e., proportion of successful fix attempts) of deployed units was 0.65, but varied widely from 0.50 to 0.92. The proportion of successful 2-dimensional (2-D) position estimates (i.e., latitude and longitude only) exceeded the proportion of 3-dimensional (3-D) fixes (i.e., latitude, longitude and altitude) in all GPS units, giving an overall ratio of 3.4:1. At the same time, mean DOP values reported with 2-D fixes (3.290 ± 2.179) were slightly less than those recorded with 3-D fixes (3.728 ± 0.980). A plot of the animal data showed a pronounced pattern of habitat patch use by all moose. Each animal resided in a small area (<1km^2) for up to 2 weeks, then moved directly to a new patch up to 10km away, and so on. The success of the pilot study led to full scale implementation of the MGEP project during a 9-day period in February, 1995. 60 adult cow moose were successfully captured and processed by Helicopter Wildlife Management Inc. (Salt Lake City, Utah): 35 in areas harvested according to Ontario's "*Timber Management Guidelines for the Provision of Moose Habitat*" and 25 in an area that has been progressively clearcut since 1978. During the first week of June, 1995, 58 of the GPS collars were downloaded for the first time. Over the first 4 months each collar accumulated more than 900 records in memory, providing a total of more than 50,000 records. By the end of August, the collars had recorded more than 80,000 records: yielding more location estimates than any previous study of moose in North America.

Software packages for estimating home range size of moose fitted with GPS collars: handling large amounts of locational data - Elise J. Lawson

A discussion of new challenges in handling large amounts of locational data from individual moose, particularly conversion of data for entry into different software packages (i.e., GPSHOST, differential correction of data, SAS, home range programs, SPANS, ARCINFO). Criteria used in the selection of home range analysis programs were presented and comparisons of the similarities and differences among 4 software packages (CALHOME, HOME RANGE, RANGES IV, TRACKER) were made. The most important differences among analysis programs were: (1) maximum number of allowable locations as input; (2) types of home range estimators calculated; (3) variations in algorithms used to calculate home range estimators; (4) ability to export polygon edge coordinates for use in Geographic Information Systems; and (5) ability to perform autocorrelation analyses. Comparisons of home range sizes calculated by different packages were made using GPS collar data from an individual moose (n=483 locations). We found large differences in calculated home range sizes using Minimum Convex Polygon (MCP) and Harmonic Mean (HM) estimators at 2 levels of resolution (95% and 50%). For example, using 95% of the locations, estimates ranged from 39.96 to 62.26 km^2 in MCP analyses and 31.60 to 90.98 km^2 in HM analyses. Such wide variation among home range sizes provided by different software programs are the result of differences in the algorithms used to calculate the estimators, decisions made with regard to the various options offered by each package in the calculations of the estimators, and values input for various parameters. Based on our observations, comparisons of animal home ranges among studies can be misleading unless researchers report the software package used, which home range estimators have been calculated, user-selected options for calculating each estimator, and the input values of required parameters. Indeed, changing home range analysis software during the course of a research project could invalidate comparisons within a single study.

Integration of GPS, GIS, and remote sensing data - Michael J. Gluck

New GPS tracking technology can dramatically enhance the ability to accurately track movement of wildlife, but its real power comes from the integrated analysis of location data with habitat data. This presents new challenges for biologists in developing protocols and techniques to bring data sets together for analysis. In this presentation I discussed how GIS provides a robust system for accurately integrating digital wildlife location data (GPS) with digital habitat data (remote sensing). Issues of how map projection, coordinate system, and geodetic datums affect co-registration of datasets were discussed. A working example, from start to finish, demonstrating how we solved these problems was presented.

Cost comparisons and future directions - Arthur R. Rodgers

Telemetry is an expensive tool in terms of both time and money. There is little doubt that a GPS system can provide greater quality, as well as a larger number of animal locations, than either ARGOS satellite or conventional telemetry (Obbard *et al.* 1997). What is not clear, is whether or not the high costs of a GPS system would be offset by a reduction in aircraft overheads and staffing requirements of conventional telemetry, or how these costs compare to the ARGOS satellite system. To that end, a preliminary cost comparison of implementing a GPS system versus satellite telemetry versus a conventional system was undertaken. Consideration was first given to the basic costs of each telemetry system, then to the costs of starting-up a telemetry program using each system, and finally the extended costs over a five-year period, corresponding to the expected field component of the Moose Guidelines Evaluation Project in Ontario. The general conclusion is that conventional telemetry would be more expensive than either satellite telemetry or a GPS-based system because of the high costs of data acquisition using aircraft. Compared with conventional telemetry, Telonics ARGOS satellite collars (Mesa, Arizona) could reduce costs by 36% over a five-year period. In spite of the higher start-up costs, Lotek GPS collars provide even greater savings by reducing costs as much as 54% over conventional telemetry and 29% compared with Telonics ARGOS satellite collars over a five-year period. A telemetry program based on Lotek GPS collars would be the least expensive over a five-year period because of reduced costs for redeployment and data acquisition. As more and more telemetry manufacturers become involved with the development of GPS-based systems, there will be a further reduction in costs associated with telemetry programs using this new technology. A high priority for further development of GPS-based telemetry systems is the overall reduction in size and weight of units attached to animals. In conjunction with smaller units, several manufacturers are developing "break-away" fastening systems to facilitate recovery of data from collars that may be deployed on small species. Future development will also proceed toward exploitation of Low Earth Orbit (LEO) satellite communication systems for re-transmission of stored data. Participants were invited to make additional comments/suggestions regarding features they would like to see in future systems.

SUMMARY

GPS-based telemetry systems are still in their infancy and a number of difficulties have yet to be resolved. Nonetheless, this special session clearly demonstrated the enormous potential of this new technology. GPS-based animal location systems not only generate large amounts of high quality data, but do so 24-hours/day and under all weather conditions, thereby overcoming the most important limitations of conventional VHF-based systems. Data are readily imported to a GIS for analysis and have the advantage of maintaining the same spatial resolution as habitat-mapping data derived from satellite imagery (e.g., 30 m resolution of Landsat TM data). When position estimates are superimposed on aerial photographs, an unparalleled view of animal movements over and around specific habitat and topographic features is revealed. A GPS system can provide automatic accumulation of data with minimal human intervention, thereby eliminating most human operating errors. Because fewer aircraft overflights are required to obtain animal locations, costs are reduced and data can be collected for more animals with a minimum increase in cost/animal.

Public concern for wildlife and the growth of environmental awareness in the 1980's and 1990's has increased the demand for high-quality studies of animals in their natural surroundings. These studies are particularly necessary in areas that have been greatly modified by human activities. Large-scale alteration of landscapes caused by human disturbances such as mining, timber extraction, and hydroelectric development, require regulatory examination, but new techniques are needed to address the problems. This special session demonstrated that the need

for highly detailed studies of wildlife habitat and resource use in support of scientific research and management policies can be achieved with new GPS-based telemetry systems. This new technology has the potential to revolutionize wildlife research by setting new standards for habitat/resource utilization studies of moose and other large animals over the next 5-10 years.

ACKNOWLEDGEMENTS

Our thanks to Murray Lankester and Tim Timmermann for their helpful suggestions regarding the format of this manuscript and their timely reviews of earlier drafts.

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