INTERPRETING BEHAVIOR FROM ACTIVITY COUNTERS IN GPS COLLARS ON MOOSE

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ABSTRACT: Activity patterns of free-ranging moose can be estimated from activity counts on radiotelemetry collars. We observed a collared moose to calibrate activity counts on a collar to activities of moose in natural habitats. If activity counts on the collar were low, it was likely that the moose was inactive. However, we recorded high activity counts when the moose was active and on 25% of time intervals when the moose was inactive. The high activity counts were probably due to collar placement and possibly due to bugs in the software of the prototype collar we used in 1994. We also analyzed activity counts from collars on 6 free-ranging moose which were not directly observed in 1995. Activity counts were lower from collars on free-ranging moose than from direct observations because collars were placed higher and tighter on the neck. There were cyclic periods of activity and inactivity throughout a 24-hour period when activity counts were taken every 10 minutes on free-ranging moose. We averaged activity counts taken on 10-minute intervals to simulate GPS observation interrvals of 1 to 4 hours typically used in this GPS collar. The correspondence between averaged activity counts and percent of time spent active each day decreased if activity counts were averaged over 2 hr because feeding and bedding periods occur together within the averaging period. We caution that this could affect interpretation of daily activity patterns of moose from activity counts averaged over periods longer than 1 hour.

ALCES VOL. 32 (1996) pp.101-108

Radiotelemetry is used to obtain location and activity information from free-ranging animals. Locations are obtained by visual observation, by triangulation, and by satellite positioning systems. Activity has been estimated by listening to pulse rates from a motion sensitive transmitter in a collar (Garshelis *et al.* 1982, Gillingham and Bunnell 1985). This method discriminated between "active" and "inactive" behaviors with 75 to 90% success rates (Gillingham and Bunnell 1985), and continuous data are available because changes in behavior are recorded as soon as they occur. An alternative approach is to incorporate an activity counter into a collar, store the activity counts on the collar, and periodically download the data. Initial tests of a collar using this approach found 100% discrimination between running and feeding/walking activities (Kunkel *et al.* 1991). Unfortunately, the authors did not observe resting and sleeping activity while the collars were on animals.

The GPS_1000 collar (Lotek Engineering, Newmarket, Ontario) records activity counts with a dual-axis motion sensor that is equally sensitive to vertical and lateral head and neck movements. The GPS capabilities of the GPS_1000 collar have been reported elsewhere (Rempel *et al.* 1995, Moen *et al.* 1996). Activity counts are stored in user-specified time intervals on the GPS_1000 collar. Unlike the collar used by Kunkel *et al.*, the GPS_1000 collar limits activity counts to a range of 0 - 255. The activity count time interval should be set by the user so activity counts do not exceed 255 in the specified time period. The time interval between GPS observations is usually longer than the time interval between activity counts in the

GPS_1000 collar for power conservation reasons. When this happens activity counts from each activity count interval are averaged over the entire GPS observation interval. For example, if activity counts are recorded on 10-minute intervals, and GPS observations are recorded on a 3 hour interval, then the reported activity count will be an average of 18 activity counts. This averaging scheme was devised by the collar manufacturer as a compromise between power consumption and memory requirements of the collar.

Activity count data from these collars have not been validated or calibrated. We observed a moose wearing a GPS collar to calibrate activity counts reported by the collar and moose behavior. We also analyzed activity counts from collars on 6 free-ranging moose for relationships between activity counts and moose behavior, distance moved, and seasonal patterns of activity. We used activity counts from 10-minute intervals collected over 24 hours to determine the utility of averaged activity counts when GPS locations occurred on 1 to 4 hour intervals.

METHODS

Collar Versions

We placed a prototype of the GPS_1000 collar collecting undifferentially corrected GPS locations on a yearling female moose at the Moose Research Center (MRC), Soldotna, Alaska from 17 to 30 June 1994. This moose was observed to determine if the level of activity by the collared animal could be calibrated with activity counts recorded by the collar. We placed the differential mode version of the Lotek GPS_1000 collar (version 2.00) on 6 free-ranging moose in Voyageur's National Park, International Falls, MN. We planned to have 12 months of GPS and activity count data from these 6 collars.

Direct Observations of Moose

The yearling moose ranged freely throughout the 2.5 km^2 enclosure at the MRC. We watched for 3 to 16 consecutive hours each day from distances < 30 m. The time interval between GPS fix attempts and the activity count time interval were both 10 minutes, therefore no averaging of activity counts occurred. Watches were synchronized with GPS units on the collar. We recorded the starting time of behaviors (bedding, bedding and ruminating, feeding, walking, standing, and other) into a portable tape recorder. The starting time and behavior information was later transcribed to determine the time spent active during each activity count interval.

Activity Counts from Free-Ranging Moose

The collars failed due to battery passivation after 4 to 6 months of operation. One collar functioned until 15 June, 3 collars functioned until 20 July, and 2 collars functioned until 20 September. Intervals between location attempts on moose were 10 minutes or 4 hours. Each collar recorded GPS location data and activity counts on 10-minute intervals 1 day per week from 1 March to 15 April, and 1 day every 2 weeks thereafter. On all other days GPS locations were taken every 4 hours. On days with 4-hour GPS observation intervals, activity count data were recorded every 10 minutes and 24 separate activity counts were averaged in each 4 hour period.

We used post-processing software to calculate differential mode GPS locations when collars were on free-ranging moose. Base station data were collected from a Trimble 4000 community base station located in Minneapolis, Minn. This base station is about 375 km from the sites in Voyageurs National Park. Base station files were converted to RINEX format with Dat-Rinx version 1.0 (William Ehrich, Minneapolis, Minn.). Differential corrections were performed with N3win version 1.0 (Lotek Engineering, Inc., Newmarket, Ont.). We converted latitudelongitude locations (NAD83 datum) to the UTM coordinate system (NAD27 datum) with ArcInfo (version 7.0, Environ. Systems Res. Inst., Redlands, Calif.).

RESULTS

Direct Observations of Moose

Data Censoring. -- A bug in the prototype collar software periodically recorded activity counts of 0. We detected this bug because activity counts of 0 were recorded for 78 consecutive 10-minute intervals each day. The prototype collar and software are no longer available so we cannot investigate this bug further. Activity observations were discarded if the 10-minute period occurred within the series of 78 consecutive 0's. Following each series of 78 0's was a series of 1 to 13 activity counts of 255. Although these counts of 255 could have been a part of the software bug, they were not deleted from the data set because they did not occur in a consistent pattern.

Calibration of Activity Counts. -- During the 15 days in which the collar was on the moose, we recorded activities for the entire 10-minute interval on 651 of 1,987 intervals. Activities were bedding (42%), feeding (28%), ruminating while bedded (19%), walking (5%), standing (4%), and other (< 3%). Only 506 of the 10-minute intervals had valid activity count data due to the bug in collar software. The moose was inactive (bedding, ruminating while bedding, or standing) for 280 of these 10-minute periods, and active (feeding, walking, other) for the entire 10-minutes in 148 10-minute periods. Intervals during which the moose was active could be classified correctly 91% of the time using a cutoff activity count of 250 (Table 1). However, 24% of the intervals during which the moose was inactive had activity counts > 250 and would have been incorrectly classified as "active" using the cutoff activity count of 250. Activity counts < 100 indicated inactivity, only 4% of periods when the moose was active for 10-minutes had activity counts < 100. A regression of activity counts on the percent of time the moose was active in a 10-minute period was not significant for the 78 periods in which the moose was both active and inactive ($P = 0.89$, $r^2 = 0.003$).

Table 1. Percent of activity counts in each count range when the moose was inactive (bedding, ruminating while bedded, or standing still) for an entire period (n = 280) and when the moose was active (foraging, walking) for an entire period (n = 148).

Count Range	Inactive	Active
1 - 50	44	3
51 - 100	16	1
101 - 150	7	1
151 - 200	5	1
201 - 250	5	3
>250	24	91

The time which would be incorrectly classifed as active would depend on the fraction of time a moose was inactive each day. For example, under direct observation the moose spent 65% of its time inactive and 35% of its time active. Using a cutoff activity count of 250 to indicate activity, predicted inactive time is 53%, and predicted active time is 47%. This example does not consider the 10-minute periods in which the moose was both active and inactive.

Free-Ranging Moose

Data Problems. -- The first release of the GPS_1000 collar had a new bug in which the activity counter did not always start at the beginning of the 10-minute interval. Activity counts would be similarly affected in all 10-minute periods because the bug was present in all collars at all activity levels. Therefore, activity counts are comparable among the 6 collars on free-ranging moose, but the potential effects of the bug will need to be considered when comparing data collected with the current collar software (ver. 2.10) which does not have this bug.

Activity Counts from Free-Ranging Moose. We analyzed activity counts for 58 24-hour periods with 10-minute GPS location and activity count intervals from collars on moose in Voyageurs National Park. In each of these 24-hour periods there was a series of high activity counts which we interpret as foraging bouts or walking separated by a series of low activity counts which we interpret as bedding (Fig. 1). We estimated the active time per day by specifying a cutoff activity count to signify when moose were active or inactive. Using cutoff activity counts of 25 and of 50, the time spent active in a day increased from about 7 hours in midwinter to about 12 hours in summer, following seasonal trends in active time per day reported for moose by other researchers (Fig. 2). The exact value of the cutoff that should be used cannot be determined because of overlap in activity counts when the moose was active and inactive (Table 1).

Expected accuracy of differential mode GPS locations from these GPS collars is about 8 m 50% of time, and 20 m 95% of the time (Moen *et al.* 1997, Rempel and Rodgers 1997). We calculated the straight-line distance between consecutive differential mode locations on 10-minute intervals. Distances were < 10 m in 56% of consecutive locations which were 10-minutes apart, and 96% of the consecutive locations at 10-minute intervals were < 40 m apart (n = 6,717). The distance moved in 10-minutes was > 80 m in < 1% of the 10-minute periods, and < 200 m in all but 7 of the 6,717 locations. These movement rates are straight-line distances between locations, the actual distance moved would have been greater than the straight-line distance. Correlation between activity counts and movement rate was low (r^2 = 0.29) because of the low movement rates and possibly high activity counts when the animal was inactive if classification errors occurred at a

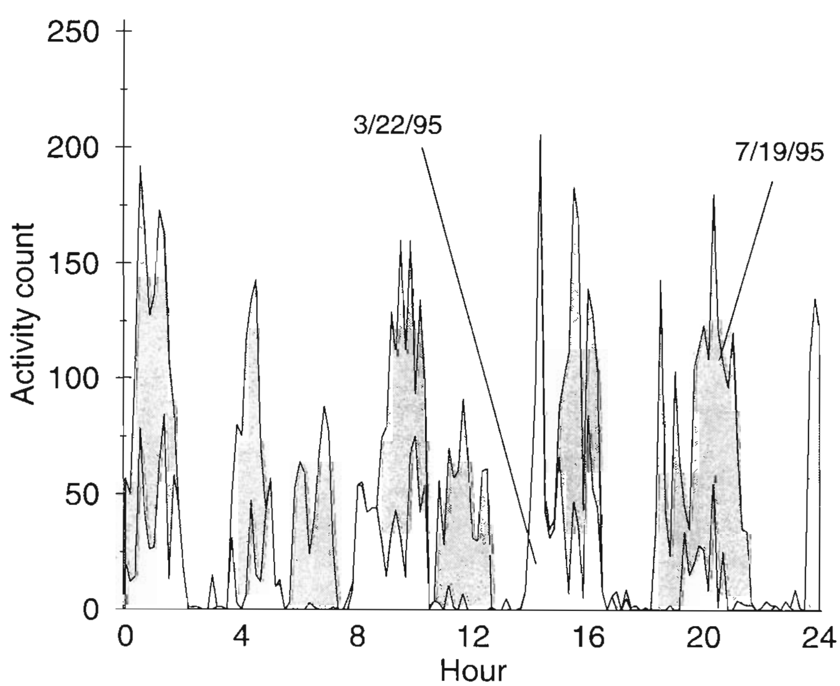

Fig. 1. Activity counts from a collar on the same free-ranging cow moose in northern Minnesota on 22 March and 19 July 1995. Both GPS and activity count intervals were 10 minutes on each day.

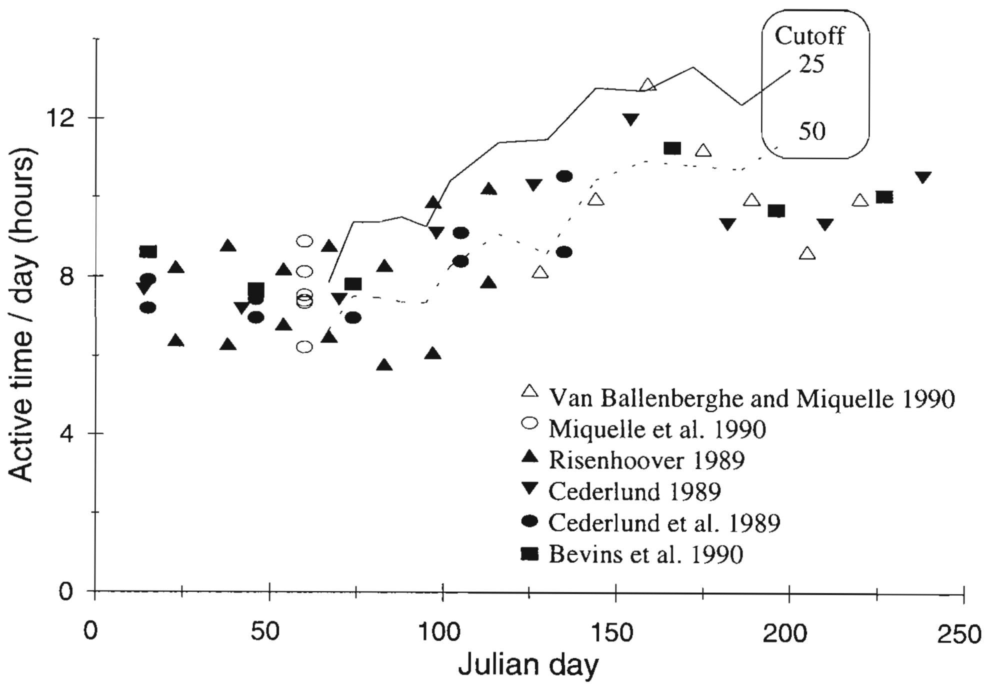

Fig. 2. Moose activity as a percentage of the 24-hour day for several studies compared to moose active time interpreted from 10-minute activity counts from March to July. The lines marked "cutoff" indicate the predicted active time per day from 10-minute activity count periods when the cutoff activity count to differentiate between activity and inactivity was 25 and 50.

similar rate as in the direct observations (Table 1).

The differentially-corrected locations indicated that moose moved shorter distances in winter than in summer. In summer 4% of movements in 10 minutes were > 5 m, compared to in winter when only 1.7% were > 5 m. Similarly, 1.4% of movements in 10 minutes were > 10 m in summer, compared to only 0.3% in winter. The shorter movements in winter corresponded to lower activity counts on 10-minute intervals in winter than in summer when collars were on free-ranging moose ($\chi^2 = 604$, $P < 0.001$).

Activity Count Comparison. -- We could not use activity counts from direct observations to calibrate activity counts from collars on free-ranging moose in Voyageurs National Park. The activity counts from free-ranging moose in Voyageurs National Park were lower than activity counts from the moose at the Moose Research Center ($\chi^2 = 2177$, $P < 0.001$). This difference in activity counts from collars on moose in Alaska and Minnesota indicates that the absolute values of the activity count data from our direct observations have limited utility in collars on other animals, and recalibration would be required in situations where a good relationship between activity counts and activities is desired. Nevertheless, the qualitative performance of the activity sensor was similar in both versions of the collar.

Activity Count Averaging. -- It is not possible to collect GPS locations at 10-minute intervals for longer than 40 days without exhausting battery power in the GPS_1000 collar. Therefore, GPS location attempts must be taken on longer intervals of 1 to 4 hours, depending on desired battery life and study design. During these longer GPS observation intervals, the activity counts are averaged in the GPS_1000 collar. We averaged the 10-minute activity count data from each 24-hour period into simulated GPS intervals of 1, 2, 3, and 4 hours to determine if averaged activity counts were similar to the original, un-averaged activity counts (Table 2). Averaging of 10-minute activity counts resulted in loss of information as expected. We placed activity counts > 150 into a single group and compared un-averaged activity counts to averaged activity counts with χ^2 Even at an averaging interval of 1 hour there was a difference between observed and averaged activity counts ($\chi^2 = 12, P < 0.006$) At averaging intervals > 1 hour observed and averaged activity counts appeared to be more different ($\chi^2 > 16, P < 0.001$).

We simulated 30-minute activity data by adding activity counts of 3 consecutive 10-minute activity counts together. If the resulting activity count was > 255, we set it to 255, the maximum recorded by the collar. There were again differences between averaged activity counts and 10-minute activity counts from which they were derived at the 1 hour averaging interval ($\chi^2 = 10, P < 0.014$), differences at averaging intervals of 2, 3, and 4 hours were greater ($\chi_3 > 61, P < 0.001$).

Table 2. Observed percent of activity counts in 10 and 30 minute intervals classified into 50-count intervals, and average percent of activity counts in each 50-count interval when the observed 10 and 30-minute activity counts were averaged over simulated GPS observation intervals of 1 to 4 hours. Data was collected from collars on 6 free-ranging moose in northern Minnesota. The 10-minute activity counts are from 24-hour periods when the collar recorded GPS observations and activity counts on a 10-minute interval. The 30-minute activity counts are the sum of 3 consecutive 10-minute intervals throughout the data set. If the sum was > 255 it was set at 255, the maximum activity count recorded by the collar.

		Averaging Interval			
Activity count	10 minute	1 hr	2 hr	3 hr	4 hr
< 50	64	60	51	61	50
50 - 99	13	21	41	30	45
100 - 149	12	14	6	7	5
150 - 199	7	3	2	2	0
200 - 249	3	2	0	0	0
250	1	0	0	0	0
n	1008	168	84	56	42
Activity count	10 minute	1 hr	2 hr	3 hr	4 hr
< 50	49	42	23	16	0
50 - 99	7	10	21	30	36
100 - 149	7	15	32	29	57
150 - 199	6	9	16	20	7
200 - 249	5	7	7	5	0
250	27	17	1	0	0
n	336	168	84	56	42

DISCUSSION

We believe that activity counts can be used to interpret seasonal changes in activity if activity count intervals are $\leq$10 minutes and activity counts are not averaged, or if activity counts are averaged over intervals of $\leq$1 hour. Activities such as ruminating or resting while bedded cannot be differentiated, but activity counts can provide a quantitative basis for comparison of activity patterns in poor and good quality habitats (Cederlund *et al.* 1989). Errors are reduced in intervals $\leq$ 1 hr long because foraging and resting are generally broken up into distinct bouts. Correspondence between averaged activity counts and un-averaged activity counts declined as the averaging interval increased because longer averaging intervals were more likely to include both foraging bouts and bedded periods (Risenhoover 1986, Cederlund *et al.* 1989, Renecker and Hudson 1989, Bevins *et al.* 1990, Van Ballenberghe and Miquelle 1990). If averaging of activity counts is necessary and is done on intervals <1 hour, caution should be used in data interpretation. Because we collected GPS and activity count data on 10-minute intervals, Table 2 can be used to predict the effect of averaging activity counts from the GPS_1000 collar when GPS observation intervals are > 1 hour.

The range of activity counts while the moose was inactive was much larger in the prototype collar than in the GPS_1000 collar. The collar was placed loosely on the neck of the moose, and we believe the counter was incremented during comfort movements and possibly when the moose was panting while bedded. The activity count sensor in the prototype collar may also have been more sensitive than those installed in the first release of the GPS_1000 collar. Because of the distinct daily patterns in activity counts from collars on 6 free-ranging moose (e.g., Fig. 1), we believe that the results presented in Table 1 from our direct observations represent the maximum misclassification error to be expected with these collars. More direct observations of moose wearing the GPS_1000 collar are required to test this hypothesis.

The seasonal change in activity counts was not unexpected. There are many reasons why head movements which increment the activity counter occur more often in summer than in winter. Movement is restricted by snow. Head movements required to strip leaves are longer than head movements required to clip twigs, and more browse is eaten per day in summer than in winter. Insect harrassment would occur in summer. Head movements while tending calves would increment the activity counter, and 5 of the 6 free-ranging moose were females with calves.

The potential for problems in hardware and in software increases as equipment becomes more technologically advanced. Mercury tip switches used to increment activity counters can fail in cold temperatures, even though collar electronics continue to function (Maier *et al.* 1996). Both the prototype version and the first release of the GPS_1000 collar had software bugs which affected the activity counts. It is necessary to be aware of the potential for bugs in any software-driven product, and it is desirable to test performace of all components of these collars in controlled situations to verify that all components work correctly.

ACKNOWLEDGEMENTS

This study was supported by a grant from the National Science Foundation's Ecosystem Studies Program. Moose at the Moose Research Center (MRC), Alaska Department of Fish and Game, Soldotna, Alaska were supported by Federal Aid in Wildlife Restoration, Project W-24-3. Dr. C.C. Schwartz and Curt and Deb Schuey provided logistical assistance at the MRC. Paul Jensen assisted with locating the moose and data collection at the MRC. We would like to acknowledge Voyageurs National Park personnel for their assistance . Dave Cramer at Lotek engineering and John Bonde of the Natural Resource Research Institute, Duluth, MN, provided expertise with GPS technology.

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