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Authors: Gundersen, Hege, and Andreassen, Harry P.

Source: Wildlife Biology, 4(2) : 103-110

Published By: Nordic Board for Wildlife Research

URL: https://doi.org/10.2981/wlb.1998.007

SHORT COMMUNICATION

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The risk of moose *Alces alces* collision: A predictive logistic model for moose-train accidents

Hege Gundersen & Harry P. Andreassen

Gundersen, H. & Andreassen, H.P. 1998: The risk of moose *Alces alces* collision: A predictive logistic model for moose-train accidents. - Wildl. Biol. 4: 103-110.

We used logistic models to estimate the risk of moose-train collisions for the Rørosbanen railway in Norway. During 1990-1997, a total of 13,506 train departures were registered along Rørosbanen during the months when the risk of collision was highest (December to March). The statistical model selected to predict the risk of moose-train collisions included train route, time of day, lunar phase and average train speed, as well as two climatic covariables, i.e. snow depth and temperature. Trains running at night, in the morning or in the evening experienced a higher risk of collision with moose *Alces alces* than day trains. The probability of collision was also higher during nights of full moons than during nights of half or no moons. As observed previously with trains in Norway moose-kills increased with increasing snow depth and decreasing temperatures. To test the predictability of the model, we used a logistic model based on train departures during 1990-1996 to predict the number of moose-train accidents during winter 1996/97. Although the model had a satisfactorily high predictability, the best models would probably be those based on a combination of both temporal and spatial aspects. We discuss how logistic models may be applied to introduce remedial actions on high-risk routes or during high-risk periods.

Key words: Alces alces, game-vehicle accidents, logistic model, railway

Hege Gundersen, Department of Biology, Division of Zoology, University of Oslo, P.O.Box 1050 Blindern, N-0316 Oslo, Norway
Harry P. Andreassen, Hedmark College, Evenstad, N-2480 Koppang, Norway*

**Present address: Department of Biology, Division of Zoology, University of Oslo, P.O.Box 1050 Blindern, N-0316 Oslo, Norway - e-mail: harrya@bio.uio.no*

Received 29 August 1997, accepted 26 January 1998

Associate Editor: Heikki Henttonen

In most parts of the world there has been an increase in the number of game-vehicle accidents during the last decades (Groot Bruinderink & Hazebroek 1996, Romin & Bissonette 1996), resulting in large socio-economic costs (Jaren, Andersen, Ulleberg, Pedersen & Wiseth 1991, Groot Bruinderink & Hazebroek 1996, Romin & Bissonette 1996) and psychological problems for people involved in the accidents (Vatshelle 1995, Gundersen, Andreassen, Haave & Storaas 1997). Game-vehicle accidents also have consequences for wildlife management, as accidental death of animals may have severe and unpredictable effects on population development (Petersson & Danell 1992).

The increasing number of game-vehicle accidents has promoted an intensification of remedial actions, and studies on the effectiveness of different mitigative techniques (e.g. Schober & Sommer 1984, Jaren et al. 1991, Waring, Griffis & Vaughan 1991, Romin & Dalton 1992, Gleason & Jenks 1993, Reeve & Anderson 1993, Lutz 1994, Groot Bruinderink & Hazebroek 1996, Romin & Bissonette 1996). The increase in the number of game-vehicle accidents has also motivated studies addressing game behavioural and environmental factors which may cause animals to be close to traffic arteries. Important game behavioural aspects include migration (Allen & McCullough 1976, Goodwin & Ward 1976, Andersen, Wiseth, Pedersen & Jaren 1991, Lavsund & Sandegren 1991, Gundersen, Andreassen & Storaas in press) and daily activity rhythm (Carbaugh, Vaughan, Bellis & Graves 1975, Allen & McCullough 1976), while influential environmental factors are snow depth (Andersen et al. 1991, Gundersen et al. in press), temperature (Andersen et al. 1991, Gundersen et al. in press) and landscape features (Carbaugh et al. 1975, Bashore, Tzilkowski & Bellis 1985, Feldhamer, Gates, Harman, Loranger & Dixon 1986, Gleason & Jenks 1993, Gundersen et al. in press). However, it is not possible to modify game behaviour and environmental factors so that the number of game-vehicle accidents will be reduced.

Some techniques used to prevent game-train accidents, such as reduced speed, ultrasonic warning sounds, as well as the newly introduced pilot car which runs ahead of trains frightening game away from the railway (T. Stephenson, pers. comm.), may be limited to certain periods of the year, or to particular routes, with a high probability of collisions with game. However, the probability of moose-collision along a specific train route, and how the risk varies according to time and various environmental and technical factors has, to our knowledge, never been estimated.

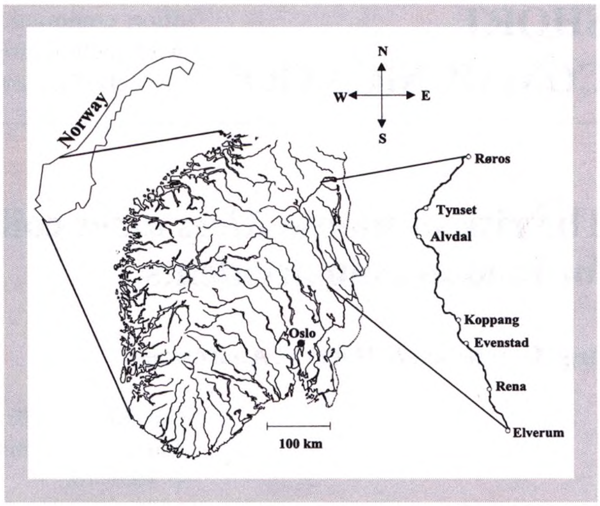

Figure 1. Location of the Rørosbanen railway study area in Hedmark county, Norway, with indications of the stations mentioned in the text.

We used a statistical logistic model to establish the most risky train departures for the Rørosbanen railway which has the highest risk of moose-train collisions per km in Norway (Gundersen et al. in press). In the model we included train speed, type of train, time of day and lunar phase, as well as climatic covariables known to be correlated with moose-train collisions.

Material and methods

Study area

The study was restricted to the Rørosbanen railway which runs through the valley of Østerdalen from Elverum (60°53'N, 11°34'E) to Røros (62°35'N, 11°20'E) (Fig. 1). Rørosbanen is 240 km long, and has the highest frequency of moose-train collisions (0.36 moose killed/year/km; Gundersen et al. in press) in Norway. The railway runs through the valley, which is surrounded by hills of boreal forest, dominated by Norway spruce *Picea abies* and Scots pine *Pinus sylvestris*, interspersed with a few boreal deciduous species such as birch *Betula pubescens* and willow *Salix* spp.

Data material

Data on train kills and on train departures were obtained from The Norwegian State Railways (NSB), The Norwegian National Rail Administration, and from the local Wildlife Committees in the municipalities of Stor-Elvdal and Rendalen from 1 December 1990 till 31 March 1997. Each record of a moose-train collision included the train route on which the collision took place. Data concerning climate, i.e. daily average temperature and snow depth, were obtained from the meteorological station in Evenstad (61°4'N, 11°7'E) (see Fig. 1).

Analyses

We have previously shown that 79% of all moose-train accidents along the Rørosbanen railway occur from December to March, probably due to migratory behaviour of moose moving from the hills with large amounts of snow down to the bottom of the valley of Østerdalen where the railway runs (Gundersen et al. in press). Thus, we chose to incorporate only the four months, December - March, with the highest risk of moose-train collisions in the present analyses. The predicted risk of moose-train collisions from April to November (i.e. the part of the year excluded from the analyses) ranges from 0.001 (July and August) to 0.009 (November). Therefore, inclusion of these months in the analyses would result in low predictability of the chosen statistical model due to the low explainable variance of the binomial response.

For each train departure on the Rørosbanen railway during the four months from December 1990 to March 1997 we registered whether the train hit a moose (coded as 1) or not (coded as 0). A logistic model was applied including all available train technical predictor variables, i.e. average train speed, type of train (freight or passenger train) and time of day (coded as night 21:00-3:00, morning 3:00-9:00, day 9:00-15:00, evening 15:00-21:00, respectively). We included daily snow depth and daily average temperature as covariables, since these two climatic variables previously have been shown to be good predictors for the yearly variation in the number of moose killed by trains in Norway (Andersen et al. 1991, Gundersen et al. in press). Personal observations suggested that lunar phase might affect the number of moose-train collisions along the Rørosbanen railway (S. Sletten, pers. comm.). We therefore tested this suggestion by including lunar phase (full moon: ± 3 days, half moon: ± 3 days, new moon: ± 3 days) in the model. However, not all train routes run all the

Table 1. Number of train departures analysed, numbers of moose-train collisions and risks of moose-train collisions along eight routes at the Rørosbanen railway. Route indicates the section of the Rørosbanen railway run by the specific train route, but no distinctions were made between north and south going trains. In parentheses the distances of the routes are given. See map of the Rørosbanen railway line in Figure 1.

Route (distance in km)	No of train departures	No of collisions	Risk (95% CI)
Alvdal - Tynset (23)	160	0	0
Tynset - Rena (157)	15	0	0
Koppang - Tynset (100)	15	0	0
Elverum - Koppang (88)	2317	31	0.013 (0.009, 0.018)
Elverum - Rena (32)	1523	1	0.001 (0.000, 0.003)
Elverum - Røros (240)	7201	317	0.045 (0.040, 0.051)
Elverum - Tynset (189)	1405	48	0.035 (0.026, 0.046)
Tynset - Røros (52)	870	10	0.012 (0.006, 0.020)

Table 2. The logit model chosen to best explain the risk of moose-train collisions. (AIC = 3228.2; AIC without train speed = 3228.7; AIC for other models > 3230.6).

Predictor	Estimate	df	χ^2	P
Intercept	-7.033 ± 0.880			
Train route		4	110.75	< 0.001
Route Elverum - Koppang	0.554 ± 0.375			
Route Elverum - Rena	-1.488 ± 1.057			
Route Elverum - Røros	1.705 ± 0.331			
Route Elverum - Tynset	1.173 ± 0.365			
Route Tynset - Røros	0			
Time of day		3	94.44	< 0.001
Morning	-0.163 ± 0.147			
Day	-1.625 ± 0.229			
Evening	0.101 ± 0.142			
Night	0			
Lunar phase		2	9.05	0.011
Full	0.358 ± 0.142			
Half	0.010 ± 0.129			
New	0			
Snow depth (cm)	0.017 ± 0.002	1	107.74	< 0.001
Average daily temperature (°C)	-0.039 ± 0.007	1	30.98	< 0.001
Average train speed (km/h)	0.016 ± 0.010	1	2.53	0.111

way from Elverum to Røros, and as the risk of moose-train accidents varies along the railway line (Gundersen et al. in press) we also included the specific section of the railway line covered by the route in the model (hereafter termed route factor). The most parsimonious model according to Akaike's Information Criterion (AIC values; Burnham & Anderson (1993)) was chosen to predict the risk of moose-train collisions.

Results

Out of a total of 13,506 train departures along the Rørosbanen railway in the periods analysed, there were 406 moose-train collisions, which killed 466 moose. Preliminary analyses showed that the probability of colliding with a moose was 0.030 (95% CI = 0.028, 0.034), but it varied considerably between routes (univariate model: $\chi^2_{7, 13,498} = 174.73$, $P < 0.001$) (Table 1). The route specific risk of killing a moose could most probably be ascribed both to variations in the distance of the route (univariate model: $\chi^2_{1, 13,504} = 153.56$, $P < 0.001$), although the slope of the linear model was rather flat (distance in km, estimate = 0.010 (SE = 0.001)), and spatial variations in collision risk along the local areas traversed by the different routes (e.g. due to different food availability and topography as shown by Gundersen et al. (in press)).

To attain convergence for a global model (with no interactions) when including the route factor, we had to exclude three routes without any train kills, consisting of 190 departures (see Table 1). The model showed no significant association between moose-kills and train type ($\chi^2_{1, 13,302} = 0.02$, $P = 0.857$), or moose-kills and average train speed ($\chi^2_{1, 13,303} = 2.53$, $P = 0.111$). The most parsimonious model, with only

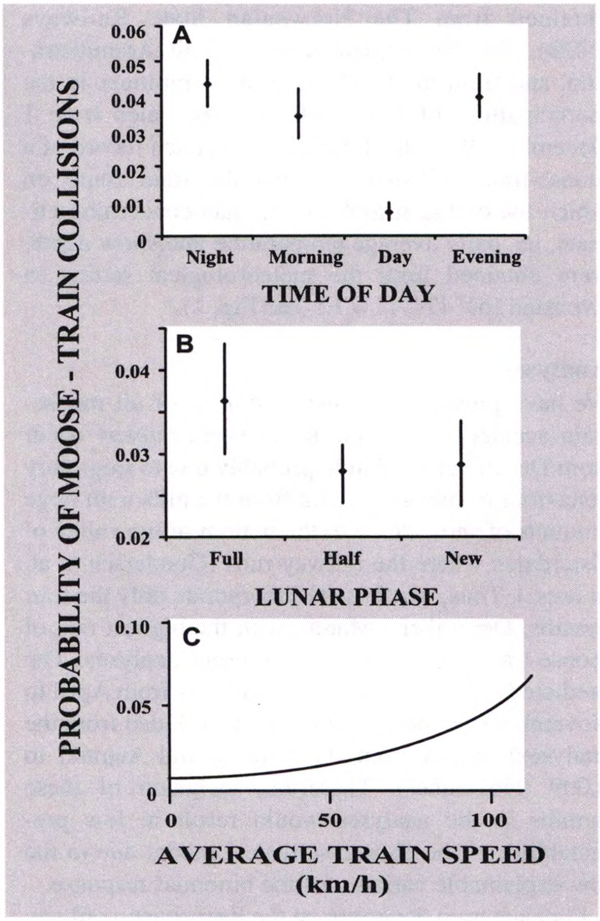

Figure 2. Probability of moose-train collisions in relation to A) the time of day, B) lunar phase and C) average train speed (see statistics in Table 2).

Table 3. The logit model used to predict the number of train-killed moose for trains running in the morning, day, evening and at night the whole distance between Elverum and Røros in winter 1996/97. (AIC = 1752.2; AIC without train speed = 1752.3; AIC for other models > 1754.0).

Predictor	Estimate	df	χ^2	P
Intercept	-6.817 ± 1.836			
Train		3	68.77	<0.001
Morning	-0.175 ± 0.193			
Day	-1.745 ± 0.295			
Evening	0.098 ± 0.181			
Night	0			
Lunar phase		2	3.57	0.059
Full	0.297 ± 0.154			
Half / New	0			
Snow depth (cm)	0.018 ± 0.002	1	68.13	<0.001
Average daily temperature (°C)	-0.031 ± 0.009	1	10.60	0.001
Average train speed (km/h)	0.036 ± 0.021	1	2.14	0.144

Table 4. Observed and predicted number of train accidents involving moose-train collisions during winter 1996/97 for departures of passenger trains leaving in the morning, during the day, in the evening and at night and running the whole distance between Elverum and Røros. G-statistics are presented for the goodness of fit test.

Train departure	No of departures	No of accidents Observed	No of accidents Predicted	G	P
Morning	201	14	6.44	3.46	0.063
Day	222	2	1.63	0.04	0.842
Evening	242	11	10.03	0.05	0.823
Night	60	2	2.03	0.00	0.992

statistically significant terms, included route, time of day, lunar phase and the covariables snow depth and temperature (Table 2). However, according to AIC, this model was indistinguishable from a model which also included average train speed (see Table 2).

The risk of collision was 5-6.8 times higher during the night, morning or evening than during the daytime (Fig. 2A), and 1.3 times higher during periods with full moons than during periods with new or half moons (see Fig. 2B). The probability of moose-train collisions increased with increasing train speed, although not significantly so (see Fig. 2C). For instance, an increase in train speed from 50 to 100 km/hour doubled the risk of collision. The probability of moose-train collisions also increased with increasing snow depth and decreasing temperature (see Table 2 for estimates, and Gundersen et al. in press).

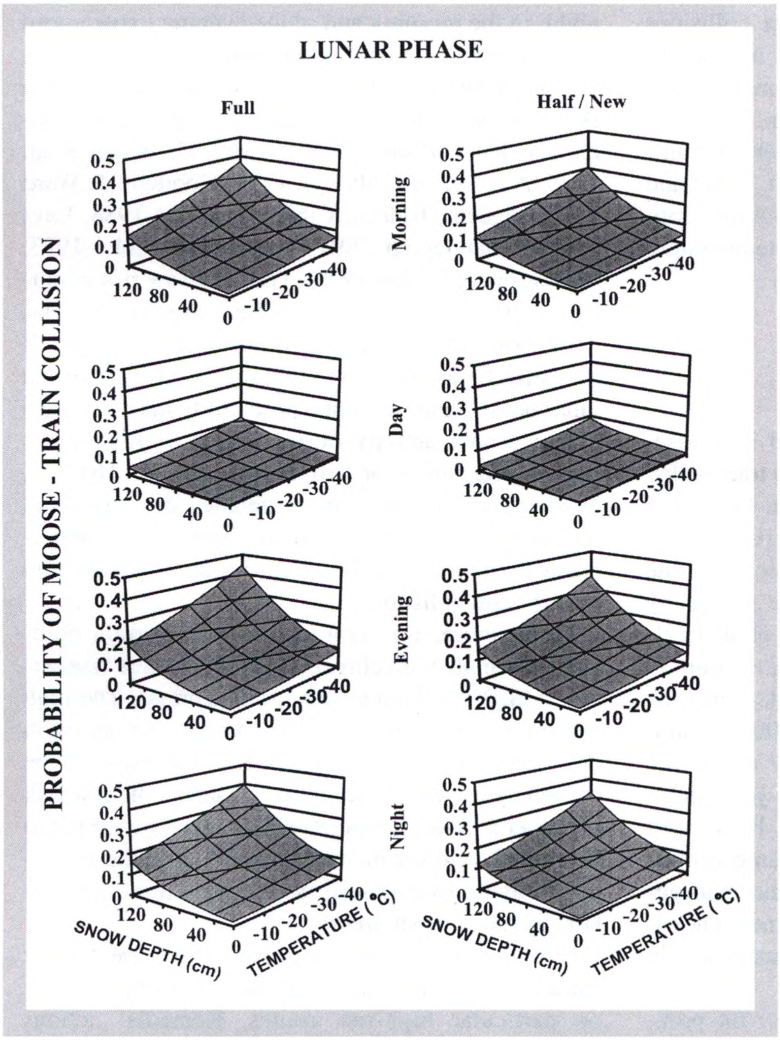

Figure 3. Probability of moose-train collisions of passenger trains running the whole distance between Elverum and Røros in the morning, day, evening and at night, in relation to lunar phase, snow depth and temperature (see statistics in Table 3).

Train specification

The above analyses included all train departures in Østerdalen. To depict the risk of different departures, we made a model containing only passenger trains running the whole distance between Elverum and Røros (there are two trains (one going south and one going north) in the morning, day, evening and night). We included snow depth, daily average temperature, lunar phase (full moon vs half/new moon), train speed and train (i.e. time of day) in the model. To test the predictability of the model we excluded the winter of 1996/97 and used the model based on the data from 1990 to 1996 to predict the number of train-killed moose for each train (morning, day, evening and night trains) during winter 1996/97.

From 1990 to 1996 there were 5,371 departures of the trains included in our analyses, and 229 moose were killed. The best model according to the AIC criteria included all predictor variables (Table 3). In winter 1996/97 there were 29 moose-train collisions (Table 4). The predictability of the model was good for all trains except the morning train, which experienced an unexpected high number of train-kills during winter 1996/97 (see Table 4). However, 6 out of the 14 collisions between moose and the morning train in winter 1996/97 occurred within a 2 km long section of the railway called Storholmen. None of the collisions with other trains occurred within this area. In previous years, 1990-1996, only 4 out of 37 collisions between moose and the morning train occurred at Storholmen. Storholmen was identified as an exceptional high-risk area in 1996/97 due to logging activity (the risk of moose-train accidents was 10 times higher in 1996/97 than in previous years, Andreassen, Gundersen & Storaas 1997, Gundersen et al. in press). When excluding the six collisions occurring at Storholmen, the observed number of collisions (8) was well predicted by the model ($G = 0.18$, $P = 0.67$), also for the morning train.

Morning, day, evening and night passenger trains had average probabilities of 0.048, 0.010, 0.062 and 0.052, respectively, of hitting a moose, but the probability varied according to snow depth, temperature and to some extent lunar phase (Fig. 3).

Discussion

In Norway, the number of moose killed in moose-train collisions have increased from ca 50 train-killed moose per year in the 1950s (Christensen 1956) to a yearly average of 676 during 1990-1996 (Gundersen et al. 1997). This has resulted in economic costs due to material damage and loss of income gained by selling meat and hunting licenses (Jaren et al. 1991, Groot Bruinderink & Hazebroek 1996, Romin & Bissonette 1996). The total economic costs were estimated by Jaren et al. (1991) to be ca $2,900 per train-killed moose in Norway. On average, 87 moose are killed along the Rørosbanen railway each year, yielding a socioeconomic loss of ca $250,000. Because of the severe socioeconomic costs of game-vehicle accidents, problems associated with game management, and the welfare of train personnel, new knowledge about game-vehicle accidents is necessary in order to diminish the problem.

By applying a logistic model to estimate the probability that a collision will take place along a certain train route, we have introduced a new approach to study game-vehicle accidents. Unlike previous studies which focused on the factors that cause game to be close to traffic arteries, we focused on the factors that cause vehicles to collide with game, because we believe that the problem cannot be efficiently tackled from the former point of view. Approaching the conflict between the game's natural behaviour and man's need for transportation, by analysing man's decision on transport remedies, might facilitate the introduction of new mitigating actions. Indeed, it seems more feasible to try to change human behaviour rather than the inherited behaviour of game.

Although our analysis was motivated by management purposes, the present study reveals interesting aspects of moose biology, especially its temporal activity pattern. Collision probabilities varied between the different train departures. Trains running at night, in the morning and in the evening experienced a higher risk of collision than the day trains. Temporal activity patterns of game species have been shown to be an important factor affecting game-vehicle accidents (Peek & Bellis 1969, Carbaugh et al. 1975, Allen & McCullough 1976, Goodwin & Ward 1976, Vincent, Bideau, Cibien & Quere 1988, Lavsund & Sandegren 1991, Gleason & Jenks 1993, Wahlström & Liberg 1995). Thus, the low risk of collision during the daytime may be caused by the relatively low activity of moose during these hours. It may also be assumed that the observed effect of the lunar phase on the collision probability may be due to higher moose activity during nights of full moons than during nights of half or new moons. There is, however, a need for a more detailed description of moose activity during the lunar phase to fully understand the correlation between the lunar phases and moose-train collisions.

Furthermore, we showed how moose-train collisions correlate with climatic seasonal factors (Andersen et al. 1991, Gundersen et al. in press). The high risk of moose-train collisions during periods with large amounts of snow has been suggested to be caused by migratory behaviour, whereas the low risk at higher ambient temperatures has been suggested to be related to lower moose activity during these periods to avoid overheating (see Andersen et al. 1991, Gundersen et al. in press).

From a management perspective, the present study suggests that remedial actions should be applied only on particular high-risk routes. Remedial actions could for instance be changing routes, i.e. avoid that trains pass through high-risk areas at high-risk times, e.g. at night. In addition, although the estimated positive slope of the association between train speed and moose collisions was not significant, we believe that reduced speed could serve as a means to reduce the number of moose-train collisions in certain areas during high-risk periods. Although the relation between train speed and moose collision is considerably uncertain statistically, the relation should nevertheless be considered carefully in the future prior to the introduction of faster trains. High-speed trains may increase the number of moose-train collisions considerably in the future, and in particular if careful attention to the time schedule when high-speed trains pass high-risk areas is not paid. Finally, techniques used to frighten moose away before the train passes through particular areas (e.g. pilot cars driven in front of trains) may be restricted to high-risk periods, e.g. night trains during periods with large amounts of snow. Limited use of mitigative efforts will also reduce the costs connected with such actions, and thus, it may be easier to find the political will to introduce such methods.

The predictability of our model was satisfactory, except for the morning train. This may have been due to the exceptionally high number of moose-train accidents at Storholmen. Storholmen is an area close to the railway which is used by browsing moose during winter (S. Hanestad, pers. comm.). During summer 1996 this area was clear-cut for cultivation. During winter 1996/97 moose were observed to move from Storholmen to the nearest browsing area along the railway, which resulted in a 10-fold increase in the number of moose-train accidents within a few kilometres, compared to what would be expected from experiences in previous years (Andreassen et al. 1997, Gundersen et al. in press). We suspect that the time when the morning train passed this area coincided with the time when moose were browsing along the railway. Obviously, predictable models should therefore include both temporal and spatial aspects.

Acknowledgements - we thank The Norwegian National Rail Administration for financial support to this study. We would also like to thank H. Brenden, H. Haave, S. Hanestad, H. Haug, L. Hesthagen, O. Kristiansen, K. Nicolaysen, S. Sletten, T. Storaas, L. Sælthun, G. Vestby, T. Øfstaas for data, comments and ideas, and S.-B. Nielsen, R. A. Ims and two anonymous referees for comments on the manuscript.

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