SPATIAL AND TEMPORAL CORRELATES TO NORWEGIAN MOOSE - TRAIN COLLISIONS

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ABSTRACT: We have analyzed how temporal variation (i.e., climatic factors and moose (*Alces alces*) population density) and spatial variation (i.e., landscape pattern and food availability) correlate with moose - train collisions along the railway running through the Østerdalen valley in SE Norway. A total of 1,177 train kills were registered from July 1985 to March 1997. The number of collisions increased with increasing snow depth and colder ambient temperature, and were located with the outlets of side valleys. The duration of a collision period lasting from when the snow depth exceeded 30 cm until the temperature stabilized above 0°C explained 82% of the yearly variation in moose - train collisions. Changes in the food availability, due to logging, increased the number of moose collisions considerably in local areas. We conclude that seasonal migrations are the main cause of moose - train collisions in Østerdalen.

ALCES VOL. 34(2): 385-394 (1998)

Key words: *Alces alces*, landscape, migrations, moose - train collisions, snow depth

During the last century natural landscapes have been intensively fragmented due to urbanization processes (Fahrig and Merriam 1994). One of the most severe changes brought upon landscapes by humans is the construction of infrastructures, like roads and railways (Forman and Godron 1986, Forman 1995). These linear elements in nature particularly affect migratory species, which follow certain routes inherited through generations (LeResche 1974; Pulliainen 1974; Cederlund *et al.* 1987; Sweanor and Sandegren 1989; Andersen 1991a, b; Sæther *et al.* 1992; Odden *et al.* 1996), as they function as barriers for the natural movements of wildlife species. In addition, because the linear elements of infrastructure often are heavily trafficked arteries, the possibility for conflict exists between the public need for transportation and the migratory behavior of game, resulting in a high number of game - vehicle collisions (Groot Bunderink and Hazebroek 1996, Romin and Bisonette 1996).

In Norway, during the period 1993 - 1996 there have been 4,189 recorded losses of game and domestic animals to train collisions, of which moose (*Alces alces*) constitute 65% (Table 1). Hence, the large number of moose - train collisions are causing great burdens both economically (e.g., by material damages and loss of a resource to the owner of the hunting rights), psychologically (e.g., by stressing train personnel), and ecologically (e.g., by complicating wildlife management (Lutz 1991, Foster and Humphrey 1995)). Moreover, each year a large number of injured moose have to be dealt with by The Wildlife Committee to reduce suffering. The need for remedial actions to reduce the number of moose - train collisions is obvious. However, to suggest where and when to introduce mitigative techniques, there is a need to know the temporal and spatial variation in the number of collisions. The temporal variation in the

Table 1. The number of game and domestic animals killed due to train collisions in Norway during the period 1993 - 1996.

Species	Number of train-killed individuals
Moose (*Alces alces*)	2705
Roe-deer (*Capreolus capreolus*)	521
Deer (*Cervus elaphus*)	54
Reindeer (*Rangifer tarandus*)	118
Muskox (*Ovibus moschatus*)	7
Lynx (*Felis lynx*)	3
Bear (*Ursus arctos*)	1
Fox (*Vulpes vulpes*)	3
Golden eagle (*Aquila chrysaetos*)	3
Sheep (*Ovis aries*)	568
Goat (*Capra hircus*)	3
Cattle (*Bos taurus*)	50
Horse (*Equus caballus*)	3
Dog (*Canis familiaris*)	150

number of collisions, may be expected to correlate to yearly variations in population densities (McCaffery 1973, Lavsund and Sandegren 1991, Lutz 1991), or to seasonal variations in climate and migratory behavior (Andersen *et al.* 1991). Whereas the spatial variation in the number of collisions may be expected to correlate to landscape features and resource availability (Carbaugh *et al.* 1975, Bashore *et al.* 1985, Feldhamer *et al.* 1986, Gleason and Jenks 1993).

In this study we examined how temporal variation (i.e., climatic factors and moose population density) and spatial variation (i.e., landscape pattern and changes in food availability) correlate with moose - train collisions in the part of Norway most burdened by wildlife collisions.

STUDY AREA

The study was restricted to Stor-Elvdal and Rendalen municipalities along the Rørosbanen railway which runs at the bottom of the Østerdalen valley from Elverum (60°53'N, 11°34'E) to Røros (62°35'N, 11°20'E) (Fig. 1). Rørosbanen is 240 km long, and is the railway line in Norway with the highest frequency of moose - train collisions, averaging 0.36 moose killed yearly per km (Andreassen *et al.* 1997) (Table 2). The most vulnerable stretch along Rørosbanen is located in Stor-Elvdal and Rendalen municipalities, where 72% of all moose - train collisions occur within a distance of 100 km (0.62 collisions yearly per km). The railway runs through the valley, surrounded by hills of boreal forest, dominated by Norwegian spruce (*Picea abies*) and Scots pine (*Pinus silvestris*), interspersed with a few boreal deciduous species such as birch (*Betula* spp.).

METHODS

Data Material

Data on train-kills stem from registra-

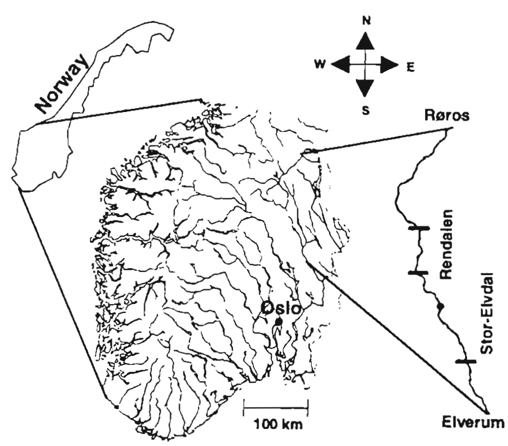

Fig. 1. The study area in Hedmark County, Norway, showing location of the Rørosbanen railway, and the 100 km section of the line including Rendalen and Stor-Elvdal municipalities analyzed in the present study. The dot along the line shows the location of the meteorological station (Evenstad).

Table 2. The number of moose - train collisions per km per year recorded in some of the longest railway lines in Norway, during the period 1993 - 1996.

Railway line	Number of train-killed moose per km per year
Rørosbanen	0.36
Gjøvikbanen	0.34
Bratsbergbanen	0.34
Vestfoldbanen	0.28
Nordlandsbanen	0.25
Meråkerbanen	0.20
Bergensbanen	0.18
Sørlandsbanen	0.18
Randsfjordbanen	0.17
Hovedbanen+Dovrebanen	0.11
Raumabanen	0.07
Kongsvingerbanen	0.06
Solørbanen	0.05
Østfoldbanen	0.02

tions performed by The Norwegian State Railway (NSB), The Norwegian National Rail Administration, and from the local Wildlife Committees of Stor-Elvdal and Rendalen municipalities from July 1, 1985, until March 1, 1997. Each registration of a moose - train collision consists of the time and the position to the nearest 100 m. Daily average temperature and snow depth were obtained from Evenstad meteorological station (61°24'N, 11°7'E) (Fig. 1). The size of the moose population was estimated by the population model "Cersim" which is based on observations made by hunters the previous hunting season (Lanestedt *et al.* 1988).

Analyzing Procedures

We have grouped our analyses into 2 categories: (1) temporal factors (i.e., climatic factors and population density), and (2) spatial factors (i.e., landscape patterns and food availability).

Temporal factors.— We compared the frequency distribution of days with certain weather conditions (expected) with the frequency distribution of collisions at the various weather conditions (observed) by a goodness of fit-test. General linear models were used to correlate moose population size and the number of collisions.

Spatial Factors.— To explain the spatial variation of collisions on a regional scale we analyzed the correlation between landscape patterns and the number of collisions. The number of collisions per 1-km-long segment of the railway was correlated to an estimate of topography and to the distance to the nearest side valley. Topography was measured as the difference in height from the bottom of the valley to the highest point within 2.5 km to the east and to the west of the line, averaged for both sides. Topography was chosen as a relevant landscape parameter as moose in Østerdalen tend to migrate from the hills down to the valley during winters (Sæther and Heim 1991, Odden *et al.* 1996). Furthermore, high hills create a narrow valley which could function as a funnel aggregating moose in a narrow area along the railway. Also side valleys were chosen as a landscape parameter due to migratory behavior, as the side valleys have been assumed to channel moose down to Østerdalen (Sæther and Heim 1991, Odden *et al.* 1996). Due to spatial autocorrelation of adjacent segments of the line we performed a preliminary analysis which showed that the number of collisions were not significantly autocorrelated if separated by 3 km or longer ($r < 0.1$, $P > 0.340$). Thus, the analysis of landscape pattern was performed by entering 3 of the 1 km long segments as a random factor in linear models including both topography and distance to side valleys.

To explain the spatial variation of collisions on a local scale we compared the number of collisions before and after changes in food availability due to logging activity in 2 areas, named Nabben and Storholmen. At Nabben food availability increased because branches of pines were available as food in a logging area near the railway. Whereas at Storholmen food availability decreased as a result of logging and clearing of an area for farmland. A linear model including factors that significantly correlated to the yearly variation in collisions (e.g., climatic factors and population density) was used to obtain an estimate of the expected number of collisions before- and after the change in food availability. The expected number of collisions before- and after the change occurred was compared with the observed number of collisions by a goodness of fit-test.

RESULTS

The number of collisions were particularly high during winter seasons, as 56% of the collisions occurred in January and February (Fig. 2). For the analyses of the yearly variation in number of collisions we counted the number of collisions occurring during a winter season, starting July 1 and ending June 30 the following year,

A total of 692 collisions were registered in Stor-Elvdal and Rendalen municipalities from July 1, 1985, until March 1, 1997. The number of collisions varied considerably from year to year (Fig. 3), and also the location of collisions showed both a temporal and spatial variation (Fig. 4).

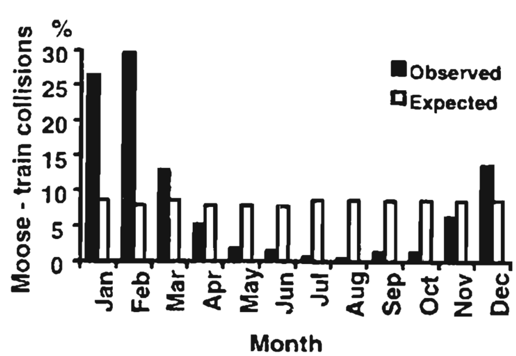

Fig. 2. Proportion of moose - train collisions per month. Goodness of fit between observed number of moose - train collisions and expected number of moose - train collisions (frequency distribution of days per month): $\chi^2 = 965.5$, 11 df, $P < 0.001$.

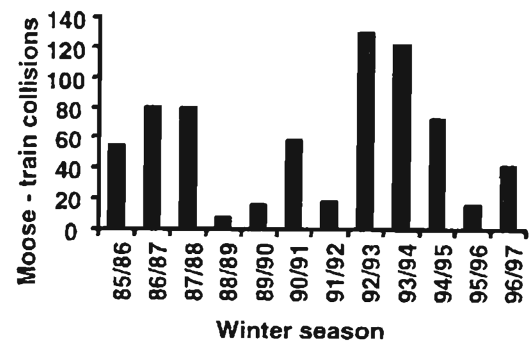

Fig. 3. The number of moose - train collisions recorded per winter season (July 1 - June 30).

Temporal Effects

There was an association between the number of collisions and temperature (Fig. 5a) and also between the number of collisions and snow depth (Fig. 5b). On days with temperatures below 0°C the risk of collision was 5.5 times higher than on days with temperatures above 0°C. The risk of collision was 12.4 times higher on days with snow depths exceeding 30 cm than on days of little (< 30 cm) or no snow. We combined temperature and snow into a variable called collision period, which started when snow depth exceeded 30 cm and lasted until the temperature stabilized above 0°C. The number of days in the collision period explained 82% of the yearly variation in moose collisions (Fig. 6).

Population density tended to correlate positively with the number of collisions, if

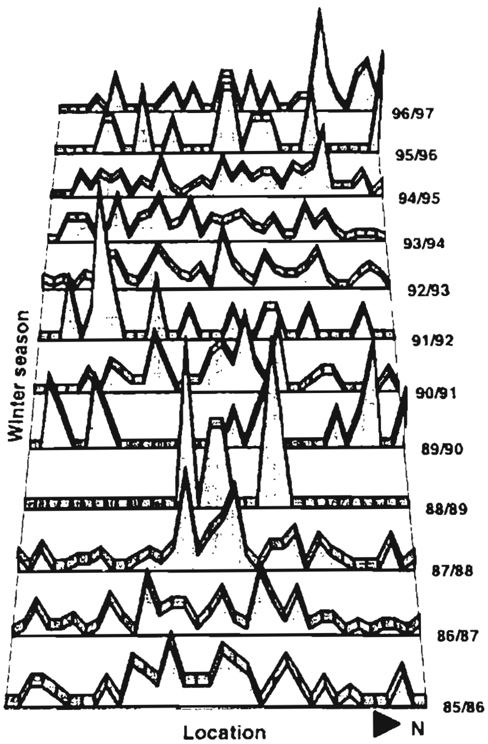

Fig. 4. The spatiotemporal variation in the number of moose-train collisions, depicted as the proportion of accidents recorded per year per 3-km along Stor-Elvdal and Rendalen municipalities. The lines were smoothed by using a running mean procedure.

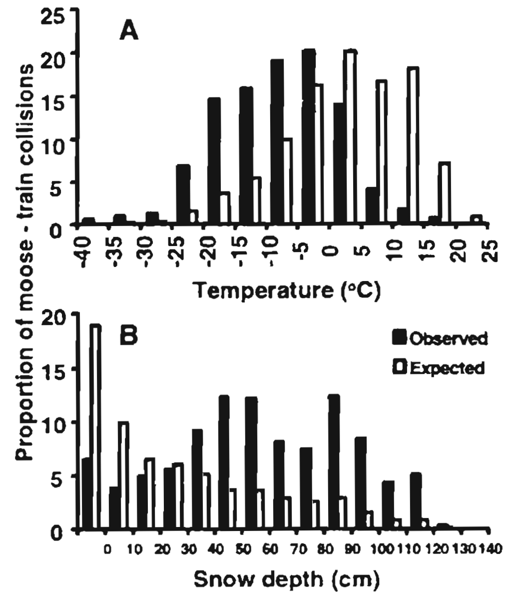

Fig. 5. (A) Proportion of days with different temperatures (expected) and proportion of train-killed moose (observed) ($\chi^2 = 851.0$, 12 df, $P < 0.001$). (B) Proportion of days with different amounts of snow (expected) and proportion of train-killed moose (observed) ($\chi^2 = 1458.0$, 14 df, $P < 0.001$).

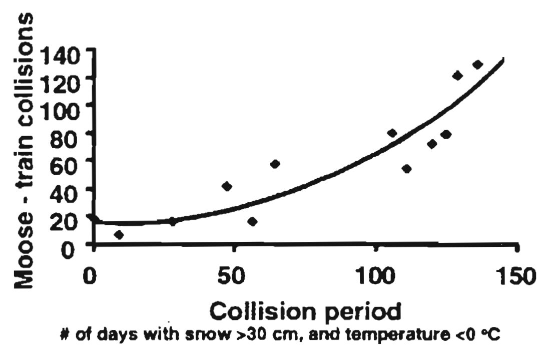

Fig. 6. The relation between the number of collisions and collision period (number of days per year starting when snow depth exceeds 30 cm and ending when the ambient temperature stabilizes above 0° C) ($F_{1,10} = 50.04$, $P < 0.001$). The number of collisions were log-transformed in the statistical analysis.

included in a general linear model together with the collision period (slope = 0.04 ± 0.02; partial $r^2 = 0.06$; $F_{1,9} = 5.04$; $P = 0.052$). The model including both the collision period and population density explained 88% of the yearly variation in the number of collisions.

Spatial Effects

There was a significant negative correlation between the number of collisions and distance to nearest side valley (Fig. 7), whereas there was no association between number of collisions and topography ($P = 0.223$).

At the 2 sites chosen to study the effects of change in food availability, the expected number of collisions was calculated from the linear model including collision period and population density. At both sites the change in food availability was

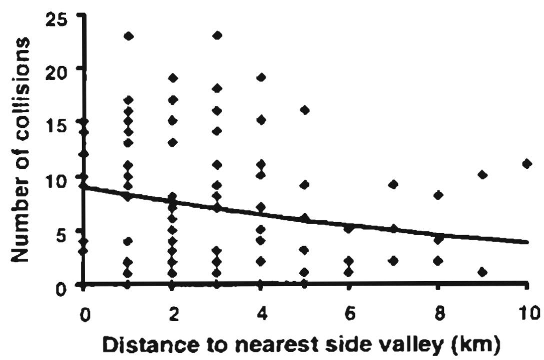

Fig. 7. The relationship between the number of collisions recorded and distance to the nearest crossing side valley. The number of collisions were log-transformed in the statistical analysis.

strongly associated to the number of collisions (Table 3). There was a 4 times higher risk for collisions at Nabben 2 years after logging than the years without logging (6 years before and 4 years after logging). At Storholmen, the cutting and clearing increased the risk of collision by a factor of 10.5.

DISCUSSION

In this study we have analyzed different spatial and temporal correlates to moose - train collisions at one highly vulnerable railway. The variation in moose - train collisions between years was mainly associated with climatic factors. Moose were killed during winter, particularly on days with great amounts of snow and temperatures below 0°C. Andersen *et al.* (1991) also found an association between snow depth and temperature and the number of moose - train collisions in a northern Norwegian railway. As moose are highly tolerant to low temperatures (-30°C) (Renecker and Hudson 1986), the lower number of train kills around 0°C suggests that moose decrease activity at high ambient temperatures in order to reduce heat production (see also Andersen *et al.* 1991).

We combined climatic factors into the collision period variable lasting from when snow depths exceeded 30 cm until the ambient temperature stabilized around 0°C. This collision period was strongly positively associated to train collisions. As Andersen *et al.* (1991) suggested, such a strong correlation between winter conditions and train kills may be due to the migratory behavior of moose populations (LeResche 1974; Pulliainen 1974; Cederlund *et al.* 1987; Sweanor and Sandegren 1989; Andersen 1991a, b; Andersen *et al.* 1991). Deep snow during a long period of time forces the moose to migrate to lower elevation areas containing a higher availability of food

Table 3. The expected and observed number of moose - train collisions at Nabben and Storholmen recorded for the years before and after the change in food availability. The expected number is corrected for the collision period and moose population density.

		Before	After	χ^2	*P*
Nabben	Expected	46	10	31.1	<0.001
	Observed	30	26		
Storholmen	Expected	23.09	0.91	42.6	<0.001
	Observed	17	7		

(Andersen and Sæther 1996). This results in a high density of moose in valley bottoms where railway lines are located. Radio telemetry studies of moose in Østerdalen have also shown that the moose migrate to valley bottoms in winter time (Sæther and Heim 1991, Odden *et al.* 1996). The radio telemetry studies of Sæther and Heim (1991) and Odden *et al.* (1996) also suggest that migratory moose utilize side valleys during migration. Hence the disproportionate high amount of collisions close to side valleys in our study also suggest that winter train kills is associated with the migratory behavior of the moose in the Østerdalen valley. Actually, a combination of the migratory direction reported by Sæther and Heim (1991) and Odden *et al.* (1996), and the spatial distribution of precipitation in Østerdalen, shows that the moose tend to migrate from local areas with high, to local areas with low, precipitation during winter (Fig. 8).

Although the presence of side valleys explained some of the spatial variation in the number of collisions, locations most exposed to collisions varied considerably from year to year. Food availability resulting from logging activities, as exemplified by Nabben and Storholmen, may partially account for such local variation. Our results

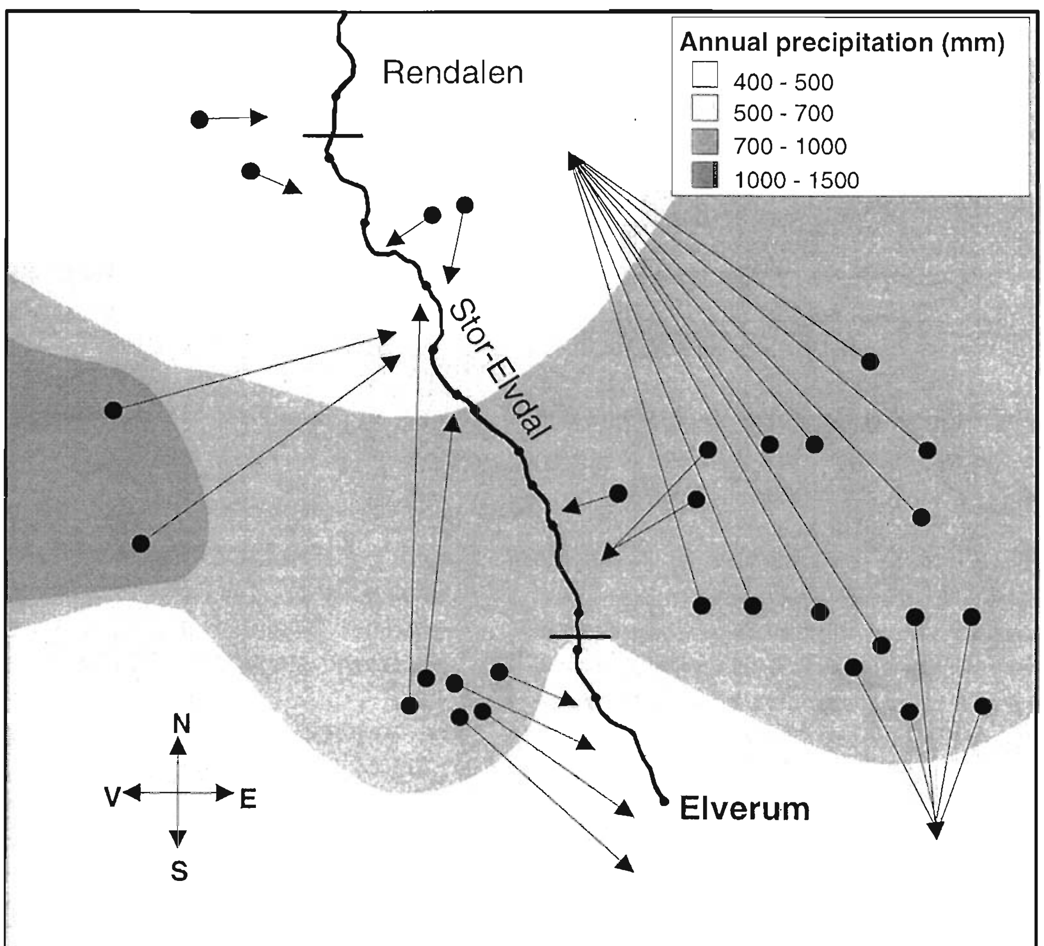

Fig. 8. Some general migratory directions for moose in Østerdalen from summer (black circles) to winter (arrows) habitats (source: Sæther and Heim 1991 and Odden *et al.* 1996) combined with a map of precipitation (source: Anonymous 1996).

suggest that, at Nabben, moose were attracted to the railway line due to the availability of branches of Scots pine, whereas at Storholmen moose had to move from a frequently used winter area due to the lack of food. Both events, although contrary in nature, resulted in a local, but probably short term increase in number of collisions. The availability of resources, such as food and water, have often been reported as a main cause of game - vehicle collisions (Peek and Bellis 1969, Carbaugh *et al.* 1975, Bashore *et al.* 1985, Feldhammer *et al.* 1986, Gleason and Jenks 1993).

We conclude that between year variation in collision frequency in Østerdalen is caused by climatic factors forcing moose down to the valley in search for food. The spatial variation in collision frequency may be explained by migratory routes, and local variations in the site of collisions by variations in food availability.

MANAGEMENT IMPLICATIONS

Previous studies have shown equivocal results with regard to population size and number of collisions (McCaffery 1973, Case 1978, Story and Kitchings 1979, Vincent *et al.* 1988, Lavsund and Sandegren 1991, Lutz 1991, Groot Bruinderink and Hazebroek 1996). The weak association between moose density and number of collisions offered little support for the opinion that a small decrease in population size would decrease the number of collisions substantially. We suggest that remedial actions to reduce the number of moose - train collisions should focus on feeding and migratory behavior of moose. For example clearing of forest vegetation along the railway to reduce foraging activity (Andersen *et al.* 1991, Jaren *et al.* 1991), and establishing feeding stations along migration routes (side valleys) may be more valuable mitigative techniques, preferably in combination with fences with overpasses in areas known to be located along traditional migration routes.

ACKNOWLEDGEMENTS

We would like to thank The Norwegian National Rail Administration for financial support to this study. H. Brenden, H. Haave, S. Hanestad, H. Haug, L. Hesthagen, O. Kristiansen, K. Nicolaysen, S. Sletten, L. Sælthun, G. Vestby, T. Øfstaas for ideas, comments, and data.

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