High voltage transmission lines and their effect on reindeer: a research programme in progress

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We review literature on high voltage transmission lines and their effect on wild reindeer (*Rangifer tarandus*) migration patterns and area use. We conclude that reliable knowledge is lacking on the effects of transmission lines on reindeer ecology. This condition relates to the lack of long-term monitoring of reindeer migration patterns in relation to existing lines. It is also related to the fact that nothing is known about hearing in reindeer (or any other deer species in Norway) in relation to transmission line noise, which is considered an obstacle for migrating reindeer.

We then outline a research programme that includes a laboratory study to determine the audiogram in reindeer and two field studies to examine the proximate effects of transmission lines – independently as well as combined with ambient environmental variables – on reindeer behaviour. The audiogram in two yearling male reindeer has been determined; this part of the study will be completed this year with the determination of a corresponding audiogram in two female yearlings. The behaviour study of domestic reindeer under high voltage transmission lines was completed in September 1999. The behaviour study of wild reindeer in the area crossed by a 420 kV power line will continue this year and its completion is anticipated in 2001.

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In southern Norway, plans for the construction and expansion of several high voltage transmission lines (300 and 420 kV) have awakened interest in the impact of these constructions on wild reindeer (*Rangifer tarandus*). In particular, the focus is on potential long-term effects on reindeer population dynamics and range use. According to Norwegian law – "The Energy Act" and "The Plan and Building Act" – the energy transmission authority (Statnett SF) is obligated to assess the ecological consequences transmission lines may impose in areas where they travel through designated wild reindeer habitat. In accordance with this, Statnett SF organized and funded a preliminary study with two objectives: 1) to ascertain current knowledge concerning possible conflicts between reindeer/caribou and high voltage transmission lines; and 2) to suggest a research strategy that will elucidate the effects of high voltage transmission lines on reindeer population dynamics and range use.

This paper is divided into two main parts: the first reviews the literature for what is known about the effects of transmission lines on reindeer and other species; the second outlines ongoing research that includes a laboratory study to determine the audiogram in reindeer and two field studies to examine the proximate effects of transmission lines – independently as well as combined with ambient environmental variables – on reindeer behaviour.

Note: most high voltage transmission lines in Norway utilize alternating current (AC) and include lines that carry more than 1 kV. The main high voltage power line system in Norway consists of lines carrying 132, 300 and 420 kV.

High voltage transmission lines and reindeer

We anticipate three possible influences on ungulates from an established power line: 1) physiological effects from electromagnetic fields; 2) disturbing noise originating from electrical discharge or wind action on lines or masts; 3) frightening visual effects from physical structures and disturbances from installation, monitoring and maintenance work on the lines. The following is based on a literature survey (Reimers et al. 1998).

Physiological effects from electromagnetic fields

Animal systems have been examined under a range of electric and magnetic field intensities and for varied exposure conditions and duration. Four reviews (Algers & Hennichs 1983; Nair et al. 1989; Sosial- og Helsedept. 1994; Thommesen & Tynes 1994) reveal uncertainty about which biological system or function, if any, is likely to be affected by fields. Experimental data are in general consistent with theoretical considerations (Thommesen & Tynes 1994). They show no unambiguous biological effects from such fields that may be suspected to have health consequences, unless field strength exceeds that necessary to induce currents compatible with the mean level of endogenous chaotic currents. From epidemiological studies there are some indications of an increased cancer risk, particularly leukaemia, among children growing up in the vicinity of power lines (Thommesen & Tynes 1994).

Electric fields from transmission lines could affect agricultural animals in three primary ways: induced body currents and fields; fields perception; or shocks due to induced voltages on objects. Two studies deal with transmission line electric fields and the possible effects on livestock. Electric fields of the strength found beneath 500 kV transmission lines (Goodwin 1975) resulted in no visible changes in grazing, feeding and drinking habits of cattle on damp ground in electric fields up to 18 kV/m. Results of this study, as well as observations of wild and domestic animals on other 500 kV transmission line rights-of-way, do not indicate any aversion of animals to entering the field area.

Lee & Reiner (1983) studied cattle behaviour near an 1100 kV prototype transmission line. The cattle showed no obvious reluctance to graze or to consume water or salt beneath the 1100 kV line. However, when the line was periodically turned off, the use of the pasture by the cattle increased. When the line was re-energized, use of the pasture decreased. Utility operating experience and overall results of research involving livestock owners indicate electric fields apparently do not noticeably affect the behaviour or health of livestock. In maximum electric field areas (i.e. 8–12 kV/m or 765 kV and 1100 kV), it is possible that some livestock species may perceive the presence of an electric field, and that in some way the electric field or noise from the lines is unpleasant to the animals. However, if no accompanying aversion or fright develops, this would not necessarily result in any outward behavioural response.

On the basis of an extensive study of cattle herds exposed to 400 kV power lines for more than 15 days per season, Algers & Hultgren (1986) concluded that high voltage transmission lines did not influence ovary function, rut intensity or pregnancy in cows which had been kept under the line for feeding. Correspondingly, in a study on possible effects from a 400 kV DC (direct current) transmission line on Holstein livestock performance, Martin et al. (1986) recorded no significant differences in milk production or reproductive capacity.

At present we have no convincing evidence that high voltage power lines and associated electromagnetic fields detrimentally affect ungulates exposed to fields for longer or shorter periods of time, neither on their biological systems nor on their functions. As reindeer probably choose not to remain in prolonged proximity to power lines – it is indeed their habit never to remain in any place for extended lengths of time – we believe that physiological effects from electromagnetic fields are of limited importance for this species.

Disturbance from sounds originating from electrical discharge or wind on lines or masts

Noise in general (Fletcher & Busnel 1978) or noise originating from electrical discharge or wind action on lines or masts is thought to affect ungulates negatively. Under climatic conditions favouring transmission line noise, animals may avoid the line corridor (Ellis et al. 1978; Lee & Griffith 1978).

In dry weather, noise from a 300 kV transmission line (Rød-Tveiten) measured 4–26, 18–29 and 22–33 dB at distances of 50, 30 and 20 m, respectively, from the outer line (NVE 1979). In humid weather, the noise increases up to 15–30 dB compared to recordings in dry weather. In a recent study, Ustad (I997) showed that discharge noise from a 300 kV power line in Slådalen dominated over background noise (wind noise) in the frequency area between 2 and 16 kHz in misty weather. Noise from the line and the surrounding vegetation was recorded in the range 30 Hz to 16 kHz, with corresponding sound pressure varying from 70 to less than 5 dB.

Most literature deals with people and audible noise. But the hearing range in animals differs from that in man; sound that might disturb animals may be inaudible to man. Audible noise measured in dB with reference to hearing in man may not be the appropriate measure of noise as it is perceived by wildlife. Most other mammals hear higher frequency sounds than do humans. For example, optimal hearing range of ungulates like sheep (Wollack 1963), cattle and horses (Heffner & Heffner 1983) is from 23 Hz to 42 kHz, with a best sensitivity between 1 kHz and 16 kHz (see Fig. 1). Lowest threshold in dB measured from −11 in cattle to 7 in horses. Correspondingly, frequency values for man range from 20 Hz to 18 kHz, with optimal frequencies from 1 to 4 kHz.

Although animals may be responsive to changes in the acoustic environment, they may rapidly acclimate or habituate. In a study on sheep (Ames 1978) which used heart rate and respiration rate as indicators of physiological responses, the hypothesis of habituation to sound type and intensity was supported.

On the other hand, the opposite phenomenon, so-called sensitization, is also known from behavioural studies. In these cases, the strength or the intensity of a response increases with repeated stimulation. This is generally the situation when

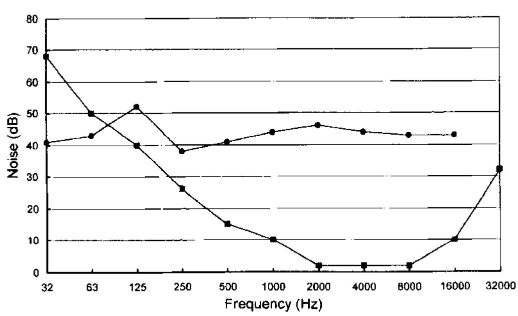

Fig. 1. Comparison between noise level from a power line and mean capacity of hearing in some ungulates. Noise measurements (•) have been taken for a 132 kV power line in rainy weather. The mean capacity of hearing for ungulates (■) is based on audiograms for cattle goat, horse, pig and sheep (Heffner & Heffner 1990).

the stimulus is uncomfortable or – in the animal's experience – is followed by something unpleasant.

Knowledge of the auditory capacities of northern deer species (cervids) like moose (*Alces alces*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*) and reindeer is currently lacking.

Disturbance from the installation, monitoring and maintenance of physical structures

In an earlier review of the effects of power lines on reindeer and caribou, Reimers (1984) concluded that information within this field reflects opinions rather than scientific facts. Based upon the available information, Reimers (1984; 1986) concluded:

1) Well-documented consequences of power lines are permanent loss of grazing land covered by mast footing and temporary loss of grazing land in connection with construction. The importance for reindeer is limited.
2) During construction reindeer may alter their migration pattern and range use.
3) Limited data indicate that semi-domestic and wild reindeer habituate to power lines shortly after their construction when the lines are not accompanied by other human activity such as road traffic, tourist tracks, settlement etc.
4) Factors that may influence whether animals cross under power lines are: the topographical location of the line (e.g. in valleys, over mountain tops); whether it is located in forested or in open terrain; the location in relation to grazing, calving and rutting areas; time of the year; presence or absence of harassing insects; climatic factors that lead to corona and wind noise from the line; and the age, sex, physical and psychological condition of the animals and their earlier experience.

Information available from Goodwin (1975), Stahlecker (1975), Ellis et al. (1978), Lee & Griffith (1978), Smith et al. (1986) and Takatsuki (1992) indicates that the general conclusion, above, also applies to deer (*Odocoileus* sp.), elk (*Cervus canadensis*), bighorn sheep (*Ovis canadensis*), pronghorn antelope (*Antilocapra americana*) and sika deer (*Cervus nippon*).

Methodology in a study of elk and other deer under an energized 500 kV transmission line (Goodwin 1975) included direct observations, time-lapse photography, track counts and vegetation analysis. Typical behaviour of most deer when entering a right-of-way or control area was to remain motionless for a few moments at the forest edge. After this, they entered the clearing and usually began feeding. After initial wariness when entering a clearing, none of the observed deer appeared to be disturbed by the presence of the transmission line. During several days of 55 to 60 dB(A) noise levels, track counts did not indicate any aversion by the animals to the right-of-way. Data obtained through this study indicates that elk movement near the 500 kV transmission line right-of-way was not significantly different than that near other forest openings. The transmission line produced audible noise levels, which at times were very annoying to humans. There was no indication, however, that noise deterred elk, other deer and several other wildlife species from entering and crossing the right-of-way.

It is important to emphasize that these power lines cut through forested areas. The line corridor provided an ecotone with excellent food resources and accessible hiding in the adjacent forest. The availability of both food and protection may have outweighed the possible negative effect of a power line.

Desert bighorn sheep were studied for six years (before, during and after construction) in relation to a 500 kV transmission line (Smith et al. 1986). It was not possible for the observers to make any meaningful comments on sheep and the transmission line as there were few interactions between the sheep and the line. In the limited observations of Smith et al., sheep crossed the line without hesitation and foraged immediately under the line without indicating any obvious distraction from the line or its associated noise.

The research programme

Research designed to address some of the current questions relating to the effects of power lines on reindeer includes: 1) determination of the hearing capability (audiogram) in reindeer, including frequency range, sound level sensitivity and the lowest threshold level; 2) examination of the hearing sensitivity and threshold levels related to recordings of transmission line noise and noise from snowmobiles, aircraft and normal vehicular traffic; 3) controlled experiments with domestic reindeer fenced in under high voltage transmission lines; 4) recording and assessing the behaviour of wild reindeer in a calving area adjacent to a 420 kV transmission line in Setesdal-Ryfylke.

The research programme started in March 1999 with taming and training of two domestic yearling reindeer males for determination of their audiogram, and the establishment of the four experimental areas in association with the power lines. Preliminary behavioural studies of wild reindeer and power lines were carried out in May 1999. The audiogram in two yearling male reindeer has now been determined and this part of the study will be completed this year with the determination of a corresponding audiogram in two yearling females. In September 1999 the behaviour study of domestic reindeer under high voltage transmission lines was completed. Data processing and write-up are in progress. The behaviour study of wild reindeer in the area crossed by a 420 kV power line will continue this year and is planned to be completed in 2001.

1) Hearing in reindeer: hearing range and sensitivity; audiogram determination

To evaluate the effect of power line noise and noise from various human activities in connection with power line construction and maintenance, we have initiated a study to determine the audiogram in reindeer, i.e. the frequency range with corresponding sensitivity levels. The behavioural methods developed should be applicable to other deer species. Knowledge of the auditory capacities of deer may be important, not only in a transmission lines context, but also in an attempt to reduce automobile/train and deer accidents. In recent years, between 5000 and 6000 animals (Official Statistics of Norway 1997) are killed annually in such collisions.

Deer audiograms may be determined from brainstem-evoked potentials recorded in various parts of the head in anaesthetized animals, or from conditioned behavioural responses to specific sound stimuli. We have selected the latter method, currently the most used method in determining the audiograms in mammals. Testing, as described below, is well underway at the animal quarter at the University of Oslo. We have now determined the audiogram for the two male yearlings and continue work with the two female yearlings. We plan to have completed determination of the audiogram for reindeer by September 2000.

Two male yearling reindeer have been trained to react to tones accompanied by a mild electric shock, using a method described by Heffner & Heffner (1990). The thirsty animal is trained to make contact with its mouth on a waterspout in order to receive a steady trickle of water. Tones are presented at random intervals and are followed by a mild electric shock delivered through the spout. By breaking contact with the spout during tone presentation, the animal avoids the shock and indicates that it has heard the tone.

Testing occurs, according to a procedure established by Heffner & Heffner (1995), in a double-walled sound chamber (2.4 × 3.6 × 2.4 m), the walls and ceiling of which have been lined with sound absorbing panels to minimize outside noise and sound reflection. An adjacent room houses the test equipment. During testing the animal is confined in a rectangular cage with a loudspeaker 1 m in front of the cage at the level of the animal's ears. The mildness of the electrical shock is empirically verified by observing that none of the animals ever develop fear of the waterspout and return to it without hesitation after receiving a shock. To receive feedback for successful avoidance, a light in the test chamber is momentarily flashed on each time a shock is delivered. Auditory threshold is determined for each frequency by reducing the intensity of the tone in 5 dB steps until the animal can no longer distinguish tone trials from silent trials. Threshold is defined as the lowest intensity yielding a performance of 0.50 (performance = hit rate − [hit rate × false alarm rate]) (Heffner & Heffner 1995). The use of pure tone stimulation is necessary when training animals to obtain their audiogram. Pure tones will in most cases only alert an animal and not cause any fright or flight reaction. Other sounds with many sound frequency components, or noise, may however, give a spontaneous fright reaction. It is therefore necessary to apply such noise in the tests as indicated in 2), below.

2) Hearing in reindeer: hearing range and sensitivity of noise related to transmission lines and human activity

Transmission line noise (wind noise and electrical discharge) and traffic sounds (aircraft, snowmobiles, vehicular traffic) will be recorded and analysed for frequency level and intensity. Noise levels are related to the audiogram of reindeer to reveal their disturbing potential to the animals. Noise recordings will be played in tests during August 2000 with our experimental female reindeer, to determine the relevance of such a testing procedure to evaluate possible behavioural effects of noise.

3) Behaviour of domestic reindeer under a high voltage transmission line

The reindeer's sensory perception of a power line is potentially a combination of stimuli from the power line alone and these same stimuli combined with environmental variables. Relevant environmental variables (weather factors, food distribution and availability, forms of harassment and combinations of these variables) can in turn strengthen or weaken the effects of the power line. The objective of this experiment, which took place in August–September 1999, was to test the reactions of reindeer toward power lines under different environmental variables and sensory stimuli (sight, sound, electric fields and general perception).

The experimental area was established adjacent to the two high voltage transmission lines (132 kV and 300 kV) along Slådalsvegen in North Ottadalen, Norway, where natural reindeer habitat and forage exist. The experiments were carried out in four oblong pens (Fig. 2) with two treatment pens located beneath the power lines, and two control pens in an adjacent area that was not influenced by the lines. The four 50 × 400 m pens were similar in size, shape, topography, vegetation cover etc.

During August and September 1999 three 1½ year old domestic female reindeer were released in each pen. Through the scan method (Altmann 1974) we recorded manually the activity of the 12 reindeer in the four pens every 10 minutes during the daylight hours. The information recorded included location of the individual animals in the pens and their activities, such as standing, feeding still, feeding slow walk, running, lying head down, lying head up. Every 20 minutes the activity of one focal animal (Altmann 1974) was recorded for 5 minutes, with the time spent in each activity noted. Data on wind speed and direction, precipitation, temperature and humidity were obtained from a portable weather station (Fig. 2). The combined recordings enabled us to determine the effects of important weather and environmental variables and test for their independent or combined effects with a power line in the reindeer's ambient environment. Replication of each treatment pen gave the opportunity to sort out the effect of individual variation between animals. By compar-

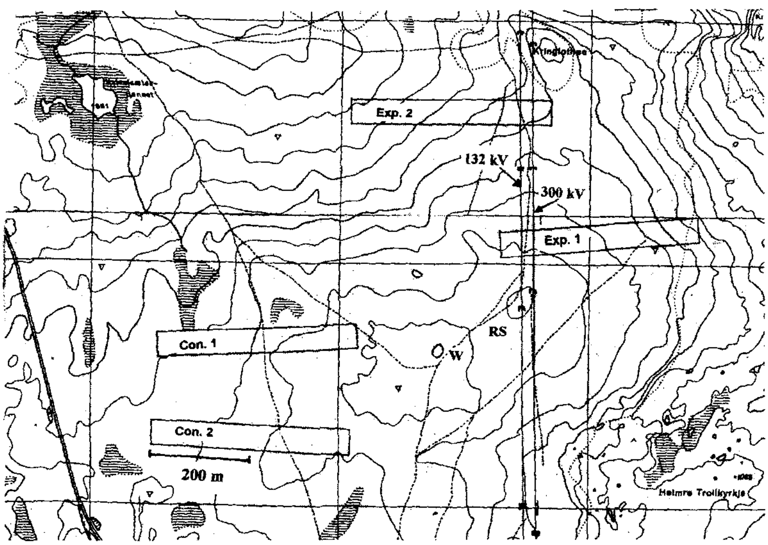

Fig. 2. The study area in North Ottadalen, Norway, showing the location of the two experimental pens (Exp. 1 & 2) under the power lines (132 kV and 300 kV), the two control pens (Con 1 & 2), the weather station (W) and the research facility (RS).

ing treatment pen and control pen the effect of the power line could be separated from the effect of the pen itself. Replication was increased by introducing 12 new animals after 2 weeks, and by a crossover between control animals and treatment animals. The animals had access to water in buckets located at two places (at 50 m and 350 m) in the pens.

4) Video monitoring behaviour of the reindeer in the four pens

Based on a monitoring concept developed by one of us (Stenseth), we have designed a monitoring approach using video as a tool for acquiring vital information about the behaviour of the reindeer in the four pens (Fig. 3). An Astraguard Video Motion Analysing System was connected to eight video cameras programmed to react to prescribed situations, while continuously analysing the scenes. The Astraguard is connected to other equipment, like video transmission, via cables called the I/O system. If Astraguard spots reindeer on channel 2, it will accordingly raise the voltage level on cable 2, telling the video transmission to select camera 2, and send pictures back to the user from this camera. Astraguard will store pictures of what it detects, even if it for some reason fails to alert the user immediately (communication lines might be temporarily out of service). One can also trigger a "trip" around the camera's view when detection occurs, to give an overview of what goes on. For outdoor applications, all of the electronic equipment may be installed in a hardened waterproof device called SCOUT (Self-Contained Observation Unit).

In our experiment, the Astraguard was programmed to divide the visible field of view into 3 zones at 100, 200 and 300+ m in each pen. For each zone we prescribed areas of interest during the tests, and Astraguard returned pictures from

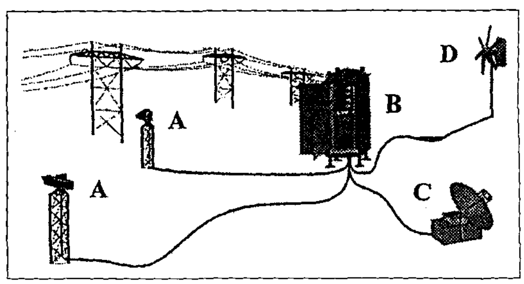

Fig. 3. The main components of an Astragard installation are: sensors (A), instrument unit with instruments (B), communication package (C), power supply and batteries (D). The cameras are connected to a video distribution amplifier which splits the video signals between the Astraguard video detection unit and the video transmission system. Astraguard is a computer, which "looks" at the video cameras view continually; when movement that fits the pattern or programmed set-up takes place, it is triggered to react in the fashion we choose. The SCOUT system (Self-Contained Observation Unit) houses the equipment and connects to a suitable number of cameras. The Astraguard computer in SCOUT, programmed to react to a prescribed situation, will continuously analyse the scenes. This reaction can be programmed as any of a number of possible actions, such as taking pictures, sending pictures to a remote location, activating a microphone or tape recorder etc.

the zones whenever reindeer crossed the zone boundaries. Due to budgetary limits we only got the cameras in one of the experimental pens (with power lines) operative. Data from these two cameras compared with simultaneous manually recording of reindeer activity showed that the cameras recorded precisely the animals shifting use of the established zones. We eventually got the other cameras to work, but no data were stored from the other pens.

Recordings of animals that crossed in either direction between zone 1 and 2 and zone 2 and 3+ in this pen were logged with image, date and time and stored in the database for later retrieval and processing. As the purpose of this experiment was to test the Astraguard recording method as an alternative to manual recording of behaviour, we conclude that this innovative system, which minimizes the possible disturbing effects of observers, opens up exciting possibilities for the study of animal behaviour.

5) Behaviour of wild reindeer in an area crossed by a 420 kV power line in Setesdal-Ryfylke

To our knowledge, no observational report exists that records and evaluates reindeer (or other animal species) behaviour upon approach to, or crossing under, a transmission line. In view of the plans for new transmission lines and reinforcement of current lines, we believe that such information is urgently needed.

To address this knowledge gap, we established in 1999 an observation area south of Botsvatn in Setesdal-Ryfylke, Norway, where a 420 kV power line crosses through a major calving area. Reindeer behaviour under and adjacent to the power line was recorded manually, in a set-up similar to the one described under 3), and on video during May. The fieldwork in this area continues in May–June 2000 and is expected to be completed at the same time next year.

Conclusion

Reliable knowledge is lacking on the effects of transmission lines on reindeer ecology. This condition relates to the lack of long-term monitoring of reindeer migration patterns in relation to existing lines. It is also related to the fact that no knowledge exists regarding hearing in reindeer in relation to transmission line noise, which may be an obstacle for migrating reindeer. It is important to fill these gaps because of actual and possible conflicts between reindeer (both semi-domestic and wild) and existing as well as planned power lines. These questions are currently addressed in an ongoing research programme with several components, the results of which will be analysed and published within the next two years.

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