SWEDISH ENVIRONMENTAL
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The impacts of wind power on terrestrial mammals

A synthesis

JAN OLOF HELLDIN, JENS JUNG, WIEBKE NEUMANN,
MATTIAS OLSSON, ANNA SKARIN, FREDRIK WIDEMO

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VINDVAL

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This report is a translation of the previous report in Swedish ”Vindkraftens effekter på landlevande däggdjur” (Naturvårdsverket report no 6499)

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Preface

There is a great need for knowledge concerning the impact of wind power on humans and landscapes, the marine environment, birds, bats and other mammals. Previous studies regarding the environmental impacts from wind farms have lacked an overall view of the effects. This has led to deficiencies in the processes of establishing new wind farms. Vindval is a program of knowledge and a cooperation between Energimyndigheten (Swedish Energy Agency) and Naturvårdsverket (Swedish Environmental Protection Agency). The purpose of the program is to collect and provide scientific knowledge of wind power impacts on humans and nature. The commission of Vindval extends to 2013.

The program comprises about 30 individual projects and also four so called works of synthesis. Syntheses are prepared by experts which compile and assess the collected results of research and experience regarding the effects of wind power within four different areas – humans, birds/bats, marine life and terrestrial mammals. The results of research and synthesis work will provide a basis for environmental impact assessments and in the processes of planning and permits associated with wind power establishments.

Vindval requires high standards in the work of reviewing and decision making regarding research applications in order to guarantee high quality reports. These high standard works are also carried out during the reporting approval and publication of research results in the projects.

This report was written by Jan Olof Helldin, Jens Jung, Wiebke Neumann, Mattias Olsson, Anna Skarin and Fredrik Widemo, all from Swedish University of Agricultural Sciences. Also Lars Edenius and Jonas Kindberg, Swedish University of Agricultural Sciences and Niklas Lindberg, Enetjärn Natur AB, participated in the compilation of data and text processing.
Jan Olof Helldin was project manager for the synthesis project, which lasted from March 2011 to May 2012.

This report is a translation of the previous report in Swedish ”Vindkraftens effekter på landlevande däggdjur” (Naturvårdsverket report no 6499).
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Vindval in August 2012

Summary

- We compiled available knowledge and experience of the impact of wind power on terrestrial mammals, both wild and domestic. The literature in the field is very limited, so we also tried to draw lessons from related fields, such as disturbance from noise, construction work, traffic, hunting and outdoor activities, and the effects of habitat change.
- Although the knowledge is generally sparse, the summary shows that it is possible that terrestrial mammals, especially large carnivores and ungulates including domestic reindeer, are affected by wind power development in various ways.
- For the larger game species as well as domestic reindeer, the influence from wind power should primarily be due to the network of access roads to the turbines. The main factor is probably the increased access for recreation, hunting and leisure traffic. It is well known that interference from such human activities can impact moose, wild deer, domestic reindeer and large carnivores, and in effect cause a habitat loss.
- New wind power farms are expected to be situated in more remote, upland, currently roadless areas, at least in the forested landscape. Such areas may serve as refugia for e.g. large predators or as important grazing areas for ungulates. Accordingly, wind power and associated infrastructure in these areas may have an impact on the population level of these species.
- By contrast, the habitat changes caused by access roads are not necessarily a problem for the larger mammal species. Open land, new edge zones and roadsides could rather benefit many wildlife species. Open land and edges create new browsing areas; roads can facilitate animal movement in the landscape or help animals escaping parasitic insects.
- The effects of power lines on reindeer tend to differ depending on the geographic scale studied; on a regional scale, an avoidance of large areas around power lines may be observed, while no effects have been shown for reindeer studied near power lines.
- A few studies available on wild deer, reindeer and large carnivores during construction work suggest that these animals may temporarily avoid wind farms during this period. However, the data is not conclusive.
- Noise emissions from wind turbines can theoretically disturb animal communication, and also visual stimuli (including reflections, shadows and lighting) may annoy or stress both wildlife and livestock. However, the few studies available suggest the lack of such effects, or a swift habituation to the disturbance, and therefore a limited impact.

- Animals may also get accustomed to the other disturbances from wind power. For example, both domestic and wild reindeer appear to remain in areas despite human presence, at least when no alternative areas are available. The ability to habituate varies with species, sex, age, individual, time of year, type of disturbance, and how frequent and predictable disturbances are, so overall, habituation cannot be presupposed.
- There may be differences in the response to disturbance, depending on landscape and current land use. In already disturbed areas, such as most agricultural landscapes, wind power may not affect the occurring species to the same extent as it would in more sparsely populated forest and mountain areas.
- The effects may also depend on the size of the wind farm. At the construction of large wind farms, even small and localised effects may sum up to significant impact, with consequences at the population level.
- Our summary highlights the large knowledge gaps in the field and indicates the need for research as well as for efficient environmental monitoring. Of particular need is to study the effects of noise and visual impacts from the turbines. Also studies are needed on the localisation of new wind power in relation to areas of particular value for ungulates and large predators. It is important that the potential cumulative impacts of wind power are considered, as these may lead to consequences at the population level and thus be most relevant from a conservation perspective.
- To address the large knowledge gaps, it is crucial that monitoring programs for new wind power are set up to create new, generalisable knowledge. We describe some principles that should be followed to achieve this. It is also important that monitoring programs are coordinated nationally and that the data are analysed on a comprehensive level.

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1 Introduction

1.1 Background

There is considerable uncertainty about whether and, if so, how wind power affects terrestrial wild and domesticated mammals. The previous attempt to compile the knowledge of wind power's environmental impact in Sweden (Wind Power Commission 1999) addressed the impact on terrestrial mammals without sufficient scientific insight. The conclusion from the survey that "neither wild nor domesticated mammals are disturbed by wind turbines" lacked substantiation. Effects on terrestrial mammals are rarely included in environmental impact assessments for wind power (Lundberg 2011; see box), which in turn has the effect that little new knowledge is generated within the context of monitoring programs for wind power.

As it is well known that mammals can be affected by various types of human disturbance and exploitation, it is reasonable that also wind power has effects. With the increasing expansion of onshore wind power, the question of effects on terrestrial mammals is increasingly brought up by hunters, conservationists, and not least reindeer husbandry. Wind power planning will increasingly include management issues relating to large carnivores, moose and other larger wildlife, and in all wind power development within the reindeer husbandry area, the impacts on reindeer and reindeer herding are important issues. A knowledge basis is needed to support the necessary trade-offs between interests.

Wind power at Kyrkberget in Mid-Sweden. Photo: Jan Olof Helldin.

All environmental assessment must be based on the best scientific evidence available. While the scientific literature on the impacts of wind power on birds and bats are relatively extensive, the literature concerning impacts on other terrestrial animals is very limited.

Also current research in the field is sparse. To approach an answer about impacts of wind power on land mammals at the current situation, it is therefore necessary to try to draw lessons from related fields of research, and also to make a scientifically based reasoning about how animals can be affected by land use, exploitation and disturbance.

Human disturbance can affect land mammals, directly and indirectly (Forman & Alexander 1998, Ingold 2005, Stankowich 2008). Unlike flying species such as birds and bats, the land-bound animals are obviously not killed by collisions with the turbines, but they could be affected by noise from the turbines, by disturbance during construction, by traffic and other human activity associated with maintenance work or by increased accessibility for leisure traffic and outdoor activities (Arnett et al. 2007, Kuvlesky et al. 2007). The infrastructure around wind power, in the form of roads and power lines, can also lead to barrier effects, and to some direct habitat loss. Arnett et al. (2007) proposed that the largest impact of wind power on terrestrial mammals lies in the indirect factors, mainly human disturbance. This impact can lead to increased stress levels in the proximity of wind farms or that animals avoid the proximity of wind farms, leading to decreased habitat quality, or in effect a greater loss of available habitat than what is caused by the actual exploitation.

Effects on terrestrial mammals are rarely described in EIA

Lundberg (2011) reviewed how potential effects on terrestrial mammals are considered in Environmental Impact Assessment (EIA). The basis for the study was 23 EIAs for Swedish wind power projects from the years 2004–2010.

The majority (52%) of the EIAs give absolutely no reference to the state of knowledge regarding terrestrial mammals, and only 22% make a specific citation in the text. The EIAs where references are given refer mainly to the national commission (Wind Power Commission 1999) or to research on reindeer. The author gives suggestions on how censuses within monitoring programs could be implemented in order to build up the knowledge of the impact on terrestrial mammals.

1.2 The aim of this report

In this report we compile the available knowledge and experience about the impacts of wind power on terrestrial mammals, both wild and domesticated animals (excluding bats, which are covered by Rydell et al. 2011). Due to the limited availability of studies of wind power, we also make an effort to draw lessons from studies of related exploitation projects.

The report covers basically all land mammal species. The focus is, however, on the ungulates and large carnivores, which merely reflects the available literature. Ungulates in this respect also comprise livestock, i.e. reindeer and other domestic animals.

2 Method for the literature search

The compilation includes scientific publications and publicly available reports (so-called gray literature) published until spring 2011. During the literature search, we followed the standard method of scientific knowledge compilation.

We used electronic databases and the internet to find relevant scientific literature and reports. We used the search engine Web of Knowledge (http://apps.isiknowledge.com/) to find published scientific papers. Google (http://www.google.se) and Google Scholar (http://scholar.google.se/) were used for internet searches. On Web of Knowledge, we used the search terms *wind power**, *wind power plant**, *wind mill**, *wind turbine**, *windfarm**, *wind park**, *wind installation** and *infrastructure*, combined with the terms *mammal**, *ungulate**, *deer*, *moose*, *alces*, *caribou*, *rangifer*, *reindeer*, *cattle*, *heifer**, *cow**, *sheep*, *goat**, *horse**, *wolf*, *wolves*, *game*, *wildlife* and *biodiversity*. Repeated searches were made, in that each wind power term was combined with each of the animal terms. The search was made without time restrictions, except for the search term *infrastructure*, where only the last 10 years were searched (since it is within that time frame that wind power has occurred on a larger scale). In a second step, we broadened our search by the terms *impact*, *forest roads*, *construction* and *power line*, combined with the terms *wildlife*, *reindeer* and *rangifer*. For *forest roads* and *construction*, we restricted the search to the last 5 years (since the earlier literature already was available from the authoring team); otherwise, we used no time restrictions. A separate search was made for cumulative effects, using the term *cumulative effects* in combination with the terms *wind power* and *road construction*. Furthermore, the search terms *forestry*, *silvicult**, *clear-cut**, *pre-commercial thinning*, *brushing* and *thinning* were combined with *mammals*, *deer*, *carnivore*, *bear*, *wolf*, *wolverine*, *lynx*, *fox*, *mustelid**, *badger*, *marten*, *stoat*, *weasel*, *hare*, *mouse*, *vole* and *shrew*. Free search via the search engine Google was made using the terms *windkraft* + *wildtiere* and *windkraftanlagen* + *wildtiere*, to search for German literature. Some additional literature was already at hand for the authoring team, and was put to the group's common disposal.

For most search terms, the number of relevant hits per search term in Web of Knowledge was so limited that all relevant articles were reviewed – only hits which obviously dealt with another topic were excluded in a first instance. After examination, we made an assessment of the relevance of papers and reports to the continuing synthesis. Since the gray literature has not undergone any independent quality review in the way scientific papers have, we made our own quality assessment, based on mainly the presence of original data, method description, and robustness of the conclusions, and included only those reports that were considered reliable.

3 Theories about the ecological and ethological effects of disturbance

3.1 Effects of human disturbance

Human disturbance can have a significant ecological, behavioural and physiological impact on animals. For domestic animals such as cattle, sheep, horses and pigs, it has been shown that disturbances of various types can lead to stress, which can be measured as increased heart rate or incidence of stress-induced hormones, reduced time for grazing, or impaired reproduction (Ames & Arehart 1972, Dobson & Smith 2000, Spreng 2000, Christensen et al. 2005, von Borell et al. 2007).

How human disturbance is manifested in wild animals depends on the species' ecological role. Each species within an ecosystem belongs to a particular trophic level, showing its location in the food chain, such as predator or prey. In addition, species are divided into different so-called guilds. A guild consists of species that have a similar ecology, even if they are otherwise different from each other, e.g. in appearance (Begon et al. 1996). Being at a particular trophic level or in a particular guild may affect a species' behaviour *visavi* predation risk and disturbances. Predators at the top of the food chain are often very sensitive to human activity (Creel et al. 2002, May et al. 2006, Berger 2007, Nellemann et al. 2007). For different species groups the response to a disturbance may be vastly different. While prey species often show escape behaviour when disturbed by humans (Stankowich 2008), large predators rather try to hide (Pedersen 2007, Stoen et al. 2010). Some medium-sized predators, such as foxes and badgers, generally are more tolerant to human presence, and benefit from a landscape changed by man and also by the absence of top predators (Huck et al. 2008, Prugh et al. 2009, Ordenana et al. 2010). Such differences in response behaviour between species groups imply a need for good knowledge of the species' ecology to evaluate the disturbance effect on the species.

A central theory in the research on effects of human activities on wild animals is that animal responses to human-caused disturbances follow the same pattern that is used to evaluate a change in animal response to the risk of being taken by a predator (Frid & Dill 2002). According to the predator-prey theory (Berryman 1992), prey responses increase with increased perceived risk. In effect, prey may choose areas where there is less risk of being taken by a predator, thereby selecting certain habitats that are perceived as more secure – this creates what is called a landscape of fear (Ripple & Beschta 2004, Brown & Kotler 2007). The theory is applicable also for the habitat selection of predator species, where predation by larger species or humans (mainly hunting) may lead to the preference of habitats or areas that are perceived as more secure.

Based on the theory of predation risk and disturbance, human disturbance also results in a trade-off, in which the animals' time and energy resources are diverted from other activities that are important for animal fitness and population size, such as foraging, reproduction, and similar activities (Frid & Dill 2002). For example deer, and especially female deer, increase their escape and vigilance behaviour in the presence of humans, and populations that are hunted by man are more sensitive to human disturbance (Reimer & Colman 2006, Stankowich 2008). Females are particularly vulnerable to disturbance during the reproductive phase. In such cases human disturbance may lead to reduced reproductive success, such as for North American elk, where the number of calves per doe decreased when the doe was frequently disturbed by hikers during the calving season (Phillips & Alldredge 2000). For domestic as well as wild reindeer and its North American counterpart caribou, it is well known that the most sensitive time of year is the calving period and directly thereafter, when the calves are small and slow (e.g. Espmark 1971, Cameron et al. 2005).

A common way to study how animals perceive their environment and thus how they respond to different types of interferences and changes in the environment is to separate the animals' activity on different geographical scales, i.e., their hierarchical habitat selection. The theory was presented by Johnson (1980), and further developed by Senft et al. (1987); it implicates that an animal selects or avoids various factors depending on the spatial scale. Quantity of forage, for example, plays a major role for herbivore habitat selection on a large scale, while forage quality may be more important on a smaller scale. The theory is based on the number of decisions that an animal makes on various geographical scales. A description of a hierarchical habitat selection of a herbivore can be that the animal first selects region, then landscape, then plant site and finally plants (Senft et al. 1987). The choice of landscape and habitat occurs relatively infrequently (once a week or once a day), while the choice of plant and plant part occurs often (maybe thousands of times per day). Within the different scales animals are affected by different factors when selecting areas (Senft et al.1987). The theory of hierarchical habitat selection has been developed mainly for herbivores, but the principle that animals choose whereabouts depending on geographic scale may also apply to predators.

An example of how hierarchical habitat selection can be expressed is described by Vistnes & Nellemann (2008). They reviewed 85 different scientific studies on the effects of various disturbance sources in reindeer and caribou and found that studies on a local scale, such as behavioural studies in direct proximity to a source of disturbance, rarely (13% of studies) found any effect of a disturbance, while larger-scale studies at regional level often (85% of studies) found that reindeer and caribou avoided areas close to infrastructure.

Ecological impacts may also include so-called cascading effects, because the species within the same ecosystem has ecological relations to one another. This means that an effect on one species may in turn affect many other species, thus creating a cascade effect. Cascade effects may result in different types of interactions, such as competition, predation, parasitism or symbiosis, depending on their effect or mechanism (Begon et al. 1996).

A changed spatial distribution of individuals due to human activity can cause similar cascade effects as predation risk. For example, large predators such as wolves and brown bears often avoid areas of high human activity, which can create a predation free area to which prey species may be attracted (Hebblewhite et al. 2005, Berger 2007, Nellemann et al. 2007, Martin et al. 2010). This spatial redistribution of large herbivores may in turn impact local vegetation structure and lead to less available forage in the areas that are actually used (Persson et al. 2000, Bråthen et al. 2007). Another risk is that the forage in undisturbed areas is already initially of lower quality. Either way, the welfare and reproductive performance of animals are negatively affected if they do not have access to good grazing areas. Cascade effects are likely to affect wildlife as well as domestic animals (Berger 2007, Muhly et al. 2010). For domestic reindeer, that are restricted to a certain herding district, it may be problematic having to move from one area to another, because they have few alternative places to use. Reindeer, as well as wild ungulates, use different areas during different seasons, and if they are forced to graze for a long time in one area, it may affect the recovery of the vegetation in that area, and the area cannot be used to the same extent in the next seasons. For other domestic animals, the options to move between fields are limited due to fencing.

3.2 Habituation

Animals exposed to prolonged or repeated human disturbance may eventually adapt both behaviourally and physiologically and become 'habituated' (Petrinovich 1973). This is likely to happen particularly if the disturbances are predictable in time and space, such as vehicles along congested roads or pedestrians along frequented paths (Dafour 1980, Reimers & Colman 2006, Stankowich 2008). Research suggests that domestic animals have an ability to adapt to certain sounds and visual cues unless these are accompanied by an immediate danger (Ames & Arehart 1972, Grandin 1997).

An animal's ability to habituate to a disturbance can be measured in the degree of tameness of the animal (Price 2002), by studying an animal's flight distance, i.e. how close a human can approach an animal before it moves or flees. The genetic background determines the conditions for how tame an animal can be, so even within a species the degree of tameness can vary (Price 2002).

As described above, the flight distance of a prey is strongly related to the predation risk, and also a very low predation risk can contribute to an increased susceptibility to escape (Scheel 1993, Hunter & Skinner 1998). Similarly, human hunting may affect the animals' response, in that hunted populations become more sensitive to disturbance and the escape distance increases, especially in direct connection to the hunt (Reimers & Colman 2006, Stankowich 2008). Hence, an animal's ability to habituate to human activity depends on species, sex, age, individual, time of year, type of disturbance, and how frequently disturbances occur (Dafour 1980, Stankowich 2008). Habituation can therefore not be presumed to occur.

In addition, the fact that an animal remains in a place in spite of human disturbance does not necessarily mean that the animal is not disturbed, but may indicate that there are no alternative habitats (Gill et al. 2001, Stankowich 2008). It is therefore difficult to determine if the animals have become accustomed to human disturbance or if there are no other options. Being forced to remain in an area despite human disturbance can affect the animals' physiological stress levels (Creel et al. 2002, Barja et al. 2007). Stress triggers the fight-or-flight response, resulting in increased alertness, which may drain the animals' energy reserves. The body condition will in turn affect the ability of the animals to manage predation risk and foraging. Animals in poor condition have less to lose and are therefore more likely to forage in more productive but risky habitats (Brown & Kotler 2007).

Habituation is exemplified here with studies on reindeer. Reimers et al. (2010) studied the flight distance in wild reindeer on the smaller Blefjellet in Norway, which had been exposed to a greater intensity of human activity for about 30 years, and compared with reindeer on Hardangervidda whose grazing area was larger and further away from human activity. They found that the reindeer at Blefjellet had a shorter flight distance and appeared to be less easily disturbed than the reindeer at Hardangervidda. This may have been because the reindeer in Blefjellet had accustomed to human activity for a longer time than the reindeer at Hardangervidda. Skarin et al. (2010) could find a similar pattern for reindeer in Sweden. They found that the reindeer in an area with lower visitor numbers (Sarek) were more active in the vicinity of hiking trails, while the reindeer in an area with higher visitor numbers (Sylarna) did not show the corresponding pattern. Thus, the reindeer from Blefjellsområdet and from Sylarna both seemed to have habituated to human activity. However, similar for these two studies was that the reindeer in the areas of higher human activity had limited opportunities to choose alternative sites and were more or less forced to adapt to human presence (Skarin et al. 2004).

3.3 Differences between wild and domesticated animals

To understand the differences in behaviour among different groups of animals covered in this report, it may be important to sort out some concepts around wild, tame and domestic animals. Domestication occurs by the selection of animals that are easier to handle and to tame, while it is necessary to continue the active taming of the animals that are to be handled (wild or domesticated), because domestication is also an individual learning process (Hemmer 1990). Tameness has little to do with whether an animal is essentially domesticated or wild; just as wild animals kept in zoos may be tame, domestic animals will become feral if they live in the wild (Hemmer 1990). The difference between a wild animal and a domesticated animal in the wild is that the domesticated animal appears to be tame, because they typically have much shorter flight distance when a human approaches. One of the most important steps in the domestication process is to reduce the animals' sensitivity to changes in their environment (Price 1999). It is generally assumed that the disturbance effects are smaller for domestic animals than for wild animals, since domestic animals are accustomed to human activity and artificial systems (Price 1984, Mignon-Grasteau et al. 2005). Therefore, one can also expect that domestic animals do not react as strongly to an exploitation or disturbance in their environment, such as a wind farm or individual wind turbines. On the other hand, the fact that domestic animals are usually fenced in make it difficult for them to avoid a disturbance source, and they will instead have to find ways to adapt.

The degree of domestication, as well as the degree of tameness, also depends on the production system that animals are kept in and on the species in focus. In a conventional farming system, where animals are kept in stables most of the year, greater degrees of domestication and tameness can be expected. Reindeer kept in a pastoral system, and additionally which live unfenced in their natural habitat, have significantly lower domestication and tameness degree than other domestic species. The domestication process of reindeer has only involved breeding for traits making it easier to gather and handle the animals for short periods; otherwise, people have taken advantage of the reindeer's natural adaptation to the arctic climate.

Another fundamental difference between wild and domesticated animals that may be of importance for the evaluation of potential environmental effects is that domesticated animals are fed and cared for, and that the density of the herd is carefully regulated (e.g. in relation to available forage). In comparison, wild animals, on average, have poorer nutritional status, and are exposed to larger food competition, winter starvation, disease and predators in a way from which domesticated animals are normally spared. One can thus say that wild animals are on average closer to the "verge of survival", and that environmental changes often have more dramatic effects, such as decreased reproduction, increased mortality and population declines.

4 Effects of wind power on terrestrial mammals

A wind farm involves not only the wind turbines, but also a number of other factors, such as infrastructure in the form of access roads, cleared areas and power lines, human activity in the area as part of maintenance work, disturbance during construction and dismantling, and improved accessibility to the area, for example outdoor recreation, hunting and leisure traffic. This means that an assessment of the impact from wind power on land mammals also has to include ecological and ethological effects of all of these different types of human intervention.
We make a review here of the impacts of wind power facilities on land mammals, both during the construction phase (section 6.1) and during the operational phase (section 6.2–6.6). The impacts are described in relation to the animals' habitat selection and behaviour on both a local and a regional scale. Based on our review, the extent of the effects is summarised (section 6.7). It should be emphasised that the review is based on the studies that were revealed through the literature search and that there may still be other, yet unexplored, effects.

4.1 Disturbance effects during construction and dismantling

The construction phase of a wind energy facility entails increased traffic, ground work, in some cases logging, and other human activity in the area, which may affect animal behaviour and spatial distribution. The few available studies of the construction phase point at some, albeit temporary, impact. Preliminary results of a study of wolves at a Portuguese wind farm show that wolves avoid the area during the construction phase (Álvares et al. 2011), but the effect is limited to a single year. Snow tracking of wolverines at the wind farm in Uljabuouda in Norrbotten, Sweden, has produced results that may indicate some reduction in the number of wolverines in the area in connection to the construction (Flagstad & Tovmo 2010), but these studies are continuing and will hopefully give more significant results. At the construction of Hitra wind farm on Eldsfjellet in Norway, there were some indications that red deer stags temporarily left the area closest to the wind farm (Veiberg & Pedersen 2010). For North American elk, Walter et al. (2006) describes some impact from the wind farm during construction, but the animals did not shift home ranges and no effects on the population level could be noted. Also for black bear, there is a study suggesting a certain avoidance during construction (Wallin 1998). However, none of these studies actually presents data that are solid enough to rule out other factors as explanations for the pattern, and in neither of these cases, the avoidance of the wind power facility is absolute. According to Arnett et al. (2007), an avoidance during construction can also be expected in species such as mule deer, white-tailed deer and pronghorn, but so far, this remains a speculation.

North American elk at a wind farm in Washington State, USA. Photo © Puget Sound Energy.

The Norwegian project VindRein, that has been running since 2005, identifies how reindeer are affected by wind farms in open terrain such as mountain areas and along the Norwegian coast. Preliminary results from the project show that the reindeer avoided wind farms during construction but that they subsequently came back to graze within the wind farms (Colman et al. 2008). It should be emphasised though, that during the expansion of large wind farms, the construction phase extends over several years, and some effects during this phase can thus be long-lasting (at least along the main access roads).

We have not been able to find records of any response to the dismantling of wind farms, which of course may have to do with the fact that wind power is a relatively new energy source and that dismantling is therefore not really an issue. Given that dismantling similar to construction will require heavy machinery, intense traffic and increased human activity in the area during a limited time, one can expect disturbance effects similar to those during construction.

4.2 Noise and visual disturbance from wind turbines in operation

Animals that live near the wind turbines can be affected by noise from turbines in operation, because the sound can disrupt animal vocal communication or impair the animals' ability to hear approaching predators. Available literature gives only one example; California ground squirrels near a wind turbine were more vigilant and more prone to return to their burrows after warning sounds compared to squirrels in a reference area without wind turbines (Rabin et al. 2006). A similar response could apply to other species using warning sounds, such as deer. Also other types of vocalisation, to establish a territory, to attract partners or keep the group together, may be masked or disturbed. Examples are bellows from deer during the rut and howling among wolf families.

A survey of small game (hare, roe deer and red fox) scats/pellets and tracks during winter in northern Germany showed no evidence of different distribution, or different habitat use, in areas with wind farms than in reference areas without wind power (Menzel & Pohlmeyer 1999). The study also showed that within a radius of 10–1000 m from a wind turbine, the distribution of pellets/scats and tracks was similar for all distances from the turbine (Menzel & Pohlmeyer 1999).

For fenced animals, with limited opportunities to move, it is possible that noise and visual effects (including shadows, reflections and marker lights) from nearby wind turbines lead to increased stress levels. In a test on semi-domestic reindeer in an enclosure near a wind turbine (distance to turbine 10–450 m), no avoidance of the part of the enclosure proximate to the wind turbine was observed, neither was any systematic change of animal behaviour indicating fear or stress from noise or rotor movements (Flydal et al. 2004). The authors emphasise, however, that fenced animals can habituate quickly to the stimuli they are exposed to, and to fully assess the effects of wind power on reindeer they recommend studies in larger enclosures or free-range animals.

A study where horse owners were asked about the animals' responses to wind power pointed at some reactions (Seddig 2004). Eleven of the 424 horses included in the study had displayed concern or avoidance of shadows from turbine wings cast against the stable window or on the ground along the horse trail . The responses were, however, described as less severe (e.g. no rearing or breaking out of box), and even these 11 horses habituated quickly.

For other domestic animals, scientific studies of disturbance from noise or visual stimuli from wind power seems to be lacking. For example, references are made to observations of animals residing directly adjacent to the turbines or resting in their shade (Wind Energy Survey 1999, Australian Wind Energy Association 2004, Sustainability Victoria 2006), but in order to draw any firm conclusions about possible interference or avoidance, more controlled trials are needed.

Photo: Jan Olof Helldin

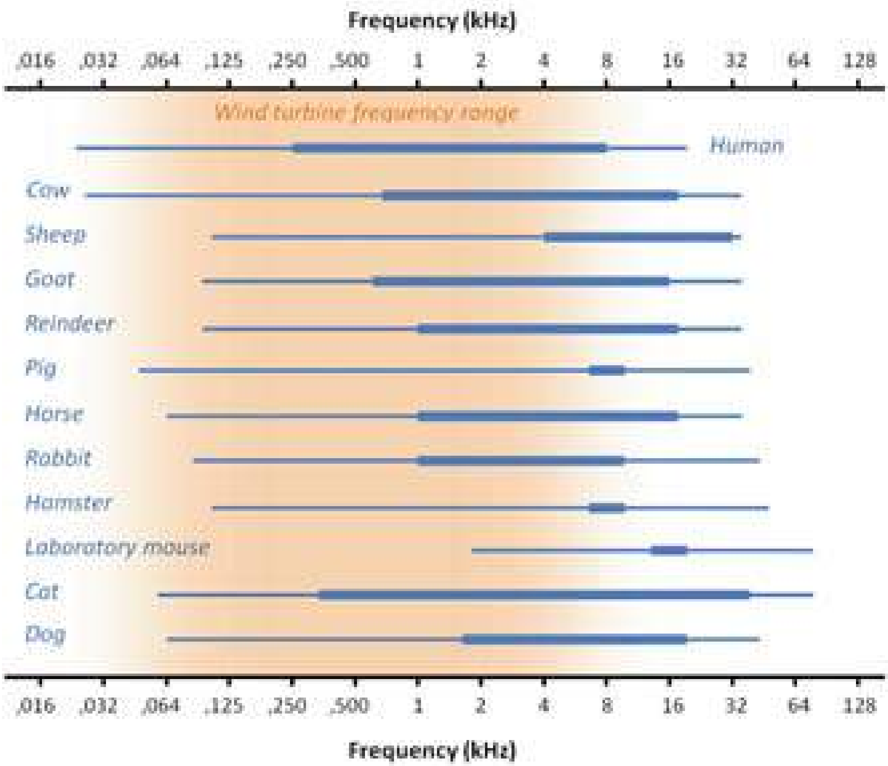
Studies of different domestic animals have shown that high noise levels cause stress. Noise levels of 60–75 dBA may cause increased respiration and heart rate, increased vigilance, and decreased time for grazing in domestic animals such as sheep and horses (Ames & Arehart 1972, Christensen et al. 2005). The Swedish limit value for technical noise in stables is 65 dBA momentary level (Jordbruksverket 2010). There is no corresponding limit for animals in outdoor environments. Our own calculations (based on Naturvårdsverket 2010) indicate that the noise level directly under a wind turbine (1.5 MW, hub height 60 m) is between 50 and 60 dBA (equivalent level), thus below the limit for stables and even below the levels where effects on domestic animals have been described.

The fact that the wind turbine noise is not associated with an immediate risk suggests that the animals should be able to habituate to the sound. Wind turbine noise can also be masked by other sounds in the environment, such as traffic or the wind in the vegetation, and thus at least at times appear less annoying (Naturvårdsverket 2010). The impact of wind turbine noise on animal well-being and health can therefore be assumed to be limited.

Animal hearing

Mammalian hearing is not that unlike human hearing. Humans can hear sound in the frequency range 20–20 000 Hz. Cattle have a hearing range of 23–35 000 Hz, with an extraordinary sensitivity around 8 000 Hz (Heffner & Heffner 1983). Horses have a slightly narrower hearing range, 55–33 500 Hz, with maximum hearing in the range 1000–16 000 Hz (Heffner & Heffner 1983). Pigs' hearing range is more toward ultrasound; frequency response is 42–40 500 Hz, with extra sensitive range at 250–16 000 Hz (Heffner & Heffner 1990). The hearing range of goats is 78–37 000 Hz, with a maximum sensitivity around 2000 Hz (Heffner & Heffner 1990). Reindeer hearing range extends from 70–38 000 Hz (Flydal et al. 2001).

The most prominent frequency range of the aerodynamic sound created by wind turbines is 63–4 000 Hz (Naturvårdsverket 2010). Accordingly, all of the above mentioned species overlap in hearing with the frequency range of wind turbine noise, suggesting that farm animals will readily hear this sound. The similarities with the human hearing range suggest that animals should perceive the sound of wind turbines in rather the same way as humans do.



Frequency ranges for hearing in humans and a number of domestic animals. Broad lines indicate the most sensitive area = audible at <10 dBA. The dominating frequency range of wind turbine noise is shown with the coloured surface. Data from Heffner & Heffner (1990, 2007), Flydal et al. (2001) and Nilsson et al. (2011).

4.3 Electromagnetism

The risk for domestic animals to be affected by the electromagnetic field around wind turbines and transmission lines has been discussed (Parent 2007). A systematic review from 1999 indicated that no evidence was found that electromagnetic fields cause bad animal health, lower productivity or fertility, or change in animal behaviour (Renaud et al. 1999). Subsequently, a number of experimental studies of cattle residing in electromagnetic fields similar to those around high voltage lines have shown changing hormone levels, decreased food intake and reduced milk production (Burchard et al. 2003, 2006, Rodriguez et al. 2004). These changes corresponded, however, to levels that cannot be considered hazardous to health (Burchard et al. 2006). Algers & Hultgren (1987) examined effects of high voltage power lines on cow fertility and found no effects.

Compared with the levels in the above studies, the electromagnetic fields in wind farms are weaker. The field strength to which animals were exposed in the studies corresponds to those just a few meters from the generator, and at ground level, the electromagnetic field from the generator should be so weak that any risk can be considered negligible (Australian Wind Energy Association 2004, Parent 2007). Where the power lines in a wind farm are located underground, both cable screening and soil serves as isolation, and again the levels on top of the surface can be considered negligible (Australian Wind Energy Association 2004). In summary, we found no results indicating that electromagnetism in wind farms should have any measurable effect on terrestrial mammals.

4.4 Roads and traffic

The network of access roads in a wind farm may affect terrestrial mammals in different ways. Traffic and outdoor activities can constitute disturbance factors. Roads cause a loss of natural habitat but also a conversion of habitat that is not necessarily negative to animals. The roads can create barriers to animal movements, thereby contributing to landscape fragmentation but can also facilitate movements.

Effects of roads are here described with respect to wildlife and reindeer; effects on other grazing livestock can be considered negligible (with the possible exception of horses that are considered more affected by traffic than e.g. cattle and sheep). Since most pastures already have access roads, an additional road to a wind turbine should not make a great difference.

4.4.1 Disturbance from utility traffic

Road traffic is a disturbance factor for many larger species, but utility traffic in a wind farm in operation is very low (perhaps a few vehicles per day) compared to the traffic levels where disturbance effects are normally considered to be apparent (which may involve at least hundreds of vehicles; Helldin et al.

2010). There may, however, be differences between species. The road network of facilities for gas extraction in North America, that has similarities to the road network of wind farms both concerning structure and operation-related traffic, were avoided by mule deer and North American elk in the winter during daytime (Sawyer et al. 2009, Harju et al. 2011). In mule deer the avoidance depended on the number of vehicles on the roads, but also roads with fewer than ten vehicles per day were avoided to some extent (Sawyer et al. 2009).

In a Finnish study of domestic reindeer on a regional scale, the reindeer's choice of home range and grazing area within the home range was studied (Anttonen et al. 2010). In this study, reindeer avoided areas with major roads, but not areas with minor forest roads, presumably due to the low activity on the latter road type. The Norwegian VindRein project showed that domestic reindeer who returned to a wind farm area after the construction phase was completed still avoided the access roads into the area (Colman et al. 2008).

Wind farm near Cottbus, Germany. Photo: Jan Olof Helldin.

These results indicate that the road network and operation-related traffic to some extent can affect the spatial distribution of both wild deer and domestic reindeer. The animals' response to roads may vary with time of day, with season (for example, a greater sensitivity during the reproductive phase) and with the traffic density; some species are also attracted to roadside habitats or use roads to facilitate movements between areas (Nellemann & Cameron 1998, Bruggeman et al. 2007, Laurian et al. 2008, Martin et al. 2010, Ordiz et al. 2011). It is thus difficult to draw any general conclusions regarding the impact of operation-related use of access roads.

4.4.2 Disturbance from leisure traffic, hunting and other outdoor activities

The recreational traffic and the increased accessibility for humans appear to be a bigger problem than the utility traffic (Helldin & Álvares 2011). Presently, many access roads in wind farms are open to all traffic. Even if roads are gated they may still be used by bicycles, motorcycles, ATVs and snowmobiles. The public use of the new infrastructure can be to gain access to new areas, reach further into nature, or simply for leisure driving. For a number of mammal species, the activity and movement patterns may be affected in the hours following a human disturbance (Andersen et al. 1996, Olsson et al. 2007, Naylor et al. 2008), but it has also been shown that disturbances can have more severe impacts, such as reduced survival, reduced reproduction or avoidance of entire areas (without available alternative sites), with a subsequent reduction in population size (Gill et al. 2001, Frair et al. 2008). In practice this means a loss of available habitat in disturbed areas.

Studies have shown that human disturbance could cause individual moose to abandon previously established areas (Andersen et al. 1996) and that mule deer in daytime avoid areas with many people (George & Crooks 2006). Two studies of domestic reindeer around a Finnish tourist resort showed that the reindeer avoided areas with snowmobile tracks and areas near the urban area, especially in the latter part of the winter, and that female reindeer avoided the area near the resort even during the summer months (Helle & Särkelä 1993, Anttonen et al. 2010).

Hunters may also take advantage of the new roads. Swedish legislation states that weapons cannot be carried on a snowmobile or ATV that runs in the terrain but on roads. Thereby, a new network of roads in a wind farm should facilitate for hunters to get to their hunting areas and to transport the game bag out of the area. Even with wind farms in agricultural areas, it is possible that the roads will facilitate hunting. It is often a challenge to hunt in growing crops, and a road network can provide an opportunity to get around easily on foot and also to shoot from an elevated position.

The increased accessibility in wind farm areas could be a problem for large carnivores. They tend to avoid areas regularly frequented by people (Theuerkauf et al. 2003, Johnson et al. 2005, George & Crooks 2006) and exhibit a preference for undisturbed, rugged terrain (Elfström et al. 2008, May et al. 2008), i.e. precisely such remote, upland areas that may be of particular

In most wind farms, roads are open for all traffic. The wind farm at Kyrkberget, Sweden.
Photo: Jan Olof Helldin.

interest for wind power. Of the four large carnivores occurring in Scandinavia (brown bear, wolf, lynx, wolverine), the most sensitive to human disturbance is probably the wolverine, which has been shown to avoid areas with roads (May et al. 2006). However, brown bear and grizzly bear are particularly well studied in this perspective, and these clearly avoid human disturbance when possible (Nellemann et al. 2007, Martin et al. 2010). When selecting denning sites, brown bears avoid areas <1 km from larger and medium-sized roads or individual houses (Swenson et al. 1996). A similar avoidance has been shown several times for grizzly in North America (e.g. Gibeau et al. 2002). Several studies have also shown that grizzly bears avoid areas with a dense network of forest roads, which can be explained by a higher hunting pressure in such areas (e.g. Mace et al. 1996). Bears (brown, grizzly and black) may abandon the den after disturbance from hunters, dogs, skiers and other outdoor activities, and such abandonment of the den is associated with weight loss for the animals, as well as with a higher mortality risk (Linnell et al. 2000).

Analyses of Swedish wolf territories show that territories have lower densities of roads (public and private), less housing areas and open land, and less human disturbance, compared with the areas just outside the territories (Karlsson et al. 2007). Also studies in Quebec show that wolves avoid areas with dense road networks, because of the higher abundance of people in these areas, and that the avoidance is strongest in the denning season (Houle et al. 2010). According to preliminary results from a study of wolves in Portuguese wind farms, the presence of wolves is reduced with increased numbers of wind turbines, explained by unregulated leisure traffic and possibly poaching (Álvares et al. 2011, Francisco Álvares pers. comm.). The same study indicates that particularly important places in the territory (such as gathering points for the wolf family, so-called rendez-vouz sites) are relocated, and that breeding dens are moved more often, after the construction of the wind farm. There is a large consensus in the scientific literature that all forms of exploitation of valuable habitats for large carnivores should be avoided, because of the species' sensitivity to disturbance and fragmentation.

4.4.3 Habitat changes

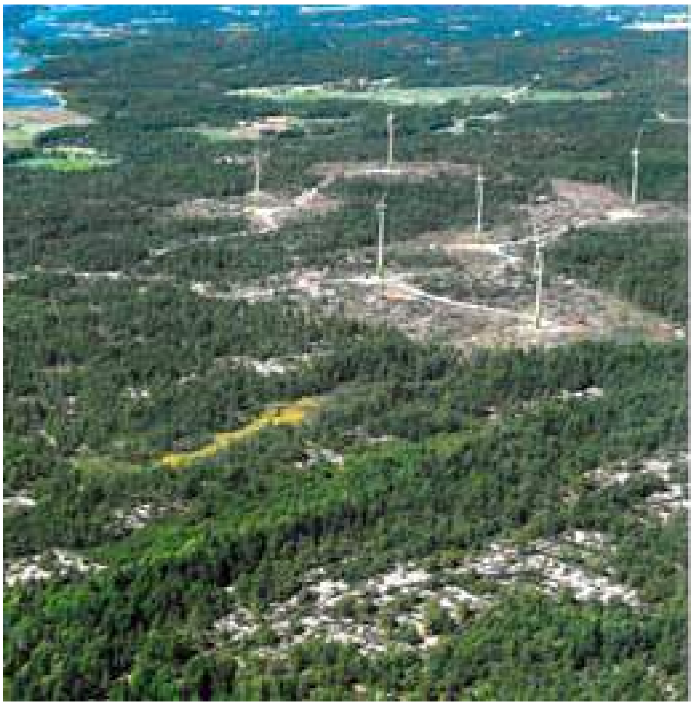
The road infrastructure is the major contribution to the direct habitat loss caused by a wind farm. The access road to each turbine can cover more than 1.5 ha of land (assuming 800 m road and 20 m width of the road area), while the individual turbine requires another 0.5 ha (Rönnqvist 2011). The loss of natural habitat is considered to be permanent, but overall, these areas make up a small part of the landscape as a whole, and for most large terrestrial mammals that regularly move over large areas, this habitat loss is probably a factor of minor significance (Arnett et al. 2007, Kuvlesky et al. 2007).

However, it is important not to exploit areas of critical importance for the animals, such as particularly attractive grazing areas (Walter et al. 2006). For example, during early spring, moose on the Swedish west coast prefer upland areas with much exposed bedrock (Olsson et al. 2010), which coincide with areas of primary interest for wind power. This is a critical time for ungulates, just before growing season starts, and much of the available food has low nutritional value. It is not clear what resources are important in these areas at the time, if animals have a seasonal attraction to the dominant plant species (heather, juniper and pine), or if it is a matter of these areas being less affected by winter grazing because the greater snow depth has prevented animals from using the areas during winter (Olsson et al. 2010).

In addition, not all species are negatively affected by ecosystem changes due to human activities. Some mammal species may even benefit from large-scale landscape changes (Andersen et al. 1998, Lavsund et al. 2003, Bowman et al. 2010, Roever et al. 2010).

In forest-dominated areas, forest edges and cut-over areas that are not replanted can increase the abundance of leaves, grass and herbs, and thus provide valuable food resources for herbivores such as ungulates (Kuijper et al. 2009, Månsson et al. 2010), hares (Hulbert et al. 1996, Hiltunen & Kauhala 2006) and rodents (Ecke et al. 2002, Christensen & Hörnfelt 2006). The open area between the road surface and the forest edge thus creates new conditions for vegetation and wildlife, and does not represent an actual habitat loss, but rather a change in habitat. In open agricultural landscapes the establishment of wind power may create greater habitat diversity (Jordbruksverket 2011). Also here, the access to shrubs, permanent grasslands and roadsides will provide food and shelter for hares, deer, small rodents and shrews. Even predators like red foxes, stouts and weasels could benefit from the increased availability of small rodents (Brandt & Lambin 2007, Sidorovich et al. 2010). If wind farms also attract moose and deer, there may be positive effects for

The wind farm at Bliekevare, Västerbotten county, Sweden, where *ca* 9 km new road has been constructed, and the average width of the road area is 21 m (Rönnqvist 2011). A 500 m line (yellow) is inserted in the picture for scaling. At the time of the image the wind farm is under construction. From Google Earth.



Wind power in rocky terrain in western Sweden. Photo: Vägverket.

large predators that to some extent may compensate for the negative effects of fragmentation and disturbance.

To further provide food and shelter for herbivores, one could choose to manage available land along roads and power lines in wind farms to promote the growth of shrubs and herbs and create diverse forest edge habitats. Such management could have a significant contribution to ungulate forage, and may decrease the grazing pressure in the surrounding woodland (assuming that ungulate populations are regulated through hunting). In this context, however, there is reason for caution that areas rich in small mammals, carrion of large herbivores, etc. can attract birds of prey, which in turn run the risk of being killed by wind turbines.

New road in Storliden wind park in northern Sweden. Photo: Anna Skarin.

Another example is reindeer, which in general use upland areas during the summer to avoid parasitic insects (Pollard et al. 1996, Skarin et al. 2004). For reindeer residing in the forest during the summer (mainly in the forest herding districts), forest roads may help in escaping the insects, by providing open areas and higher wind speed. Roads in wind farms will to some extent occur in areas with higher wind speed, and may therefore potentially be attractive to reindeer wanting to escape insects.

The argument that herbivores may benefit from habitat changes in wind farms should perhaps end with the notion that this is true given that animals are not avoiding the area due to disturbances by traffic or other human activities. It also assumes that the vehicle traffic in the wind farm is so sparse that the risk of road accidents is negligible.

4.4.4 Barrier and corridor effects

All land mammals probably experience high traffic roads as barriers to movement in the landscape (Helldin et al. 2010). Roads built or adapted for wind power in the forest environment is, however, functionally and structurally different. They should rather be compared with low traffic logging or forest roads, but with the difference that they do not follow the terrain as well as minor forest roads; they have wider side areas, and higher cuttings and embankments. Roads in wind farms are thus structurally intermediate between a forest road and a paved public road.

Even small, low volume gravel roads can pose significant barriers for small rodents (Kozel & Fleharty 1979, Swihart & Slade 1984, Rico et al. 2007), and the barrier effect increases with the width of the road and with traffic density (Oxley et al. 1975, Mader 1984). Small rodents may run a risk of being predated when crossing small roads with low traffic volume, due to lack of protective vegetation (Brehme et al. 2011). The barrier effects can be cumulative, in the sense that the overall barrier effect increases with increasing road density in the landscape (McGregor et al. 2008). This means that a network of relatively small roads can be an effective barrier to movements at the landscape level for these species. The barrier effect can, however, be reduced by allowing protective vegetation to develop at roadsides (Goosem 2001).

The pine marten is associated with forest environments (Brainerd & Rolstad 2002, Sidorovich et al. 2010), and avoid moving over open areas, even narrow forest roads. This species could locally be negatively affected by the additional forest fragmentation caused by roads in wind farms.

For larger species, narrow forest roads are no significant barriers. Instead, animals frequently move along roads with low traffic, creating so-called corridor effects. The corridor effect can be positive or negative. Predators such as foxes and wolves often move along roads, which is of course positive for these species, but may represent an increased predation in an area along the road. Roads cleared from snow may be important migration routes for ungulates, when deep snow otherwise impedes movements. Also for domestic reindeer, this can be positive in the short term, but may in the long term lead to the animals being more dispersed, which complicates the management of the herd (Larsen 2002). Furthermore, it may have the effect that reindeer arrive earlier in areas that are supposed to be used later in the season, which in turn can lead to overgrazing in these areas (Larsen 2002).

4.5 Power lines and power line corridors

Some studies of wild reindeer have indicated that the species avoid areas near power lines (Nellemann et al. 2001), and that the power line corridors act as barriers to movement in mountain areas (Nellemann et al. 2001, Vistnes et al. 2004). Preliminary results from studies of reindeer distribution during summer, in a forest area that is of current interest for wind energy development, show that the reindeer generally use areas near and under power lines less than other areas (Skarin & Rönnegård 2011).

Other studies indicate no such avoidance. Reimers et al. (2007) could not find that wild reindeer avoided the area around a power line. In this study, however, only reindeer within 3 km from the power line was studied, while other studies have noted that reindeer avoid a zone up to 4 km away from major power lines, and instead choose to reside in areas 4–10 km away from power lines (Nellemann et al. 2001, Vistnes & Nellemann 2001, Vistnes et al. 2004). A more recent study on reindeer habitat choice within 5 km of a transmission line showed that they did not avoid the area around the power line (Bergmo 2011). Local studies of reindeer behaviour in the vicinity of power lines

New power line at Jokkmokkliden wind farm in northern Sweden. Another new power line, for Storliden wind farm, is visible in the background. Photo: Anna Skarin.

(Flydal et al. 2004, 2009) found that the behaviour did not change and was not adversely affected (no less time to graze or ruminate) near the power lines. However, the study was done on reindeer in enclosures, not being able to move more than 400 m from the power line.

The different results is probably due to studies conducted on different scales, i.e. in studies on the regional scale reindeer tend to avoid power lines, while the studies where no effects have been found were made on the local scale.

Ongoing research projects on reindeer, reindeer husbandry and wind power

Currently, three research projects in Sweden and Norway are underway, that specifically address how reindeer are affected by the development of wind power and power lines. All three projects are focused on collecting information about the reindeer distribution and movement patterns, using GPS-equipped animals and pellet counts.

The Norwegian "VindRein" project started in 2005 by Jonathan Colman and colleagues at the University of Oslo. In 2007, the "KraftRein" project was also started, and the two projects are presently run in close collaboration. They are expected to continue until at least 2016. The projects are primarily designed to study the effects on wild and domestic reindeer and reindeer husbandry in Norway. At present, the VindRein project is active in five different study areas along the Norwegian coast and in the mountain area: Essand, Kjøllefjord, Vannøy, Fosen and Setesdal. In the Essand reindeer herding district, the effects of a new 420 kV transmission line (Nea-Järpströmmen) on the reindeer's area use are studied, and also in Setesdalen's wild reindeer range the effects of a new 420 kV transmission line are studied. Preliminary results show that the reindeer movement speed increases under the power lines in both areas, but that one cannot rule out the possibility that there are other causes for the higher speed than disturbance from the power line. In Kjøllefjord, the effects on the reindeer of a wind farm (17 turbines) running from 2006 are studied. In particular, the barrier effect of roads into the area has been studied and how the reindeer have used the area around the wind farm. Here, experiments with re-vegetation of the area also have been conducted. In the project at Vannøy, the effects on reindeer of Fakken wind farm (18 turbines), expected to be operational in 2012, are studied. On Vannøy, large re-vegetation efforts have been conducted. Here, preliminary results show that the reindeer have used the area close to the highway (including a 22 kV power line) more than areas located further away from the road, which is probably due to primary grazing areas being located near the road. In the Fosen herding district, six wind farms of different sizes are approved, and VindRein monitors the effects of all farms by having 22 GPS-equipped reindeer, before, during and after construction. In all of these study areas, data collection is ongoing, and compilations of results from different years can be found in the project's annual reports (see, for example, Colman et al. 2008, 2010).

In Sweden, a project is running 2009–2012, directed by Anna Skarin at SLU and funded within the VindVal program. The project studies how domestic reindeer in forest are affected by wind power. A report on methods for pellet counts has been published (Skarin & Hörnell-Willebrand 2011). The project has developed a reindeer habitat model to predict and evaluate grazing areas under consideration for wind power development in the forest landscape. The habitat model is designed to facilitate the planning of wind power, for the purpose of securing land for both reindeer and wind power development. The study area is located in the Malå forest herding district, an area with several new wind farms. The project mainly studies the situation at the wind farms Storliden (8 turbines) and Jokkmokksliden (10 turbines).

To complement the studies in the mountain area and in the forest summer grazing area, another project relating to forest winter grazing areas was started. It is a Swedish-Norwegian project running 2010–2013, and operated by Christian Nellemann at Norut Alta and Anna Skarin at SLU. Study areas are in Västerbotten within the Vilhelmina Norra herding district/Stor-Rotliden wind farm (40 turbines), and in Norrbotten within Östra Kikkejaure herding district/the Markbygden project (330 turbines included in the study area).

4.6 Possible fencing

To reduce the risks of falling ice and other objects from wind turbines, fencing of the area around the wind turbines has been discussed. Such fencing would obviously have effects on large mammals, but because fencing of wind farms is currently not an issue, neither in Sweden nor abroad, we choose here not to raise the issue further.

4.7 Overall assessment of the effects

Based on the literature and the reasoning described above, we make here a general assessment of the extent of the effects of wind power on terrestrial mammals (Table 1). The criteria used in the assessment are as follows:

Reliability

1: Studies are lacking; assessment is based on general knowledge of species and behaviours
2: The literature is very limited; knowledge is derived from nearby fields, but still gives some foundation for a scientifically based assessment
3: The knowledge base provides an adequate foundation for a scientifically based assessment
4: The knowledge base is solid and gives a reliable assessment

Effect

Weak: Small effects on a limited number of individuals; results from different studies can be contradictory
Moderate: Obvious but no strong effects – intermediate between weak and strong
Strong: Strong effects on a large proportion of the individuals concerned

Spatial extent

Small: The effects are limited to the wind farm or the area within a couple of hundred metres from turbines, access roads and power lines.
Large: The effects extend outside the vicinity of the wind farm

Temporal extent

Short: The effects only occur during construction and/or dismantling
Long: The effects occur during construction, operation and dismantling
Permanent: The effects remain even after a potential dismantling

Impact factors leading to moderate or strong effects, and having large spatial extent and long temporal extent may entail consequences at the population level of the current species. It should be noted that if wind power construction takes place at many sites in the landscape, or if a new construction project begins right after an already completed project, also effects with a small spatial or short temporal extent may result in effects in a larger area and on the population level. Such ”cumulative effects” are described further in section 7 below.

Table 1. Overview of the effects of wind power on terrestrial mammals described in section 6. Criteria are explained above. For each species group the list only includes factors where the effects on terrestrial animals have been studied. It is possible that factors not studied may be of significance, and combinations of species groups and factors that are missing in the table thus express knowledge gaps.

	Impact factor (reference to section of the text)	**Reliability** (1=low, 4=high)	**Effect** (negative, unless otherwise indicated)	**Spatial extent**	**Temporal extent**
Large carnivores	Disturbance during construction (6.1)	2	Strong	Small	Short-Long[1]
	Noise/visual disturbance from turbines in operation (6.2)	1	Moderate	Small	Long
	Disturbance from leisure traffic and recreation (6.4.2)	2	Strong	Large	Long
	Roads as barriers/corridors (6.4.4)	2	Weak (possibly positive)	Small	Long
Ungulates & reindeer	Disturbance during construction (6.1)	2	Moderate	Small	Short-Long[1]
	Noise/visual disturbance from turbines in operation (6.2)	1	Weak	Small	Long
	Disturbance from utility traffic (6.4.1)	2	Weak	Small	Long
	Disturbance from leisure traffic and recreation (6.4.2)	2	Moderate-Strong	Large	Long
	Habitat changes (6.4.3)	2	Weak (possibly positive)	Small	Long/ Permanent
	Roads as barriers/corridors (6.4.4)	2	Weak (possibly positive)	Large	Long
	Power lines, power line corridor (6.5)	2	Moderate	Small	Long
Small mammals	Noise/visual disturbance from turbines in operation (6.2)	2	Weak	Small	Long
	Habitat changes (6.4.3)	2	Weak-Moderate (possibly positive)	Small	Long/ Permanent
	Roads as barriers/corridors (6.4.4)	3	Weak-Moderate	Small	Long
Livestock	Noise/visual disturbance from turbines in operation (6.2)	3	Weak	Small	Long
	Electromagnetism (6.3)	2	Weak	Small	Long

[1] Depending on the temporal extent of the construction phase.

5 The effects in a larger perspective

Wind power development is only one of several human factors that can affect the numbers and behaviour of mammals. It is therefore necessary to put the effects of wind power in relation to other anthropogenic impacts. Most relevant from a conservation standpoint is to consider the cumulative effects, i.e. the effects of a project in combination with the effects from other past, present and planned exploitation or land use. Although the population densities of the larger game species are largely determined by hunting, agriculture and forestry, any new impact factor, such as wind power development, can give unexpectedly large effects when added to an already affected system. Cumulative effects are generally neglected in all forms of environmental assessment (Cooper & Sheate 2002, Folkeson 2010), also for wind power projects (Fox et al. 2006, Masden et al. 2010).

Although the knowledge base is generally small, the overview above displays that it is possible that terrestrial mammals, especially large carnivores and ungulates, including reindeer, may be affected in different ways by wind power development. The effects described may not appear dramatic, but they should be seen in the light of other impacts on these species. They should also be seen in the light of the future development of wind power expected in the forested Swedish inland.

For the larger species, the impacts of wind power depend mainly on the network of access roads to the turbines. It is partly a matter of barrier and corridor effects and some disturbance from utility traffic, but primarily a disturbance through the increased accessibility for outdoor recreation, hunting and leisure traffic. If animals avoid disturbed areas, the result is in effect a loss of available habitat. On a larger geographical scale, the roads in wind farms are only a small addition to the already existing network of major and minor roads, and one can accordingly argue that the addition is insignificant. However, because wind farms, at least in the forested landscape, are expected to be sited in previously unexploited areas, which may be refuges to e.g. large carnivores, new roads in these areas may have a significant impact on these species.

On the whole, there is a need for a geographical analysis of the areas tha t are identified as suitable for wind power, for example areas designated for wind power in municipal master plans, or areas of national interest for wind power. Such an analysis would reveal whether these areas have some special environmental characteristics, such as low road density or rugged terrain preferred by bears and wolverines for denning, or remaining important grazing areas for reindeer or other ungulates.

Another example of where the cumulative effects are of major interest is when exploitation (and not just for wind power) occurs at several locations within a reindeer herding district. This can lead to an overall deterioration of the entire reindeer grazing area, although a single development makes no great difference. Therefore, it is important not to exploit several nearby areas simultaneously, but evaluate the consequences of each development before the next is commenced. If wind power development means that reindeer avoid the area, the grazing pressure will increase in other areas, resulting in reduced grazing overall. The same reasoning may apply to wild ungulates.

Similar cumulative effects may also arise from the development of large wind farms. Even small and localised effects can summarise to a significant impact on population levels. For example, disturbances during construction are temporary, but a gradual expansion of a large wind farm can make the construction span over several years, resulting in a prolonged impact on a larger spatial scale. There may be thresholds, where the cumulative effects increase disproportionately. Such a non-linear response to road density is described, for example, for North American elk (Frairs et al. 2008).

In addition to the disturbance, the road network also entails some loss of natural habitat, but for most land mammals, which move over large areas, this loss is probably of marginal importance, particularly in comparison with the large-scale landscape conversion caused by modern agriculture and forestry. Also, habitat changes need not be negative but can, for example, create new food resources for herbivores. Reindeer can use forest roads to avoid insects. Several species, such as wolf, fox, moose and reindeer, also use low traffic roads for movements (in the case of wolf and fox, it may in turn result in an increased predation near roads).

It can be added that for domestic animals other than reindeer, new roads for wind power should be a negligible factor, because in most cases there are already roads adjacent to the pasture (if, however, the new road leads to increased traffic, a certain effect cannot be excluded; research is lacking on this).

There may be differences in how the disturbance effects are manifested, depending on the landscape and the current land use. In already disturbed areas, such as most agricultural landscapes, wind power development may not affect the occurring species to the same extent as it would in more sparsely populated forest or mountain areas.

6 Particular knowledge gaps

The overview of the impact of wind power on terrestrial mammals presented above has revealed major knowledge gaps. There are many issues that would need to be studied, but we particularly point out the research needs within the following three areas:

- Effects of noise and visual impacts of wind turbines on land mammals

The overview shows that such knowledge is virtually non-existent. Disturbances from the construction, maintenance and infrastructure of wind farms can be discussed based on studies of the effects of other types of exploitation; there is however an almost complete lack of scientific studies of the effects of the turbines themselves. This deficiency can be remedied by standardised protocols for environmental monitoring (see below).

- Cumulative effects of wind power and other developments

Several wind power projects, each of which may have a limited effect, can together have a large impact, for example by creating barrier effects at the landscape level. Similarly, the effects of wind power projects must be assessed in combination with the effects of other types of development, for example in the form of a more extensive road network and a more fragmented landscape. The lack of knowledge in terms of cumulative effects is not unique to wind power but is especially troublesome since there is also an incomplete understanding of the effects of the individual projects.

- Effects on the landscape level

There is a strong demand for a geographic analysis of wind power development at regional and national levels. Not only can wind power lead to cumulative effects (see above), which might require that consideration be given to developments in other municipalities or counties. The many wind power projects at the national level may result in a sharp decrease in certain habitat types. One example is such remote, hilly and rugged terrain preferred by large carnivores for denning; another example is grazing areas of special importance for ungulates. The areas occupied by these species are among those that presently are likely to be selectively targeted for wind power development. There is a need for an analysis of the available habitat for large carnivores and the degree to which these areas could be claimed for wind power, in order to assess how any development can affect the populations of these species.

7 Recommendations in relation to licensing

Given the inadequate knowledge base concerning impacts of wind power on terrestrial mammals, it is difficult to make any clear recommendations concerning the planning and construction of new wind power facilities. The lack of general understanding of the issue calls for discretion when drawing conclusions about either effects or lack thereof. A key recommendation is to take each exploitation as an opportunity to strengthen the knowledge base, by implementing monitoring programs (see below).

As a precautionary principle, one should aim at minimising negative effects on terrestrial mammals, even when the effects are not fully proven. That would mean, for example, to avoid construction work during particularly sensitive periods (e.g. during calving), to limit public access to roads, or to avoid placing wind farms in areas likely to be of particular value for reindeer or large wildlife.

In addition to minimising the negative effects, available land along roads and power lines can be managed to provide extra food and shelter for herbivores, by promoting the growth of shrubs and herbs and creating diverse forest edge habitats. Such management could, however, be discussed on the basis that it may create so-called ecological traps, where animals are attracted to areas where they run the risk of being killed by vehicles or, if birds of prey are also attracted, killed by wind turbines and power lines.

8 Design of monitoring programs

In order to gradually fill the large knowledge gaps identified in this report, we call for a better implementation of monitoring programs for new wind power projects. Such monitoring programs should be coordinated nationally, and derived data should be made available for research and other comprehensive analysis. Monitoring and analysis are cornerstones of an adaptive system – a system that creates new knowledge for better environmental adaptation of future investments, and thus gradually improve the situation.

To provide a monitoring program of such quality that it creates new, generalisable knowledge, certain principles should be followed, which in themselves do not increase the cost of the program. In return, knowledge is gained that can reduce the future need for follow-up studies and that can form a scientific base for wind power development in line with environmental objectives and legislation. We describe here these principles in brief:

1. *Define objectives.* An important starting point for a monitoring program is to make a well-defined objective, to clarify what issues should be addressed. These issues must be environmentally relevant, e.g. regarding species, effects, temporal scale and spatial scale. The objective statement must come first, and form the basis for selection of method and analysis. The program must generate data of sufficient quality and quantity that the analyses can provide answers to the given questions.

2. *Minimise extrapolation.* The method selected should produce results as close to the given questions as possible, i.e. results should not have to be extrapolated to an entirely new situation in order to be relevant. For example, if changes in population density are at issue, one should not only study the behaviour, since the link between behaviour and population density is based on a number of assumptions which cannot be controlled for. It is also important that the temporal and spatial scales of the study do not differ from the scales in the questions.

3. *Use standardised methods*. The methodology should be tested and accepted by research or by environmental monitoring. The survey method and experimental set-up should also be reasonably similar between different monitoring programs, to ensure comparability. The results from several smaller studies can then be combined in larger analyses, to address new questions and give more solid answers.

4. *Follow the BACI principles.* A well thought-out layout of study plots significantly increases the strength of the results. We suggest to follow the BACI principles (Before-After-Control-Impact, see box below) as far as the available funds permit.

5. *Describe cumulative effects.* Since it is the cumulative effects that show the full consequences of developments, the effects of wind power as far as possible should be described in relation to other past, present and planned wind power developments and other impacts on the species studied.

6. *Write a plan.* In addition to objectives, research questions, methodology and analyses, the plan should clearly describe the who, where, how and when each stage should be performed.

As a first step toward the standardisation of the survey method proposed above, a guidance document for selection of method should be written. Skarin & Hörnell-Willebrand (2011) and Lundberg (2011) give overviews of survey methods suitable for studying the effects of wind power on terrestrial mammals (wildlife and reindeer). These reports can be used as a starting point for the guidance document. Skarin & Hörnell-Willebrand (2011) describe different designs of reindeer pellet counts that can also be applied to other ungulates. Lundberg (2011) considers pellet counts in sample plots, distance sampling of pellets or animals along transects, capture-recapture, track counts on snow combined with GPS mapping, and possibly DNA analysis, as useful methods for wildlife. All of these methods have advantages and disadvantages depending on the issues and animal groups in focus, available budget and what margins of error that can be tolerated. A combination of methods is recommended to increase the accuracy of the results.

Design of monitoring programs following BACI

Following the so-called BACI principles of experimental design will greatly increase the strength of the results. BACI (Before-After-Control-Impact) basically means to monitor not only the area affected by wind power (Impact), but also a similar area not affected (Control), and to begin the monitoring before the wind power establishment, so as to obtain data from the periods both before and after the onset of the impact (see BACI in the figure below). Ideally, both periods (before and after) should be >1 year to cover any annual variation.

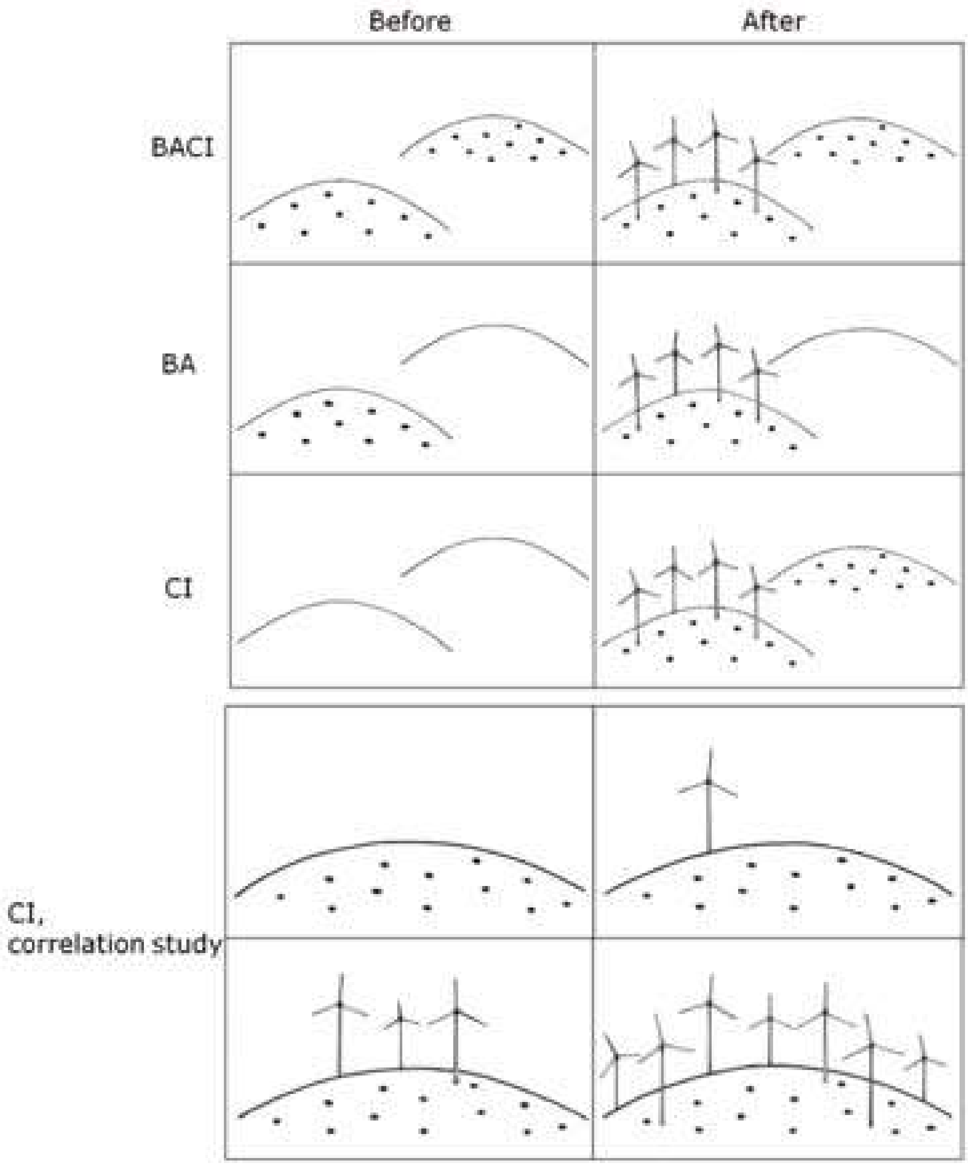
An investigation should ideally include >1 such BACI pair, in order to further exclude the possibility that an observed difference is due to some other environmental factor than the wind power facility. Depending on the geographical scale of the study, such a replication can be achieved within a single program or by the combined results from several monitoring programs (provided that the survey method is the same).

A variation of the BACI concept which may be relevant in terms of wind power is BDACI = Before-During-After-Control-Impact, where a further period of study is identified, during the actual construction phase. Such an approach is required to distinguish effects related specifically to the construction.

If a BACI design for any reason is not possible to achieve, one of two partial designs can be adopted, each with its limitations. The first of these partial designs follows only the affected area before and after the wind power establishment (BA, see figure below). With this set-up it will not be clear whether any change in the measured variable would have taken place on the site even without the wind power facility. The second partial design does not start until wind power is already established, and only compares the affected area with an unaffected reference area (CI, see figure below). This set-up leaves the possibility open that a difference in the measured variable between the two areas is actually due to some other environmental factor than the wind power.

A common variation on the latter approach, that can generate a relatively strong result, is to study several areas with different degrees of impact (it could, for example, be wind farms with different numbers of turbines), and check for a correlation between the degree of impact and the measured variable (CI correlation study, see figure below). This set-up relies on the assumption that a statistical correlation implies a causal connection.

More on these principles is found in Green (1979), and an example of a BACI study of the effects of wind power on birds and small mammals is described by De Lucas et al. (2005).



Experimental design following BACI-principles. Black dots represent study plots (e.g. for pellet counts). See box text for further explanation of figures. Illustration Lars Jäderberg.

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The impacts of wind power on terrestrial mammals

REPORT 6510

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A synthesis

This report is a translation of the previous report in Swedish "Vindkraftens effekter på landlevande däggdjur" (Naturvårdsverket report no 6499).

There are significant knowledge gaps concerning impacts of wind power development on terrestrial mammals. The main effects appear to be caused by habitat changes and different types of disturbances. Roads in wind parks allow for an increased access for outdoor recreation, hunting and leisure traffic. It is well known that disturbances from such human activities can affect large wildlife as well as domestic reindeer – and in effect lead to a loss of available habitat.

This report compiles the available knowledge in the field. The compilation shows that the increased human access can be a problem for large carnivores and deer. These species tend to prefer such remote, upland areas with low human disturbance that are currently of particular interest for wind power development. A main conclusion is that better monitoring of effects of wind power on wildlife and domestic reindeer is needed.

Vindval is a programme that collects knowledge on the environmental impact of wind power on the environment, the social landscape and people's perception of it. It is aiming to facilitate the development of wind power in Sweden by improving knowledge used in IEAs and planning- and permission processes. Vindval finances research projects, analyses, syntheses and dissemination activities. The programme has a steering group with representatives for central and regional authorities and the wind power industry.

SWEDISH ENVIRONMENTAL PROTECTION AGENCY

Swedish Energy Agency

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