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Impacts of human activity on reindeer and caribou: The matter of spatial and temporal scales

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Abstract: The impacts of human activity and infrastructure development on reindeer and caribou (*Rangifer tarandus*) have been studied for decades and have resulted in numerous debates among scientists, developers and indigenous people affected. Herein, we discuss the development within this field of research in the context of choice of spatial and temporal scale and concurrent trends in wildlife disturbance studies. Before the 1980s, the vast majority of *Rangifer* disturbance studies were behavioural studies of individual animals exposed directly to potential disturbance sources. Most of these local studies reported few and short-term impacts on *Rangifer*. Around the mid 1980s focus shifted to regional scale landscape ecology studies, reporting that reindeer and caribou reduced the use of areas within 5 km from infrastructure and human activity by 50-95%, depending on type of disturbance, landscape, season, sensitivity of herds, and sex and age distribution of animals. In most cases where avoidance was documented a smaller fraction of the animals, typically bulls, were still observed closer to infrastructure or human activity. Local-scale behavioural studies of individual animals may provide complementary information, but will alone seriously underestimate potential regional impacts. Of 85 studies reviewed, 83% of the regional studies concluded that the impacts of human activity were significant, while only 13% of the local studies did the same. Traditional ecological knowledge may further increase our understanding of disturbance effects.

Effekter av menneskelig aktivitet på rein og caribou: Betydningen av valg av skala

Sammendrag: Effektene av menneskelig aktivitet og utbygging på rein og caribou (*Rangifer tarandus*) har vært studert i flere tiår og har resultert i utallige debatter mellom forskere, utbyggere og berørt urbefolkning. I denne artikkelen diskuterer vi utviklingen innenfor dette forskningsfeltet i forhold til valg av skala i tid og rom, og i forhold til trender innen forskning på forstyrrelse av vilt generelt. Før 1980-tallet var størsteparten av forstyrrelsesstudier på rein og caribou adferdsstudier av enkeltdyr eksponert direkte for potensielle forstyrrelseskilder. Flertallet av disse lokale studiene konkluderte med få og kortvarige effekter på *Rangifer*. Rundt midten av 1980-tallet skiftet fokus over til regionale landskapsøkologi-studier, som fant at rein og caribou reduserte bruken av områder innen 5 km fra infrastruktur og menneskelig aktivitet med 50-95%, avhengig av type forstyrrelse, landskap, årstid, toleransenivået til flokken, og kjønn og alder til dyrene. I de fleste tilfellene der unnvikelse ble dokumentert var det fremdeles en mindre gruppe dyr, oftest bukker, som oppholdt seg nær infrastruktur eller menneskelig aktivitet. Adferdsstudier av enkeltdyr over korte avstander kan gi utfyllende viten, men vil isolert sett føre til en alvorlig underestimering av potensielle regionale effekter. Av 85 gjennomgåtte studier konkluderte 83% av de regionale studiene med at effekten av menneskelig aktivitet var betydelig, mens kun 13% av de lokale studiene konkluderte likeens. Tradisjonell økologisk kunnskap kan åpne opp for økt kunnskap om forstyrrelseseffekter.

Introduction

Over the last century, humans have dramatically altered the face of the planet and triggered the highest extinction rate of flora and fauna in recent history (Chapin *et al*., 2000; Clark *et al*., 2001; Loreau *et al*., 2001). Roads, railway lines, power lines, airports, harbors, and dams form the central nervous system of the modern world (UNEP, 2001) and is necessary for accessing, developing, and transporting people, goods and services (Leinbach, 1995). Infrastructure development, however, has many environmental costs and has been shown to disrupt the physical environment, alter the chemical environment, impact species relationships, accelerate introduction of invasive species, modify animal behavior and induce changes in land use in areas proximate to developed roads (Andrews, 1990; Forman & Alexander, 1998; Lawton *et al.*, 1998; Trombulak & Frissell, 2000).

Natural resources exploitation and anthropogenic activity in the Arctic has expanded rapidly during the last 50 years (UNEP, 2001). The Arctic is considered to hold large reserves of hydrocarbons and minerals (Ivanov, 1999; UNEP, 2004). Today oil and gas development is the keystone to many northern economies, with plans underway to extend the infrastructure and development network to new regions (Magomedova *et al.*, 1998; Matushenko, 1999). Examples of this expansion are found in the Yamal Peninsula of Russia, in the National Petroleum Reserve and Arctic National Wildlife Refuge of Alaska, and the Barents Sea region, as well as in numerous other regions of the Arctic.

Following the large industrial development projects of petroleum exploration and hydro power in Canada and Alaska in the 1970s (Coates, 1991), concern was raised upon the potential damaging effects on caribou. As a result, a series of research projects developed to assess potential impacts. Among the most extensive and long-lasting were the investigations related to the Trans-Alaskan Pipeline and the Prudhoe Bay and Kuparuk oilfields of Alaska (White *et al*., 1975; Cameron & Whitten, 1979; Fancy, 1983; Curatolo & Murphy, 1986; Cameron *et al*., 1992; Pollard *et al*., 1996; Cronin *et al*., 1998b), that have supplied approximately 15% to 22% of the US domestic oil supply since 1977 (National Research Council, 2003).

Studies of human disturbance of *Rangifer* have projected anything from none or positive effects on behavior and reproductive success of *Rangifer* to negative impacts. This research has periodically been reviewed (Klein, 1971; 1980; Martell & Russell, 1985; Bergerud *et al*., 1984; Reimers, 1984; Cronin *et al*., 1998a; Wolfe *et al*., 2000). Herein, we discuss the research done within this field in the context of literature on fragmentation and disturbance of wildlife in general (UNEP, 2001). In this context, (human) disturbance is defined as a deviation in an animal's behavior from patterns occurring without human influence (Frid & Dill, 2002). The term "disturbance studies" is used on research conducted on potential, hypothesized disturbance sources, independent of whether or not the study concluded that the potential disturbance source really was disturbing. We also discuss why different studies on the same herds and infrastructure can conclude differently, as well as knowledge gaps and future challenges. A key question is how the choice of temporal and spatial scale can be identified to enhance our understanding of the ecological effects of human activity and development on the ecology of *Rangifer*.

Disturbance studies before 1985

In the 1970s and 1980s, the majority of disturbance studies were behavioural studies of individual animals; focussing on direct observation of animals physically adjacent to or physically exposed to development or stress. The approach was probably a natural extension of the scientific experimental traditions on investigations of animal stress done in laboratories, largely dominated by physiological measures (Broom, 1968; Duncan & Wood-Gush, 1971). Typical studies on *Rangifer* included short-term behavioural responses of animals to aerial overflights (McCourt *et al*., 1974; Calef *et al*., 1976; Gunn & Miller, 1978; Miller & Gunn, 1980; Valkenburg & Davis, 1985) or when encountering roads, railways, power lines or pipelines (Bergerud, 1971; Johnson & Todd, 1977; Hanson, 1981; Koskela & Nieminen, 1983; Johnson, 1985). Most of these studies concluded that effects of disturbance were few and short-term, stress reactions lasting only a few minutes and fleeing distances being < 1 km. As a measure of habitat loss, many studies mapped the surface area physically altered, whether it was areas dammed or covered by roads or other infrastructure (Martell & Russell, 1985). These mappings most often revealed that only a few percent of the total available habitat was physically lost, even in large development projects, and conclusions were drawn that habitat loss was insignificant to *Rangifer* (Maki, 1992).

Several studies also used photographs of reindeer or caribou crossing pipelines or roads as evidence that the animals were unaffected by development. As we will see from later research, such studies neglected the likelihood that only a small proportion of the animals actually crossed, and that the animals close to infrastructure may represent particularly tolerant individuals, such as bulls or yearlings (Cameron *et al*., 1992; Nellemann & Cameron, 1996; 1998).

Disturbance studies after 1985

Around the mid 1980s, the focus and scale of disturbance studies started to change. This was likely triggered by experiences from previous studies, claims by indigenous peoples, and advancements worldwide in the field of landscape ecology (Forman & Alexander, 1998; Andrews, 1990; Turner & Gardner, 1991).

Regional avoidance studies, designating studies that looked at the distribution of local or meta-populations in relation to fragmentation, human activity or infrastructure, were conducted for a wide range of species. Animals were shown to shift away from locations of human presence, infrastructure, and livestock. Attention was in particular given to the effects of infrastructure, mainly roads (see reviews of Andrews, 1990; Forman & Hersperger, 1996; Forman & Alexander, 1998; Trombulak & Frissell, 2000). Research included regional studies on distribution of insects (Hanski *et al.*, 1994; Kruess & Tscharntke, 1994; Saville *et al*., 1997; Lawton *et al*., 1998); amphibians and reptiles (Gillespie & Hollins, 1996; Vos & Chardon, 1998), birds (Hockin *et al.*, 1992; Sorley & Andersen, 1994; Reijnen *et al*., 1995; Robinson *et al*., 1995), small mammals (Henderson *et al*., 1985; Ims *et al*., 1993; Andreassen *et al*., 1996), as well as larger mammals such as ungulates and their predators (Jensen *et al*., 1986; Mech, 1989; Brody & Pelton, 1989; Barnes, 1996; Mace *et al*., 1996; Cole *et al*., 1997; Støen, 2006). In a review of 106 empirical studies on the effects of infrastructure, UNEP (2001) found that 98% of 151 species reviewed were impacted in areas within 0-10 km from roads and other infrastructure. Nellemann *et al*. (2003) found in a review of 309 papers that near 95% of the 204 species investigated declined in density out to 10 km from infrastructure, the majority out to 5 km.

The landscape ecology-influenced school of research, operating at wider spatial and temporal scales, thus concluded that human disturbance had a larger impact on wildlife than what had previously been documented through local and short-term behavioral studies of e.g. stress or flight behavior. The use of the term avoidance became more frequent, depicting the phenomenon when a large share of the animals in a group or specific region reduce their use of areas close to human activity and development, the size of the area affected and the reduction in animal density depending upon a number of variables. Most species show sex, age or seasonal variations, where females with young usually are the most sensitive (Ciuti *et al*., 2004; Apollonio *et al*., 2005). Correspondingly, animal density may increase in areas away from potential disturbance sources, leading to increased competition or greater risk of predation (Kilgo *et al*., 1998; Gill & Sutherland, 2000). Methodologically, it is important in avoidance studies that the compared areas close to and away from potential disturbance sources are comparable, i.e. that vegetation, snow conditions, elevation etc. are similar. Avoidance behavior requires that alternative habitat is available (Gill *et al*., 2001), although it may not be of the same quality as the habitat avoided (Nellemann *et al*., 2000; Vistnes & Nellemann, 2001). Facing the risk of predation, it may be more beneficial to reduce the probability of death by e.g. fleeing, than to continue fitness-enhancing activities such as grazing, parental care, or mating. The same types of responses are observed for a number of species when being exposed to nonlethal disturbance stimuli (e.g., Walther, 1969; Dill & Houtman, 1989; Bonenfant & Kramer, 1996; de la Torre *et al*., 2000; Frid & Dill, 2002). The risk-disturbance hypothesis may thus explain avoidance of nonlethal human activity, predicting that when being disturbed, an animal should follow the same economic principles used by prey encountering predators (Berger *et al*., 1983; Madsen, 1994; Frid & Dill, 2002).

This shift from local to regional scale research and from studies of individual animals to large groups was also reflected in the studies on *Rangifer*. A series of investigations from around 1990 and onwards demonstrated avoidance by caribou and reindeer to roads, pipelines, power lines, recreational resorts, logging operations and industrial development across the boreal zone and the Arctic. The first studies were done in the Prudhoe Bay-Kuparuk oilfield region of northern Alaska, showing differences in the abundance of caribou apparently negatively correlated to oilfield infrastructure (Cameron *et al*., 1992; Nellemann & Cameron, 1996). In Finland, Helle & Särkelä (1993) documented avoidance by female reindeer to a tourist resort. In Canada, Smith *et al*. (2000) and Dyer *et al.* (2001) found lower densities of caribou near logging activity and industrial development. In Norway, a range of studies documented avoidance at varying levels by reindeer to roads, power lines, resorts and dams (Nellemann *et al*., 2000; 2001; 2003; Vistnes & Nellemann, 2001; Vistnes *et al*., 2001; 2004a). Several of these latter studies also documented visible effects on lichen cover, reflecting differences in grazing pressure with distance to human activity and infrastructure. Studies within shorter distances, such as 1-2 km from disturbance without comparing with control areas further away did not find signs of avoidance by caribou (Burson *et al*., 2000; Yost & Wright, 2001).

Some regional scale studies concluded however that the impacts of human activity and infrastructure on caribou were negligible or inseparable from natural factors (Pollard *et al*., 1996; Cronin *et al*., 1998b; 2000; Noel *et al*., 2004). These studies looked primarily at distribution of caribou on Alaska's

North Slope during insect harassment, when caribou are forced closer to the coast and onto pads seeking the only available insect relief (Nellemann *et al*., 2001; Joly *et al*., 2006). The results point out that reindeer and caribou may be most tolerant to human activity during insect harassment, in particular when the only insect relief areas available are close to human activity (Pollard *et al*., 1996; Skarin *et al*., 2004). The US National Research Council reviewed the research done on impacts of oil drilling on wildlife (National Research Council, 2003). This report concluded that petroleum development had impacted both distribution of caribou during calving and that reproductive success may have been lowered in the portion of the herd exposed to oil development. A Norwegian report looked at the effects of hydro power and power lines on reindeer (The Research Council of Norway, 2002). Its conclusions were somewhat similar, namely that while reindeer could be observed close to or under power lines and near roads, a large share of the animals appeared to avoid or minimize contact with such areas. Again, avoidance effects varied with type of disturbance, landscape, season, sensitivity of herds, sex and age distribution of animals. The densities of animals were most typically 50-95% lower than expected from availability within 5 km from infrastructure and correspondingly higher in less disturbed areas (The Research Council of Norway, 2002; National Research Council, 2003).

Pre - and post development studies

Several pre - and post development studies have found results corresponding to those obtained in studies assessing only post development distributions. Along the Milne point road in Alaska, surveys on the same dates prior to and following development showed that abundance of caribou declined out to 4 km and increased beyond (Cameron *et al.,* 1992). As development increased in the decade following this investigation, caribou gradually abandoned the areas for calving. This change in abundance shifting the calving grounds further south did not take place in the eastern part of the calving grounds virtually unaffected by development (Cameron *et al*., 2005; Joly *et al*., 2006). This study, along with National Research Council (2003), also pointed to potential differences in productivity between the eastern and the western portion of the herd.

Mahoney & Schaefer (2002) investigated the effects of hydroelectric development on caribou, conducting surveys before, during, and after construction. They found a diminished use within 3 km of the construction site in the years after construction. Another Canadian study revealed a long-term range recession of woodland caribou correlated to the northward shift in logging activity across a whole century (Schaefer, 2003). In Norway, a pre- and post-development study of hydroelectric development found substantial reductions in use by reindeer of areas within 2.5-5 km from roads and power lines associated with roads, habitat loss as a result of flooding and disruption of migration corridors, and a substantial increase in reindeer abundance in the few remaining undisturbed areas in both winter and summer, including in the insect harassment period (Nellemann *et al*., 2003). Unlike in Prudhoe Bay, insect relief was available away from infrastructure and human activity.

Change of scale in research

When summarizing the investigations on reindeer/caribou and human activity found in the reviews of Wolfe *et al*. (2000), National Research Council (2003) and Vistnes *et al.* (2004b) in terms of distance categories studied (0-2 km versus 0-10 km), we clearly see a shift in spatial scale from local scale studies to regional scale studies (Table 1). While local scale studies still are conducted, regional scale studies were scarce prior to 1985-1990. We have used the authors' conclusions to categorize whether or not no or positive effects on behaviour or productivity were observed, or whether the authors characterized the impacts as being negative in terms of loss of habitat, loss of significant grazing opportunities, heavy grazing pressure, decline in reproduction rates etc. (Table 1). While this classification evidently will be a rough one, considering the wide array of methods used and conclusions drawn, it may still illustrate trends within this field of research. Several conclusions can be drawn from the table directly: 1) *Rangifer* observed close to infrastructure are seldom severely stressed or impacted otherwise; 2) There is a significant amount of studies documenting loss of habitat as a result of reduced use of areas close to human activity and development; and 3) The scale of the assessment will strongly influence the probability of detecting impacts, underlining the importance of addressing long-term (several years or even decades) and cumulative impacts at regional scales. This is in line with the recommendations of i.e. the World Bank on environmental assessments of roads (World Bank, 1997), but is still neglected in many development projects (UNEP, 2001).

Table 1. The distribution of 85 studies of disturbance and infrastructure development on reindeer and caribou before and after 1985, scale of assessment (local scale studies versus regional scale studies) and subsequent conclusions. Studies are listed in Wolfe *et al*. (2000), National Research Council (2003) and Vistnes *et al*. (2004b).

Scale assessed	Prior to 1985	After 1985	Positive effects	No or minor effects	Negative effects
Short-term (min/hours) or local studies (0-2 km)	22	14	0	32	4
Long-term(months/years/decades) and regional studies (0-10 km)	5	44	1	7	41

The space-time principle

The results found in Table 1 correspond with the space-time principle of landscape ecology, predicting that long-term changes affect a large area, while short-term changes affect smaller areas (Forman, 1995: 8). The same principle states that phenomena at a broad scale may be more stable than those at finer scales. The two categories of disturbance studies that have been discussed here operate at different scales both in space and time, as well as in number of animals studied. While local scale studies investigate behavioural responses of individual animals close to potential disturbance sources, the responses often being short-term, regional scale studies investigate possible avoidance behaviour of a large number of animals within a wide region. This response has proven to be long-term with few documentations of habituation, while many studies report avoidance of 4-10 km wide zones from infrastructure decades after construction, provided that human activity continues around these structures (Cameron *et al*., 1992; Nellemann *et al*., 2000). In search for long-term, persistent effects of human disturbance it becomes important to choose a sufficiently broad scale reaching, in the case of *Rangifer*, several km out from the potential disturbance source.

While avoidance studies show that some animals remain within 0-3 km from disturbance sources, they are most often not representative of the majority of the herd. Investigating behavioural responses or distributional changes only within 0-3 km from development, we are unlikely to see any distance-related trends, and may erroneously conclude that there is no apparent distributional pattern in relation to potential disturbance sources (Fig. 1). The local and regional scale approaches are therefore not contradictory but complimentary; merely reflecting differences in scales and the proportion of animals being investigated.

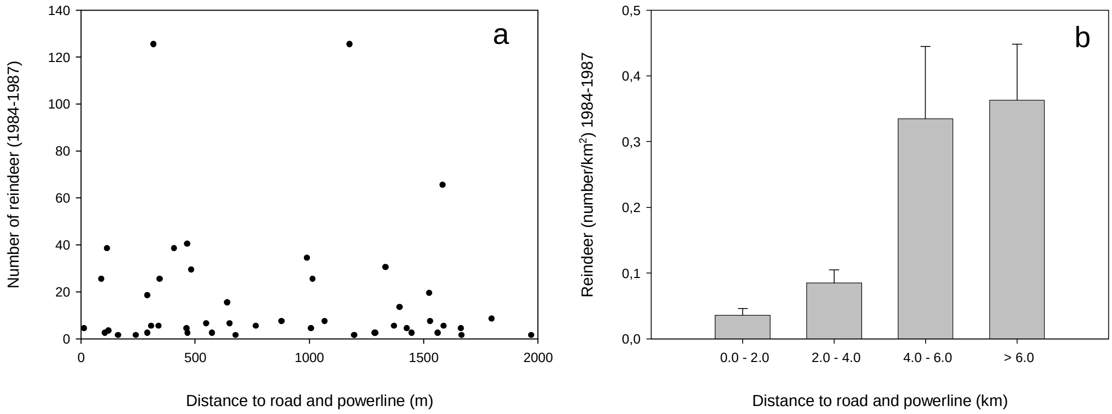

Fig. 1. The effect of scale on assessing disturbance impacts on *Rangifer*: a) Distribution of reindeer within 0-2.0 km from infrastructure, with no apparent pattern of avoidance; and b) distribution of reindeer at 2-km intervals from the same infrastructure. Notice that (a) and the first bar in (b) are the exact same data; 1226 reindeer or 15% of the animals were observed within 0-2 km of infrastructure, an area comprising 51% of the study area. Data from Nellemann *et al.* (2003).

Knowledge gaps and future challenges

In their guide to environmental impact assessments, the World Bank (1997) lists three types of effects of disturbance: direct, indirect and cumulative effects. While this review shows that there are numerous studies on direct (local scale) and indirect (regional scale) effects of human activity and development on *Rangifer*, few studies have succeeded in mapping cumulative effects on survival or reproduction possibly caused by avoidance behaviour (Cronin *et al*., 1998a). Within local behavioural studies, estimations of energy costs of direct encounters with disturbance have shown that repeated disturbance by e.g. overflights or seismic blasts may decrease caribou reproduction rates (Luick *et al*., 1996; Bradshaw *et al.*, 1998; Maier *et al.*, 1998) or calf survival rates (Harrington & Veitch, 1992). It seems probable that also avoidance behavior leading to habitat loss will negatively affect productivity by increasing grazing competition and possibly predation risk, as studies on other species have documented (Phillips & Alldredge, 2000; see review in Frid & Dill, 2002). Developing methodologies for exploring the link between productivity parameters and disturbance level remains one of the challenges in disturbance research, and will be important to increase our understanding of consequences of human development in *Rangifer* habitat.

The increased use of GPS-collars will also provide more sophisticated analyses of habitat use on temporal and spatial scales in relation to human activity and infrastructure. This method is already widely used on caribou (e.g., Bradshaw *et al*.,1997; Dyer *et al.*, 2001; Johnson *et al.*, 2001), and is emerging in research on semi-domestic reindeer (Fielitz *et al*., 2003; Skarin 2006). Using GPS-collared semi-domestic reindeer, Skarin (2006) found that reindeer used habitat close to hiking trails during night when traffic was low, and stayed closer to hiking trails before the hiking season started than during the hiking season.

The field of mapping traditional or ecological knowledge of reindeer herders and caribou hunters is also an emerging one, especially in Fennoscandia and Russia, whereas this school of research is more established in North America (Ferguson *et al.*, 1998; Huntington, 2000; Usher, 2000). Interviews with and letters from reindeer herders reveal intimate knowledge of avoidance behavior and variations with season, landscape, and numerous other factors (see reference to letters in Reimers, 1984). Kitti *et al*. (2006) interviewed Sami reindeer herders in Finland on pasture quality, and found that peaceful grazing conditions were considered highly important, as reindeer only fed properly when human disturbance was minimal. Indigenous culture groups that herd and hunt reindeer and caribou and who have experienced development conflicts include (but are not limited to): in Eurasia; Sami, Nenets, Komi, Khanti, Dolgan, Nganasan, Yukagir, Even, Evenk, Sakha (Yakut), Chukchi, Koryak, and Chuvan; and in North America; Gwich'in, Iñupiat, Dogrib, Koyokon Dene, Metis, Cree, Chipewyan, Innu, Naskapi, Yupiit, Inuvialuit and Inuit (Kofinas *et al.*, 2000). Further studies of traditional knowledge of human disturbance effects on reindeer may give us a more holistic understanding of the complexity of grazing ecology and how humans affect this ecosystem.

Conclusions

Reindeer may be observed close to infrastructure, but most regional studies find that the majority of the animals reduce their use of areas within 1-5 km from development by 45-95%. Provided that mitigation measures take place, including regulation of human traffic and development and protection of large areas, reindeer and caribou can continue to co-exist with man, but perhaps at lower densities as areas become smaller and more fragmented. The continuous loss of habitat poses however a huge challenge in relation to the growing impacts of climate change. By reducing *Rangifer* habitat and migration opportunities, we also limit their resilience and capability to cope with natural and man-made changes (Tyler *et al*., in press).

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