SEASONAL AND DIEL VARIATION IN ROAD AVOIDANCE BEHAVIOR OF FEMALE SCANDINAVIAN BROWN BEARS

Inger Marie Yri

NORWEGIAN UNIVERSITY OF LIFE SCIENCES
DEPARTMENT OF ECOLOGY AND NATURAL RESOURCE MANAGEMENT
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Inger Marie Yri

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Department of Ecology and Natural Resource Management
Norwegian University of Life Sciences

Preface

This thesis is part of the Scandinavian Brown Bear Research Project in cooperation with the Norwegian University of Life Sciences, Department of Ecology and Natural Research Management. The project is founded by the Norwegian Directorate of Nature management, the Norwegian Institute for Nature Research, the Swedish Association for Hunting and Wildlife Management, the Swedish Environmental Protection Agency, the World Wildlife Fund – Sweden, Orsa Besparingsskog in addition to several private foundations.
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Inger Marie Yri

Abstract

Modern forestry, with its intensive logging, road building and human activity has shown to affect wildlife populations to a great extent. Brown bears (*Ursus arctos*) behavior in relation to different types of roads was studied from May to August 2004 and 2005 in Dalarna, south-central Sweden. Eight bears were collared with GPS radiotransmitters and in total of 38,893 valid GPS positions (71,3% GPS fix rate) were used to perform the analyses. Through GIS analysis I investigated avoidance behavior towards different road types; paved national highway, paved highway, good gravel roads, small gravel roads and ungravelled forestry roads. When testing avoidance behavior towards all road categories pooled, the bears showed significant avoidance at 200 m from the nearest road. When pooling the positions from each bear and each year and testing for each road category separately, the χ^2 tests showed that the bears clearly avoided the paved national highway more than the other road categories. Corrections for temporal and diel variations were made through analyses in a Fisher exact test using data from each bear individually. The avoidance of roads was greater during the berry-foraging season when avoidance distance reached 2 km in one road category, than during the mating season when avoidance distances never exceeded 500 m. I'm suggesting that mating strategies and forage availability during mating season might overrule the road avoidance behavior, or that human activity is more common in the forests during late summer when berries ripen. When comparing avoidance behavior between four activity periods, there was a clear indication that the bears increase the distance at which roads were avoided during daylight-hours, and particularly during human working hours, suggesting that this behavior is caused by an attempt by brown bears to avoid human activity by having their activity periods opposite of those of humans.

Key words: Brown bear, GIS, GPS, human activity, roads, Scandinavia, *Ursus arctos*

Sammendrag

Moderne skogbruk, med intensiv hogst, veibygging og menneskelig aktivitet har vist seg å påvirke viltstammer i stor grad. Brunbjørnens (*Ursus arctos*) adferd i tilknytning til ulike typer veikategorier ble studert fra mai til august i 2004 og 2005 i Dalarna i sentrale Sør-Sverige. 8 bjørner var utstyrt med halsbånd med GPS radiosendere og totalt 38,893 GPS posisjoner (71,3% vellykkede posisjoneringer) ble brukt i analysene. Ved bruk av GIS-analyser studerte jeg unnvikelsesadferd mot forskjellige veityper; asfaltert nasjonal motorvei, asfaltert motorvei, god grusvei, mindre grusvei og skogsbilvei. Når jeg testet bjørnenes unnvikelsesadferd mot alle veikategorier slått sammen, viste de en unnvikelsesadferd 200 m fra nærmeste vei. Ved å slå sammen posisjonene fra hver bjørn og hvert år og teste hver veikategori for seg, viste χ^2 testene at bjørnene unnvek den asfalterte nasjonale motorveien i større grad enn de andre veikategoriene. Jeg så etter forskjeller mellom sesonger og døgnvariasjoner ved å bruke data hva hver enkelt bjørn i en Fisher exact test. Unnvikelsesadferden var større i løpet av bærsesongen, da unnvikelsen nådde 2 km for en veikategori, i motsetning til parringssesongen da unnvikelsesadferden aldri oversteg 500 m for noen av veikategoriene. Trolig er dette fordi parringsstrategier og mattilgjengelighet i parringssesongen overskygger unnvikelsesadferden, eller fordi det er mer menneskelig aktivitet i skogen på sensommeren når bærene modner. Sammenligning av unnvikelsesadferd mellom fire aktivitetsperioder viste en klar indikasjon på at bjørner unnviker veier til en større grad i løpet av timene med dagslys, og særlig i løpet av menneskers arbeidsdag. Antagelig er dette en måte for bjørnen å unngå menneskelig aktivitet på ved å legge sine egne aktivitetsperioder til perioder med menneskelige inaktivitet.

1 Introduction

Human use of natural landscapes is increasing. Most habitats can today be exploited both economically and recreationally (Aanes *et al.* 1996). Habitat fragmentation due to human interference is a major threat to wildlife populations (Forman & Alexander 1998). Implications of habitat fragmentation are loss of habitat, reduced patch size, an increasing distance between patches, and a decrease of possible new habitat (Andrèn 1994). Maintaining opportunities for animals to move freely across landscapes is an important consideration in conservation biology (Singleton *et al.* 2004). Roads, in particular large highways, can have significant impacts on animal movement (Ng *et al.* 2004). In areas with productive forests, roads are built to make forestry more effective, thus creating barriers in the landscape (Forman & Alexander 1998). Reduced landscape connectivity, and reduced movement abilities due to roads might result in higher mortality, lower reproduction, and ultimately smaller populations and lower population viability (Chruszcz *et al.* 2003). Roads themselves do not cause habitat loss to a large extent, but they can severely alter the surrounding habitats (Forman *et al.* 2003). The human activity often associated with roads has been shown to cause avoidance behavior by animals (Swenson *et al.* 1996*a*; Mace *et al.* 1999) and traffic noise has also shown to have major ecological effects on some wildlife populations (Foreman & Alexander 1998).

Considering their great mobility and huge spatial requirements, large mammalian carnivores are particularly vulnerable to the effects of roads (Chruszcz *et al.* 2003; Kaczensky *et al.* 2003; Ng *et al.* 2004). One exception being wolves (*Canis lupus*) which have been known to use low-volume forestry roads for facilitated movement (Hamre 2006). Most studies considering road avoidance behavior in bear populations have been conducted in North America (e.g. McLellan & Shackleton 1988; McLellan 1989; Burson *et al.* 2000; Yost & Wright 2001; Gibeau *et al.* 2002; Wielgus e*t al.* 2002 & 2003; Chruszcz *et al.* 2003; Waller & Servheen 2005;) some show avoidance behavior and others not. Scandinavian studies on the topic are rarer (but see Swenson *et al.* 1996*a*). In addition, most North American studies use the grizzly bear (*Ursus arctos horribilis*) as a study species, which might show behavioral differences compared to the Scandinavian brown bear (*Ursus arctos arctos*) (Swenson *et al.*1996*b*).

Many studies that document avoidance of areas near roads by bears also show that bears react differently to different types of roads. In contrast to low-volume roads, bears seem to use areas close to high-volume roads less than expected (Chruszcz *et al.* 2003), especially in human active periods (Mueller *et al.* 2004).).Waller *et al.* (2005) showed that grizzly bears strongly avoided areas within 500 m of a highway and Kasworm and Manley (1990) found that American black bears (*Ursus americanus*) and grizzly bears avoided roads within 0-900 m of the roads, depending on season. Based on radio-telemetry, Swenson *et al.* (1996*a*) found that Scandinavian brown bears avoided areas within 600 m of a national highway, 400 m of smaller paved roads, 200 m of good gravel roads and 100 m of both medium and poor gravel roads.

In the denning period, the bears are more vulnerable to human disturbance than during the active period (Swenson *et al.* 1996*a*). Linnell *et al.* (2000) showed that bears generally selected dens 1 to 2 km from sites of human activity like roads, habitation and industrial activity. Studies on grizzly bears have also shown that different age classes of bears might react differently to roads. Subadult grizzly bears were more likely to use areas near high-volume roads than were adult bears, probably because they were forced to use more low-quality habitats (Mueller *et al.* 2004).

Diel and seasonal activity patterns are important components of behavioral ecology (Palmer 1976; Cited in Gervasi *et al.* in press). Both male and female brown bears decrease their home ranges in the berry-foraging season compared to the mating season when they range wider searching for mates (Dahle & Swenson 2003*a*). Moe (2005) found that Scandinavian brown bears selected for different types of forests during the mating and berry-foraging seasons. The bears also used different forest types during four different activity periods during 24 hours (Moe 2005). The activity pattern shown in bear populations, with a nocturnal activity period, is believed to be caused by avoidance of human active periods (Kaczensky *et al.* 2006). All this underlines the importance of studying animal activity at different temporal scales because it provides important knowledge about behavioral ecology (Gervasi *et al.* in press).

For the first time in Scandinavia, I have used GPS (Global Positioning System) technology to investigate how roads affect female Scandinavian brown bears, a wide-ranging mammalian carnivore. I have used GPS positions from eight female Scandinavian bears to: (1) determine if female brown bears show road avoidance behavior, and if so, at what distances they show this behavior; (2) determine whether the bears show seasonal and diel differences in road avoidance; and (3) discuss the results in the light of modern forestry, human activity and management of brown bear habitats.

2 Methods

2.1 Study area

The study was conducted in Dalarna County, Sweden (61ºN, 15ºE) (Figure 1). This area is within the southernmost core area of the Scandinavian brown bear population. Forests, bogs and lakes dominate the area, and small and scattered villages comprise the human settlements (Swenson *et al*. 2005). The productive forest is highly managed and creates a patchy environment of forests of different stages. The turnover time in this forest is about 90-100 years, with 8% consisting of clear-cuts and 42% being less than 35 years old (Swenson *et al.* 1999). Due to intensive forestry, a dense road network also characterizes the region. Together with the intensive logging, this creates a fragmented landscape with a median patch size of 22,500 m^2 (Jansson 2004). The landscape is undulating with altitudes ranging from 200 to 700 m above sea level. Scots pine (*Pinus sylvestris*) is the dominating tree species and comprises, together with lodgepole pine (*Pinus contorta*), 66% of the forest volume (Swenson *et al*. 1999). Other common tree species are Norway spruce (*Picea abies*), birches (*Betula* spp.) and aspen (*Populus tremula*). The ground and shrub layer consists mainly of bilberry (*Vaccinum myrtillus*), cowberry (*V. vitis-idaea*), crowberry (*Empetrum hermaphroditum*), common juniper (*Juniperus communis*), heather (*Calluna vulgaris*), willows (*Salix* spp.) and, in most areas, mosses and lichens. The mean temperature in July is 15ºC and in January -7ºC and snow cover lasts from approximately October to early May (Swenson *et al*. 1999) The density of brown bears on the study area is approximately 30 bears per 1000 km^2 (Bellemain *et al*. 2005). In comparison, the density of moose (*Alces alces*) is about 920 per 1000 km^2 in this area (Swenson *et al.* 2005).

Figure 1. The three core areas for breeding in the Scandinavian brown bear (*Ursus arctos*) population and the location of the study area (After Swenson *et al.* 2005 and Moe 2005)

2.2 GPS data

In total, 38,893 GPS (Global Positioning System) positions from eight brown bear females are included in this study. GPS coordinates from six female brown bears were recorded between 20 May and 24 August 2004. Coordinates from three of these brown bears and two additional females were recorded from 1 May to 30 August 2005. The number of GPS coordinates from these eight bears ranged from 3000-5000 positions in total per bear during the total study period. GPS positions were recorded every half hour 24 hours a day (48 times a day with optimal conditions). All bears were fitted with GPS-Plus-3 and GPS pro-4 neck collars with activity loggers and GSM (Global System of Mobile communications) modems (VECTRONIC Aerospace GmbH, Berlin, Germany). For bear capture and immobilization methods, see Arnemo *et al.* (2006*a* and *b*). All bears were without young, and between the age of 3 and 10 years.

In any study using GPS technology, data from GPS collars could be biased because of different types of interference affecting the satellite signals (Frair *et al.* 2004). Topography, local vegetation and animal behavior can influence how well the system performs, and lead to lowered fix success and location error (Cain *et al.* 2005). Especially canopy cover has been shown to influence the GPS positioning in the manner that the fix rate is reduced when the canopy cover increases (D'Eon *et al.* 2002). This can lead to bias in the results, because positions in certain areas might be underrepresented due to lack of GPS fixes (D'eon & Delparte 2005), which can cause increasing type II error and wrongful scientific conclusions (Cain *et al.* 2005; D'Eon 2003).

Seasonal patterns were corrected for by separating the GPS coordinates into mating (1 May- 16 July) and berry-foraging (17 July- 30 August) seasons. The berry-foraging season started on the day the first berries were found in bear scats in the field. For one of the brown bears, GPS positions were only available until 17 July. This bear has been excluded from the seasonal analysis, but included in the overall analyses.

Also the effect of diel patterns was examined by separating the 24-hour day into four activity periods according to the activity loggers on the bears' collars in 2004 (Moe 2005; Table 1). These activity periods can differ approximately ±30 minutes depending on the season (Moe 2005; Jansson 2004).

Table 1. Primary daily activity levels of Scandinavian brown bears in Dalarna County, Sweden, during the study period 2004. (Moe 2005).

Period	Time	Activity level
Night Rest (R1)	00:30 – 02:59	Non-active
Early- Day Activity (A1)	03:00 – 08:29	Active
Day Rest (R2)	08:30 – 17:59	Non-active
Late- Day Activity (A2)	18:00 – 00:29	Active

2.3 GIS analyses

Home ranges were calculated using digital land cover maps from the Swedish CORINE Land Cover Data and Geographical Sweden Data (GSD) map data (Engeberg 2004) containing all road categories in the study area. These data were imported to ArcView GIS 3.2 (Environmental Systems Research Institute, Inc, California, USA) for analysis. Five different road categories occurred in the study area (Table 2). These roads range from paved highways to forestry roads. The GIS analyses were performed in ArcView GIS 3.2 with the Home Range and Animal Movement extensions. Home ranges for each brown bear were defined as the 100% Minimum Convex Polygon (MCP) that encompassed all the GPS positions in a certain period (Figure 2). Home ranges for the berry-foraging and mating season were defined for each individual. For each MCP a number of random points that equalled to the number of actual GPS positions were created for each brown bear. From every GPS position and every random point, I measured the distance to the nearest road of all road categories combined, and from each position to the nearest road of each road category. This procedure was repeated for the GPS positions in each of the two seasons, and for each diel activity period.

Table 2. The five road categories used in this thesis, from Geographical Sweden Data (GSD) used for analysing differences in road avoidance behavior of brown bears to different road categories in Dalarna, Sweden 2004 and 2005.

Category	Road type	Width (meters)	Category code (GSD)
1	Paved national highway	5-7 m and >7 m	5021 and 5024
2	Paved highway	5-7 m and >7 m	5022 and 5025
3	Good gravel roads	> 5 m	5029 and 5061
4	Small gravel roads	≤ 5 m	5071
5	Ungravelled forestry roads	<5 m	5082

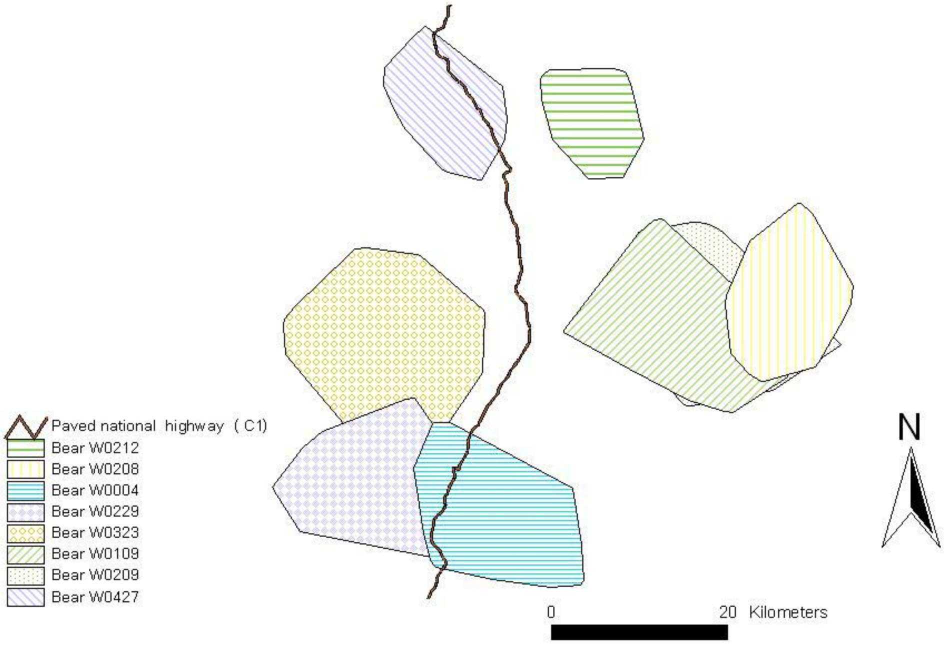

Figure 2. Home range areas (100% MCP) of 8 female brown bears in the study area, Dalarna, Sweden 2004 and 2005 in relation to a paved national highway (C1). The home ranges were defined from GPS positions from each brown bear during the study period.

Straight line movement calculations of brown bears in the study area in 2004 gave a median movement of 361 m during the sampling interval (30 min). The maximum distance walked in 30 min was 2,551 m (Moe 2005). The longest distance a bear would have to walk to exit one distance category and enter the next within the sampling intervals is 1000 m, thus I conclude that the data points can be regarded as independent.

2.4 Statistical analyses

In the first analyses, pooled GPS positions from each bear and the corresponding random positions were used to test for general avoidance behavior in relation to all road categories pooled. A Chi-square (χ^2) contingency table test was used with the actual GPS positions as the observed units and the random points as the expected units (Figure 3). All χ^2 tests were performed in Minitab 14.0 (Minitab Inc., Pennsylvania, USA). Six different distance-from-road categories were used for testing road avoidance behavior; <100 m (0-99 meters), <200 m (0-199 m), <500 m (0-499 m), <1000 m (0-999 m), <2000 m (0-1999 m) and >1999 m (all positions over 1999 m). These broad category divisions were a compromise between possible accuracy in distances closest to the roads and the certainty that the last category is beyond the point where the road has any effect on the animal (for distance comparisons see McLellan & Shackleton 1988; Linnell *et al.* 2000). The positions were divided into two groups; those within each distance category and those beyond. They were tested against the corresponding distribution of the random data to find the distance at which significant road avoidance occurred, using all the GPS positions. This procedure was repeated for GPS positions from each individual bear separately. All the χ^2 tests between the GPS positions and the random points were performed up to the point of non-significance. Thus, the distance of significant road avoidance was the last distance category where significant avoidance was found, before the tests in the next distance category gave a non-significant result. No tests were made beyond >1999 m, because roads at this distance probably do not affect the animals (for distance comparisons see McLellan & Shackleton 1988; Linnell *et al.* 2000).

Because the high number of GPS positions used as units in the χ^2 tests in itself might lead to higher significance levels, a more conservative approach was used to test differences in road avoidance between the two seasons and the four activity periods.

For each individual bear, the significant distance of road avoidance from the χ^2 test was determined using a Fisher exact one-tailed test. I then determined significant avoidance distances for the two seasons and each of the four diel activity periods. For each distance category and each road category for the different seasons and activity periods, the number of individual bears that showed significant avoidance behavior was tested against the number of individuals that did not avoid roads in each of the different categories (Figure 3). In this way I got a p-value for each season and each activity period separately. In the case where the Fisher exact test showed that a significant number of bears showed road avoidance at different distances in one season compared to the other, or in one diel activity period compared to the remaining activity periods, I concluded that there were differences between the seasons or between the activity periods. The number of bears showing avoidance behavior and those who did not was tested in the Fisher exact test against the assumption that no bears show road avoidance behavior. All reported results from the χ^2 test are the longest distance where I found significantly more bears avoiding roads than expected from the random points. Reported results from the Fisher exact test is the longest distance where a significantly larger number of bears show avoidance behavior than those who did not.

For the three bears with GPS positions from both 2004 and 2005, I performed the GIS analyses for each year separately and pooled the results in the χ^2 and Fisher exact test. In the case where a bear did not have a road of a certain road category within their home range, or the distance exceeded 2 km, this was includes in the analysis but considered non-avoidance behavior (see discussion).

The Fisher exact tests were performed on the Vassar University official statistical website (http://faculty.vassar.edu/lowry/VassarStats.html). All significant results are given at $\alpha \leq 0.05$.

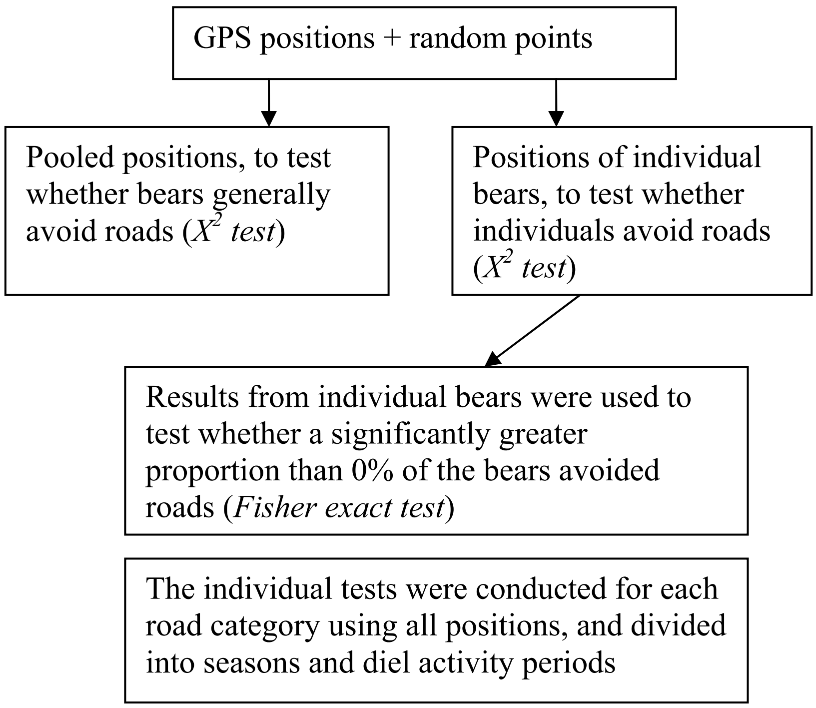

Figure 3. Methodological approach for studying road avoidance behavior according to different road categories from GPS positions from 8 brown bears divided into seasons and diel activity periods in northern Dalarna County, Sweden in 2004 and 2005.

3 Results

A total of 38,893 valid GPS positions, representing 71.3% location success, were used to perform the analyses. In the analysis of differences between the mating and berry-foraging seasons, one bear was excluded due to a lack of GPS positions after 17 July. The opposite results seen in figure 4 and 5 for road category C1 and C2 are caused by methodological differences, because only 3 and 4 bears (respectively) have these roads within their home range (see discussion).

3.1 General road avoidance

When pooling all of the GPS positions for every bear and year, the results showed that the bears significantly avoided roads combined (all road categories) within their home ranges up to a distance of 200 m (χ^2 =347.3, df=1, p<0.000). Here the nearest road to each GPS position and random point was tested. When analyzing the use of area in relation to the different road categories, with the pooled GPS positions for all bears, I found that the bears showed different degrees of avoidance behavior to the different road categories (Figure4). The bears significantly avoided the paved national highway (C1) < 2000 m, compared to the random points (χ^2 =315.3, df=1, p= 0.000). The avoidance was less for the other road categories, with corresponding distances of significant avoidance for the other categories of < 200 m for road category 2 (χ^2=28.3, df=1, p=0.000), <500 m for road category 3 (χ^2=11.9, df=1, p=0.000), and <200 m for both road category 4 (χ^2=159.9, df=1, p=0.000) and road category 5 (χ^2=6.0, df=1, p=0.013) (Figure4).

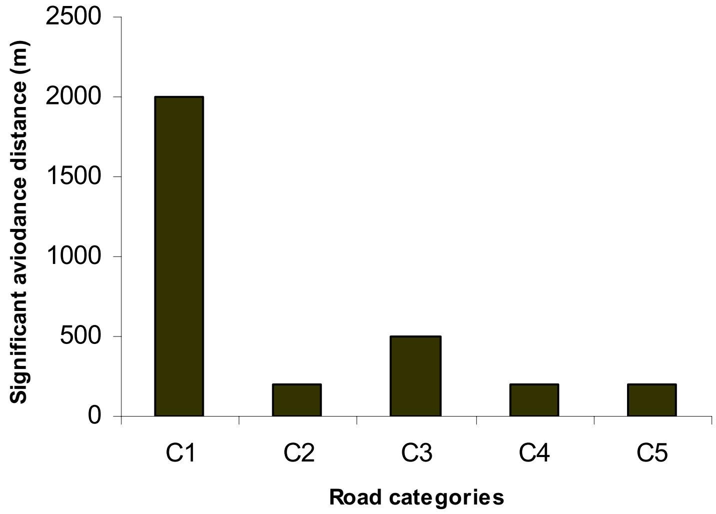

Figure 4. The distances at which brown bears showed statistically significant avoidance of different road categories; paved national highway (C1), paved highway (C2),good gravel roads (C3),small gravel roads (C4) and ungravelled forestry roads (C5) compared to random points in northern Dalarna County, Sweden. The results are based on Chi-square contingency table tests on all pooled GPS positions from all eight bears in 2004 and 2005.

I also investigated whether each individual bear (N=8) avoided each road category using a Fisher exact one-tailed test. I found no significant difference between the number of bears that avoided and did not avoid road category 1 and category 2 at < 100 m from the road (Fisher exact test, p= 0.100 and p=0.233, respectively). However, for road category 3, significantly more bears avoided the roads, and this avoidance behavior was evident at <500 m (Fisher exact test, p= 0.038). The same situation was found for road category 4, but the significant difference in avoidance was evident at <200 m (Fisher exact test, p= 0.003). The behavior in relation to road category 5 was different, with significantly more bears avoiding these roads at distances <2000 m (Fisher exact test, p= 0.038) (Figure 5).

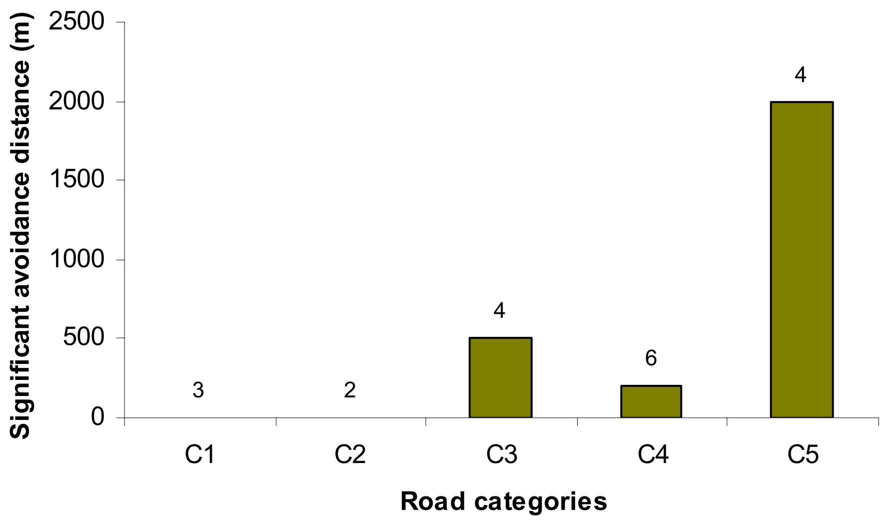

Figure 5. The distances at which a significantly greater number of brown bears (N=8) was found to avoid areas near roads, grouped according to different road categories; paved national highway (C1), paved highway (C2), good gravel roads (C3), small gravel roads (C4), and ungravelled forestry roads (C5). The study was based on GPS positions of eight brown bears in Dalarna, County, Sweden, during 2004 and 2005. The results are based on a Fisher exact one-tailed test. The column labels show the number of individual bears avoiding the different road categories at each distance in relation to the total number of bears (N=8). This total number is lower for road categories C1 and C2, because not all bears had these categories within their home range.

3.2 Seasonal difference in road avoidance

I divided the study period into two seasons, and used the Fisher Exact test with data from each individual bear to determine whether area use in relation to roads changed between the mating and berry-foraging seasons. The bears were tested within each season separately, giving two p-values. When significant avoidance was detected at different distance categories in the two seasons, I concluded there was difference between them.

When testing the bears that showed avoidance behavior against those that did not within each season separately, I found no difference in avoidance distance between seasons for either road category 1 (Fisher exact test, p [mating]= 0.100; p [berry]= 0.233) nor road category 2 (Fisher exact test, p [mating]= 0.100; p[berry]= 0.233).No avoidance behavior was found in any of the seasons for these road categories. I found a seasonal difference in avoidance behavior for road category 3, with a significant difference in number of bears showing avoidance and non-avoidance up to 200 m in the mating season (Fisher exact test, p= 0.038) and a corresponding significant difference exceeding 2000 m in the berry-foraging season (Fisher exact test, p= 0.038). A difference between the seasons was also found for road category 4, where the number of bears avoiding these roads was significantly more than those bears that showed no avoidance behavior; <100 m in the mating season (Fisher exact test, p= 0.003) and <200 m in the berry-foraging season (Fisher exact test, p= 0.003). Finally the analyses showed that significantly more bears avoided road category 5 at <100 m in the mating season (Fisher exact test, p= 0.038) and <500 m in the berry-foraging season (Fisher exact test, p= 0.038) (Figure 6).

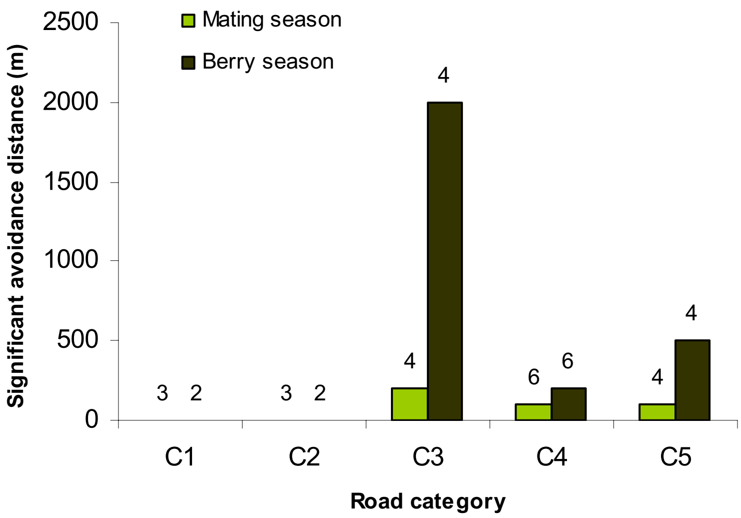

Figure 6. The distance at which a significantly larger number of 8 individual brown bears in 2004 and 2005 showed avoidance behavior to different road categories compared to bears that did not, grouped according to ; paved national highway (C1), paved highway (C2), good gravel roads (C3), small gravel roads (C4), and ungravelled forestry roads (C5) in Dalarna, Sweden. A Fisher exact test was used, based on GPS positions separated into mating and berry-foraging seasons. The column labels show the number of individual bears avoiding the different road categories at each distance out of the total number of bears (N=8). This total number is lower for categories C1 and C2 because not all bears had these categories within their home range.

3.3 Diel difference in road avoidance

I also investigated whether behavior in relation to roads varied throughout the 24-hour period, based on the general four activity periods shown by brown bears; night rest (R1), early-day activity (A1), day rest (R2) and late-day activity (A2) (Table 1). The bears were tested within each activity period separately, giving one p-value per period. When significant avoidance was detected at different distance levels in the four activity periods, I concluded there was difference between them.

When testing the number of bears that showed avoidance behavior against those which did not within each activity period, the Fisher exact test showed no difference between the activity periods for road category 1 (Fisher exact test, p [R1]= 0.233; p [A1]=0.100; p [R2]=0.100; p [A2]=0.100). For road category 2, significantly more bears avoided these roads than those who did not up to < 100 m during the day rest (Fisher exact test, p [R2]=0.038), whereas no difference was found for the rest of the day (Fisher exact test, p [R1]=0.233; p [A1]=0.233; p [A2]=0.233).

Significantly more bears avoided category 3 roads up to <500 m during the day rest (Fisher exact test, p [R2]=0.038), whereas no significant number of bears avoiding this road was found in any of the other activity periods (Fisher exact test, p [R1]=0.233; p [A1]=0.100; p [A2]=0.233). No significant avoidance of road category 4 was found during the night rest at <100m (Fisher exact test, p [R1]=0.233). In the early day activity period there was a significant higher number of bears avoiding these roads <200 m (Fisher exact test, p [A1]=0.038). During the day rest period this occurred at <500 m (Fisher exact test, p [R2]=0.000), and during the late day activity period it occurred at <200 m (Fisher exact test, p [A2]=0.038). For road category 5, there was no significant difference between the avoidance distance during the night rest (Fisher exact test, p [R1] =0.100) and late-day activity periods (Fisher exact test, p [A2]=0.100), but significantly more bears avoided areas <200 m from these roads during the early-day activity period (Fisher exact test, p [A1]=0.038) and the day rest (Fisher exact test, p [R2]=0.012) (Figure 7).

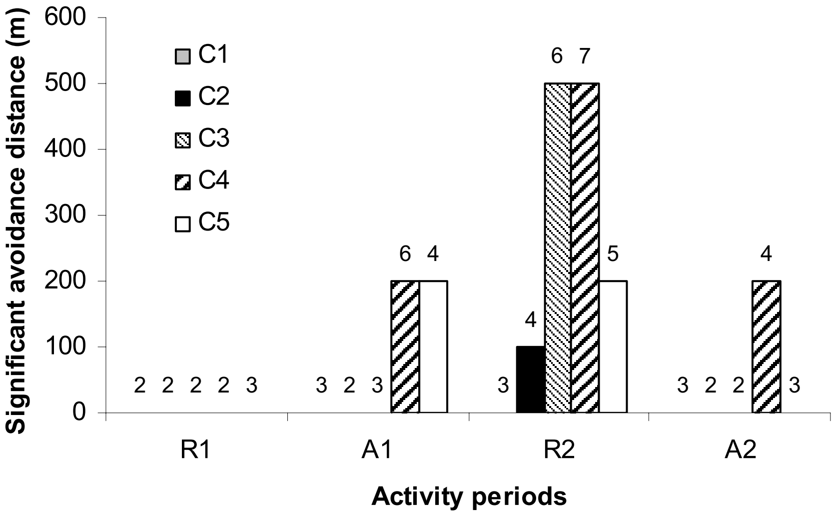

Figure 7. The distances at which a significantly greater number of brown bears were found to avoid roads, grouped according to different road categories; paved national highway (C1), paved highway (C2), good gravel roads (C3), small gravel roads (C4) and ungravelled forestry roads (C5) in four different diel activity periods (R1=Night rest, A1=Early day activity, R2=day rest, A2=late day activity). The study was based on GPS positions of eight brown bears in Dalarna, County, Sweden, during 2004 and 2005. The results are based on a Fisher exact test. The column labels show the number of individual bears avoiding the different road categories at each distance out of the total number of bears (N=8). This total number is lower for categories C1 and C2, because not all bears had these categories within their home ranges.

3.4 Roads in home range areas

Analyses performed in Arc View 3.2 showed that nearly all bears extended their home range areas during the mating season compared to the berry season (Table 3 and 4).

Table 3. Home range areas (km^2) in the mating season and the amount of roads (km) of each different road category (paved national highway (C1), paved highway (C2), good gravel roads (C3), small gravel roads (C4) and ungravelled forestry roads (C5)) within the home range of each individual GPS-collared brown bear in the study area in Dalarna County, Sweden, during 2004 and 2005.

Bear id	Home range (km^2)	Road (km)				
		C1	*C2*	*C3*	*C4*	*C5*
W0209-04	295,3	0	0	20,5	118,8	25,8
W0209-05	154,2	0	17,1	25,8	227,9	88
W0004	225,1	15,5	0	12,8	137	16,9
W0229	223,9	5,1	0	33,2	162,3	30,7
W0109	307,1	0	0	40,5	214,5	26,4
W0208-04	129	0	15,9	3,3	122,5	38,3
W0208-05	156,9	0	16,3	1,5	149,1	36,6
W0323-04	341,9	0	0	41,0	170,0	35,8
W0323-05	512,8	0	0	29,2	165,8	34,9
W0427	140,0	15,6	0	29,4	58,3	19,7
W0212	112,7	0	12,2	16,7	78,7	2,7

Table 4. Home range areas (km^2) in the berry season and the amount of roads (km) of each different road category (paved national highway (C1), paved highway (C2), good gravel roads (C3), small gravel roads (C4) and ungravelled forestry roads (C5)) within the home range of each individual GPS-collared brown bear in the study area in Dalarna County, Sweden, during 2004 and 2005.

Bear id	Home range(km^2)	Road (km)				
		C1	*C2*	*C3*	*C4*	*C5*
W0209-04	146,5	0	7,9	17,6	118,2	24,5
W0209-05	146,1	0	0	2,4	96,5	19,8
W0004	206,9	14,7	0	5,4	137,4	16,9
W0229	131,0	0	0	22,9	88,5	23,6
W0109	157,8	0	0	22,8	109,7	15,0
W0208-04	144,9	0	16,0	2,5	140,8	34,6
W0208-05	153,3	0	14,7	2,4	146,8	34,7
W0323-04	163,8	0	0	14,9	61,3	20,9
W0323-05	*	*	*	*	*	*
W0427	95,9	0	0	21,8	33,1	17,2
W0212	44,7	0	5,2	8,8	28,4	1,0

* Bear W0323 lacks GPS positions after 17 July 2005.

4 Discussion

4.1 Methodology

One important methodical consideration in this study that becomes evident when comparing figure 4 and 5 that show opposite patterns, is that only three individual bears had home range areas that included the paved national highway (C1), and only one bear had the paved national highway in its home range during berry-foraging season. The home ranges of the remaining six bears were never closer than 2 km from this road. Distances over 2 km from the roads were considered non-avoidance behaviour this study, because it is beyond the point where the road should have any effect on the animal (for distance comparisons see McLellan & Shackleton 1988; Linnell *et al.* 2000). The same consideration has to be taken when discussing avoidance of the paved highway (C2). Roads of this category were within the home range of four of the bears in this study. Due to the methodology that the Fisher exact tests in this thesis are based on, this will give a nonsignificant number of bears avoiding both the paved national highway (C1) and the paved highway (C2) using this conservative approach. When looking at each individual bear *per se,* all the bears that had the paved national highway (C1) within their home range showed significant avoidance behavior for all distance categories. Among the 4 bears having the paved highway (C2) running through their home range, 3 of them avoided areas less than 300 m to the road and 2 of these 3 bears showed avoidance exceeding 2 km from the road. When considering the results from the Fisher exact test in the light of selection of home range areas, this could be considered avoidance behaviour, only at a larger scale. The bears might actively avoid having high-volume roads within their home range. A study of the impact of high speed, high volume roads on brown bears in Slovenia (Kaczensky *et al.* 2003) suggested that larger traffic axes might affect the animals in a zone of 10 km from the road, considering that the average home range for a female brown bear in this area was 10 km in diameter, and that the bears avoided selecting home range areas close to high volume roads. In areas where bears have larger home ranges, like the Scandinavian bear population (Dahle & Swenson 2003*a*; Bjärvall *et al.* 1990), the possible area affected by highways could be even bigger. This explains the difference in results in road avoidance behavior towards different roads categories seen in figure 4 and 5. This methodological consideration should be kept in mind during the following discussion.

4.2 General road avoidance

The bears showed road avoidance behavior towards all road categories to different degrees. In all five road categories the bears used the areas close to the roads less than expected when pooling the positions from each bear each year. The paved national highway (C1) that runs through the study area is a high speed (speed limit 90-110 km/h), high-volume road that clearly affects the animals more than the other road categories according to results from the pooled GPS positions. I found that the bears used areas adjacent to this road less than expected up to 2 kilometres from the road. This coincides with a previous study using radio-telemetry on Scandinavian brown bears, showing that the degree of road avoidance increases with increasing road standards, but it differs in the degree of avoidance. The former study showed road avoidance behavior 600 m from the high volume road (Swenson *et al.* 1996a) which is much closer than the results in this thesis. This difference could be explained by more accuracy in distance measurements using GPS technology compared to radio-telemetry, but also individual differences could be a reason. This may become more evident due to the relatively low sample size in this thesis.

Avoidance of high-volume roads in bear populations is also evident from studies in national parks in North America. In Canada grizzly bears tended to be closer to roads with low traffic volume than to those with high traffic volume (Chruszcz *et al.* 2003) and in Montana, USA, scientists found that grizzly bears strongly avoided areas within 500 m of a highway (Waller *et al.* 2005). This could be because of the increased human activity (e.g. villages, truck stops and picnic areas) connected to high-volume roads or because of the traffic noise that has shown to have a negative effect on some wildlife populations (Forman & Alexander 1998). Swenson *et al.* (1996a) showed that Scandinavian brown bears increased their avoidance behavior with increasing density of houses and that villages were avoided to a larger degree than single houses. This, together with the findings that bears increased their distance to roads when road standards increased, suggests that it is the human activity connected to roads or houses that is avoided and not the road constructions in itself. Gunther (1998) found that bears activity was significantly reduced in areas greater than 500 m from forest cover in a valley open for human recreational activity and the bears strongly avoided areas around backcountry campsites. Burson *et al.* (2000) and Yost & Wright (2001) studied grizzly bears in relation to road traffic in Denali National Park, Alaska. Both studies found no effect of roads on grizzly populations. In contrast to other studies on grizzly bear in North America these two studies were conducted in an area that has been protected from hunting since 1917. This suggests that bears in this area might have fewer negative associations to humans and therefore use areas close to roads more than expected. Habituation to roads and the traffic noise connected to it might appear when the stimuli do not provide negative reinforcement (Burson *et al.* 2000; Aanes *et al.* 1996). Wielgus *et al.* (2002) found that grizzly bears showed stronger avoidance behavior to closed roads that were used by hunters, fishermen and berry pickers who left the roadway than to restricted roads that were used by forestry workers that rarely left their vehicles. In addition, no hunting was allowed in the areas with restricted roads which might have caused the bears to habituate to these roads. This could correspond to the difference in avoidance distance between the good gravel roads (C3) and the small and ungravelled forestry roads (C4 and C5 respectively) in analyses from the pooled GPS positions, where the good gravel roads are used by humans, but the smaller forestry roads might be used more by people leaving their vehicles for hunting or berry-picking activities. In general one could say that roads increase access for hunters and also poachers. It increases the probability of vehicle-bear collisions and the frequency of energy costly flight responses by the bear (McLellan & Shackleton 1988). In this study area bears are hunted annually. In 2004 and 2005 the hunting took place from 21 August till 15 October. In Dalarna County, where we find the study area, 25 bears were legally shot in 2004 and 22 in 2005 (Swedish veterinary institute web page, www.sva.se). Studies by Dahle (2000) and Swenson & Sandegren (1999) found that illegal mortality of brown bears was 0,6 times that of legal hunting in this study area. If this number was the same today, we could suggest 40 bears were killed legally and illegally by humans in Dalarna County in 2004 and 38 in 2005, although there is reason to believe that the amount of illegal killing has decreased since 2000 (S. Brunberg pers. comm.). As for bear-vehicle collisions, 42 bears have been reported killed by traffic during the period between 1990 and 2006 in all of Sweden. Of these bears, 20 were killed by train (A. Söderberg pers. comm.). All deaths, except three, occurred during crepuscular and nocturnal hours. There were no differences in vehicle-bear collisions between seasons, 52,3% of them being within the mating season and 47,6% within the berry-foraging season. When looking at the results in light of this information, there is reason to believe that legal and illegal hunting can cause bears avoiding roads connected with human activity, whereas bear-vehicle collisions is of lesser importance in the study area.

4.3 Seasonal difference in road avoidance

The results show a clear difference in road avoidance behavior when comparing the mating and berry-foraging seasons. For the paved national highway (C1) and the paved highway (C2) there was no statistically significant difference in the avoidance behavior between the seasons, whereas differences were found between the mating and berry-foraging season for both the good and poor gravel roads (C3 and C4 respectively) and poor forestry roads (C5). Especially the good gravel roads (C3) were strongly avoided in the berry-foraging season compared to the mating season. The good gravel roads in the study area connect the different villages and are frequently used with an 80 km/h speed limit. Picnic areas and fishing lakes are found adjacent to these roads, resulting in a higher human activity along these roads than in connection to more high volume traffic axes. This is similar to results in Wielgus *et al.* (2002), who found a clear avoidance by grizzly bears to smaller roads often used by fishermen and berry pickers.

Both the poor gravel road (C4) and the poor forestry road (C5) are also avoided more by the bears in the berry-foraging season than in the mating season, but the avoidance distance is less than the distance seen for the good gravel road (C3). This is probably due to less human activity, at least for ungravelled forestry roads (C5).

A difference in forage availability could explain the differences in road avoidance between seasons. Ants comprise 30% of a bear's assimilated energy during the mating season in the study area (Johansen 1997). In North America, anthills occur more frequently on clearcuts, with a peak accruing in clearcuts between 25 and 30 years (Nielsen *et al.* 2004). This implies that the bears during this season are forced to use areas with a larger amount of adjacent roads to meet their energy requirements. During the berry-foraging season cowberries (*Vaccinium vitis-idaea*) and blueberries (*V. myrtillus*) comprise 54% of the brown bear diet in the study area (Neumann 2001). Nilsen (2002) found that during berry-foraging season in central Sweden, bears selected sites where berries were abundant, often in coniferous forests. In this period the bears may have more opportunity to avoid forests adjacent to roads and human activity. A study by Kasworm & Manley (1990) found that grizzly bears avoided roads within 0-275 m in spring and 0- 914 m during fall. This was explained by food availability in higher elevations during fall that was further away from roads. All this could explain the difference in road avoidance between seasons for the three smaller road categories in the study; C3, C4 and C5.

During the mating season female brown bears with cubs restrict their home range size (Dahle & Swenson 2003*a*) and are seen more often in areas near roads (McLellan & Shackleton 1988). This has been seen as a mean of avoiding potentially aggressive and infanticidal adult males (McLellan & Shackleton 1988), forcing the female bears to use poorer quality habitats, whereas adult males use more remote areas (Gibeau 2002) farther away from human activity. In this study all the bears were solitary females, so no correction for females with cubs have been possible, but the results could indicate that there is spatial intraspecific avoidance between different dominance classes within bear populations as seen in Gibeau (2002) and Mueller *et al.* (2004). This could become more evident in the mating season when both males and females extend their home range area and roam more to meet several prospective mates (Dahle & Swenson 2003*a* and *b*). Subordinate/subadult females might have be forced to use low-quality habitats near roads involuntarily in this period to a higher degree than during the berry-foraging season. In this study 5 bears were between 3 and 4 years, none having reared any cubs yet. These could be considered subordinate or subadult females (S. Brunberg pers.comm.).

4.4 Diel difference in road avoidance

The bears showed a temporally dependent road avoidance behavior when dividing the 24 hour day into four activity periods. The results clearly showed an increase in avoidance distances when humans are most active. Since most studies concerning road avoidance in bear populations have been conducted without the use of GPS technology, important diel variations might have been overseen. Using VHF-transmitters and locating the animals during daylight hours might lead to an underrepresentation of areas that bears use during human inactive periods. This study shows a clear relationship between road avoidance and human activity for nearly all road categories. During the bear’s day rest period (R2), which corresponds to the working hours of humans, the bears increased their road avoidance distance compared to the other activity periods. This coincides with finding of Moe (2005), that resting behaviour is mainly restricted to human working hours, whereas foraging behaviour was restricted to the crepuscular and nocturnal hours. During the bears’ night rest period (R1), which coincides with human inactivity, the results show no significant road avoidance behaviour in any of the five road categories (except for road category 1 see discussion under methodology). During the bears’ late day activity period (A2), the bears showed no significant avoidance to roads, except for small gravel roads (C4) which were avoided < 200 m from the road. This period coincides with a period of human activity, but not human working hours. Maybe avoidance to this particular road at this time could be explained by people using these smaller roads for recreational causes during the late day. McLellan & Shackleton (1988) stated that habitats often associated with roads are especially vulnerable to bears because they contain high-quality food both in spring and autumn. This could explain why bears use areas adjacent to roads to a larger degree during night time. The darkness provides cover and the traffic will also be somewhat reduced. Gibeau *et al.* (2002) also found that grizzly bears used areas closer to trails more during periods when human were inactive when within high quality habitat and further away than when within poorer quality habitats. No analysis of habitat selection is included in this study, which could bias the results if areas adjacent to roads are non-preferred habitats. In this way it could be the habitats that are avoided, not the roads. Yet there is little reason to believe that this would be the case in the study area. Moe (2005) found that clearcuts, that are associated with roads, are preferred bear habitats in the study area, implying that it is the roads that are avoided, not the habitats.

4.5 Conclusions and management implications

Productive forests are inevitably associated with an increasing road density to make forestry more effective. In turn, increased road densities in bear habitats make areas more available to human use. Mace *et al.* (1996) found that the spatial avoidance of roads by grizzly bears increased and their survival decreased as traffic levels, road densities and human activity increased.

In areas where human use has a significant influence upon landscapes, it is important for managers to secure areas that protect the bears from disturbance (Gibeau 2002). The key to this lies in managing human use of the areas. A landscape assessment by Crist *et al.* (2005) demonstrated how roadless areas and remaining relatively undisturbed forested lands are essential for maintaining biodiversity and landscape connectivity. The importance of intact natural ecosystems to maintain native biodiversity and ecological processes is obvious.
The Scandinavian brown bears seem to be vulnerable to road disturbance. Pooling all the road categories, the bears showed road avoidance at 200 m. The paved national highway (C1) is highly avoided by all the bears in its vicinity, suggesting a high impact of this road on the bear population. The remaining road categories are avoided to different degrees, probably best explained by different degrees of human interference. The bears show a seasonal and diel variation in road avoidance, with the three smallest road categories all being avoided to a

larger extent during berry-foraging season. The temporal variation is seen through a clear pattern of bears avoiding roads more during human active periods and daylight-hours than during night time. The seasonal differences can be explained by forage availability and social dominance, and together with the diel variation most importantly explained by the avoidance of humans, especially during human working hours.

Increased road access is one of the human-made impacts that imposes the greatest effects on bear populations (Aanes *et al.* 1996). To summarize, roads and the corresponding human activity cause an affect on normal brown bear behavior; they change the bear habitats; prevent the bears from using areas near roads, especially during day-light hours; and increase access for hunters/poachers.

So how can we combine modern forestry with an increasing bear population? A possible way to diminish the effect roads have on bear populations is to detect primary and secondary bear habitats in the given area (Nielsen *et al.* 2006). Road development should be limited within such habitats, and particularly primary habitats, and human access controlled. If construction of roads within primary habitats is necessary, efforts should be made to restore similar habitats elsewhere. Closing and re-vegetation of roads no longer in use or seasonal closure of roads in high quality habitats is also a possible means of management (Nielsen *et al.* 2004). In this way we can maintain viable brown bear habitats and populations in areas with modern forestry.

4.6 Further research

The relative low sample size in this thesis might have caused biased results due to individual variation. A future study using a larger number of study animals could give more reliable results. A larger sample size could also increase the opportunity to conduct separate analyses for bears with the larger road categories within their home range, and exclude other bears in these analyses, and perhaps include the railway in the analysis. This would give a better picture of how the different roads affect the brown bear, and compare avoidance of roads to railways. Also it would be beneficial to include male brown bears in the study to see if the different sexes react differently to roads or human activity, and even females with cubs, to see if their behavior towards roads and humans separates from females without cubs as seen in other studies. All these corrections could strengthen the conclusions in a similar future study.

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