Sveriges lantbruksuniversitet
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Department of Ecology
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Master's thesis
Grimsö and Uppsala 2014

Independent project/Degree project / SLU, Department of Ecology 2014:1

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2014-03-22

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Credits: 30 hec
Level: A2E
Course title: Independent project/Degree project in Biology
Course code: EX0565

Place of publication: Grimsö and Uppsala
Year of publication: 2014
Title of series: Independent project/Degree project / SLU, Department of Ecology
Serial no: 2014:1
Electronic publication: http://stud.epsilon.slu.se

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Abstract

After the storm Gudrun in 2005, the Swedish Transport Administration started clear-cutting of railroad corridors to reduce the risk of trees falling down on the tracks. Simultaneously, train accidents with moose and roe deer have become more frequent and the costs for consequent delays and repairs of engines are of growing concern. There is reason to assume that tree-clearance of railroad corridors may have contributed to an increase in number of accidents with moose and roe deer because the cleared areas provide attractive forage and thus may attract wildlife. The objective of my study was to investigate how clearing of trees affected the number of accidents with moose and roe deer. I compared deer-train collision frequencies before and after clearance of the selected railroads and compared these with uncleared control railroads in a BACI (before-after control-impact) approach. I have further investigated possible differences between regions and seasons. The results suggest that although there was a significant increase in the frequency of accidents on both controls and tree-cleared railroads over time, there was no effect of tree-clearance. Only in two regions and only during the summer months, significantly more accidents were observed along cleared sections. However, when performing a Bonferroni correction, the p-values were very close to the adjusted significance level. I discuss possible reasons for the observed increase and the lack of effect of tree clearance. More research is needed to unveil the reasons for the overall increase and to better understand why and how train-deer collisions occur.

Key words: Tree clearance, railroads, train collision, moose, roe deer, ungulate-train collision

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Sammanfattning

Järnvägstransporterna ökar i Sverige som ett resultat av den uttalade politiska agendan att minska utsläppen av koldioxid. Ett pålitligt och fungerande järnvägsnät är en förutsättning för detta, och driftstörningar kan få omfattande konsekvenser för både enskilda resenärer, samhälle och ekonomi. Stormen Gudrun ställde till stora problem för järnvägstrafiken under sin framfart 2005, vilket ledde till att Trafikverket började trädsäkra (avverka) träd längs vissa sträckor där nedfallande träd bedömdes kunna göra stor skada och leda till förseningar. Under de senare åren har antalet tågolyckor med älg och rådjur ökat, vilket, förutom lidandet för djuren, orsakar förseningar och kostsamma reparationer av tågen. Eftersom trädsäkringen skapar nya miljöer där olika arter av sälg, björk och asp kan förväntas etablera sig, och eftersom rådjur och älgar föredrar dessa växter, befarar man att ökningen av olyckor kan ha ett samband med ökad trädsäkring. Tillgången på attraktiv föda kan göra att djur uppehåller sig mer i området längs de trädsäkrade järnvägsspåren. Syftet med denna studie var dels att undersöka om trädsäkringen har påverkat antalet olyckor längs med järnväg, samt dels att undersöka om olycksfrekvensen ändras över tid efter trädsäkring.

För att undersöka om trädsäkring ökar antalet olyckor jämfördes trädsäkrade sträckor med kontrollsträckor som inte hade trädsäkrats. I studien ingick information om älg och rådjursolyckor som inträffat mellan 2001–2012. Trädsäkringen inleddes år 2006 och pågick under hela studietiden.

Antalet olyckor har ökat längs både kontrollsträckor och trädsäkrade sträckor, men ökningen längs de trädsäkrade sträckorna var inte större än ökningen längs kontrollsträckorna. När man däremot jämför olycksfrekvensen uppdelat på två årstider (sommar och vinter) och tre geografiska regioner (syd, mitt och norr) så har antalet älgolyckor ökat mer längs de trädsäkrade sträckorna i Mellansverige under sommaren, samt för rådjur i Sydsverige under sommaren. Det har skett en ökning i antalet olyckor, både i relation till årtal, men även i relation till det år trädsäkringen utfördes. Antalet olyckor befanns då öka något 2–3 år efter trädsäkring, men variationen var för stor för att kunna säkerställa detta statistiskt.

Denna undersökning pekar därför mot att ökningen av olyckor med älg och rådjur sannolikt inte beror på trädsäkringen, utan på andra faktorer. Persontrafiken på järnväg har årligen ökat med 2,8% och godstransporterna med 1,1% mellan 2001–2012, vilket kan vara en viktig förklaring. Men eftersom olyckorna har ökat med 4,3% årligen för älg och 3,1% för rådjur är trafikökningen inte den enda förklaringen.

Antalet djur skjutna under jakt används ofta för att uppskatta olika populationers utveckling mellan år. Avskjutningen under 2001–2012 tyder dock på att rådjursstammen har minskat kraftigt medan älgstammen har varit ganska stabil eller minskat svagt. Ökningen av olyckor kan därför troligen inte förklaras av en ökande viltpopulation.

Slutsatsen är att trädsäkring inte ökar antalet tågolyckor med älg och rådjur på nationell nivå, men eftersom det har skett en ökning i olycksfrekvens under de senaste åren är det viktigt att studera vilka andra faktorer som kan ligga bakom denna ökning för att i framtiden kunna minska dessa.

Introduction

The Swedish railroad network consists of 13 642 km of tracks. Railroad transport of goods and people is quickly gaining importance in Sweden, as a result of the political agenda to reduce CO_2 emissions. A reliable and efficient rail transport is thus a crucial ingredient in the future sustainable transport system.

In January 2005, the storm Gudrun caused a lot of damage on its way through Europe. The strong winds caused 75 million m^3 timber to fall down (Svensson et al 2011). During the days after the storm, 340 trains were cancelled, and it took 34 days before the railroad traffic worked without disturbance afterwards (KBM 2005). The effects of the storm raised concerns, and in 2006 the Swedish Transport Administration began clear-cutting railroad corridors from the tracks and up to 20 meters away to reduce the risk of tree fells and consequent damages to the tracks, power lines and traffic.

In 2012, 3 711 km of railroads had been cleared and a remaining 1 150 km is scheduled to be completed before 2016. A problem that has been acknowledged more in the most recent years is the increasing number of ungulate-train collisions (UTC), especially with moose (MTC) and roe deer (RTC) (Seiler et al 2011). UTC result in costly delays and repairs (Pär Söderström, SJ, pers. comm.), let alone the death and injury of thousands of animals. The mean cost for materials for repairs of train for SJ after a single moose accident has been calculated to 74 000 Swedish kronor (Ann Malmborg, SJ, pers. comm.). To assess the total cost we need to add costs for work and delays, which is unknown.

After clear-cutting of railroad corridors started, accident frequencies have been increasing, which raised the question if tree-clearing was a factor behind the observed increase. Clearance of trees transforms the habitat in railroad corridors from mature forest into early successional stages with a high proportion of willow, birch and aspen. This provides attractive forage for many herbivores including moose and roe deer (Jan-Erik Lundh, Transport Administration, pers. comm.) and may consequently lead to an increased risk of train-animal collisions.

Moose are abundant throughout the mainland of Sweden. Their diet consists of a variety of leaves from bushes and trees, but some species such as rowan, aspen and willow are preferred (Cederlund and Okarma 1988, Shipley et al. 1998, Jensen 1994). Månsson et al (2007) found that rowan, willow and aspen had a 14 times higher probability for being browsed than scots pine and downy birch.

Roe deer are common in the whole country, except for the most northern and mountainous parts. Their diet consists of a wide range of herbs, grass and arable crops during the summer. Branches from trees and bushes, heather and blueberry are of importance during the winter season (Jensen 1994). Also, roe deer show a preference for willows during all seasons of the year (Bergström and Hjeljord 1987).

There are few studies on deer-train collisions, their causes and pattern. Both Gundersen and Andreassen (1998) and Modafferi (1991) found that deep snow cover during winter increases the number of accidents. More snow can be expected on the open areas around the railroads. This may make animals avoid the area around the railroads, but, they may however also be drawn to the actual railroad tracks, since the limited snow depth on the tracks will allow for easier migration to other areas, especially during years of deep snow cover.

A large population of animals is one of the most important factors explaining a high occurrence of accidents (Seiler 2004). Other factors found to increase the accident frequency is decreasing temperature (Gundersen et al 1998, Andersen et al 1991), and game behaviour that increases the movement of ungulates, including migration (Gundersen et al 1998) and daily activity patterns (Gundersen and Andreassen 1998). Seiler et al. (2011) observed that clear-cuts in vicinity to railroads correlated with increased accident frequencies for both moose and roe deer, suggesting that the same relationship might also apply to tree-clearing within railroad corridors.

However, there are also observations that suggests that tree-clearing may reduce the number of accidents with moose and roe deer, as the open space would allow ungulates to detect the train earlier, and consequently avoid an accident. On roads, Rost and Bailey (1979) found that animals were more prone to avoid roads in habitats characterised by open areas compared to wooden habitats. Found and Boyce (2011) found that wide roadsides (>40 m) produced fewer deer-car collisions, but pointed out the importance of vegetation maintenance to avoid succession of attractive forage. The wider corridors could make it easier for the ungulates to see the train, and consequently avoid an accident. In Norway, Jaren et al (1991) found vegetation removal to be efficient to reduce the number of accidents involving moose, but points out the importance of continuous vegetation removal to avoid creating attractive habitats. However, this result may not be applied to the tree-clearances performed along railroads in Sweden since both the area cleared and the methods used are different.

Rea et al (2010) found moose to prefer areas where shoots are available over the snow during winter. This indicates that it is important to continue to remove vegetation after clearance along railroads to avoid creating habitats preferred by the animals during winter.

In addition, Putman (1997) suggests that vegetation at greater distances from railways or roads may be managed to provide cover or foraging habitats for deer to decrease the number of accidents.

Vegetation removal is a practice used along roads to increase the visibility for drivers. Johansson (1987) found a decrease in accident frequency after vegetation removal along roads in Sweden where ungulate-vehicle collisions had been a problem, but the statistical significance in the study was low. Even though trains do not have the same maneuverability as cars, the cleared areas still make it easier for train-drivers to spot animals in and around the tracks, which gives them time to alert the animals by light or sound signals. According to a questionnaire with train-drivers, the signal horn of trains often (but not always) makes the animals move away from the railroads (Seiler et al 2011).

The objectives of this study are to compare ungulate collision statistics along railroads before and after clearance of trees with the frequency of accidents along railroads where trees have not been cleared. I focused on two main questions; does tree removal along railroads affect the frequency of collisions with moose and roe deer, and do collision frequencies change over time after tree removal?

In this study, I compared deer-train collision statistics before and after clearance of selected railroads. I used a before-after control-impact (BACI) approach and compared the change of accidents in tree-cleared railroad sections with uncleared controls.

Methods and data

Ungulate train collisions (UTC)

In my study, I used data on train collisions with moose (MTC) and roe deer (RTC) recorded by the Swedish Transport Administration between 2001 and 2012. The accidents were reported by train drivers or by the staff involved in the subsequent repair or management of accident sites. All reported incident reports were manually checked and verified (see also Seiler et al 2011). I defined UTC as any incident involving a witnessed wildlife fatality either as a direct collision or as found carcass. The Swedish railroad network is structured in traffic places that are connected by railroad sections of variable length (0–53.2 km; 8 km on average). UTC incidents are reported, not by location, but by occurrence along a given railroad section (80% of all data) or as in vicinity to a traffic place. In the further analysis, I therefore refer to the frequency of UTC as the number of reported incidents per 10 kilometres of railroad section and year, using only railroad sections longer than one kilometre.
I chose not to include hunting statistics in this thesis. Hunting is not corresponding with the accident frequencies, as shown in figures 3a and b. It is also not matching the spatial scale of railroad sections, since it is on a larger (county) scale.

Tree removal

Data on tree clearance of the railroads was provided by persons who have worked with tree-clearing of railroads (Stefan Olaison, Forestlog; Jörgen Brännvall, Skogs och Kraftkonsulterna i Norr AB; Peter Söderberg, Skogs och Kraftkonsulterna i Norr AB; Lars Hedman, Trafikverket; Hans Larsson, Skogstjänst Mörrum AB; Tommy Söderström, Trafikverket; Jan-Erik Lundh, Trafikverket). The clearance of trees started on selected railroad sections in 2006 and is planned to continue until 2016. I have used the year when the clearing of a section was finished as year of clearance. In some cases, however, the clearing was conducted over more than a year, as the agreements with all landowners were not finalised when the clearing started. All other non-cleared sections were used as controls.

I divided the railroad network into three zones in the study, south, central and north, to detect possible regional differences. I also differentiated between winter (November–March) and summer (April–October) accident statistics to test whether there was a difference between the seasons. Year of clearance was not included in the analyses. The controls were also divided into before and after clearing to match the data for tree cleared sections in the same way, even though there was only one accident frequency value for each of the year 2001 to 2012.

Figure 1. An example of a tree-cleared railroad, first picture after clearing was conducted, second picture one vegetation season after clearing, third picture two vegetation seasons after clearance, and the fourth picture shows the vegetation after three vegetation seasons. Photos from a STRIX-movie, provided by the Swedish Transport Administration.

Data

During 2006 to 2012, a total of 480 railroad sections (4 137 km of railroad) have been cleared from trees. The amount of newly cleared railroads differs between years and regions; most sections were cleared during 2010 in the southern region (Table 1). The cleared railroad sections were compared to 983 control sections that were not cleared during the time (controls). Table 2 shows the number of years included in the analysis and the number of sections after tree clearance.

Table 1. Distribution, length and number of cleared railroad sections and control sections in three geographical regions of Sweden (Fig. 2).

	Southern region		Central region		Northern region		Total	
Tree-cleared	Count	km	Count	km	Count	km	Count	km
2006	0	0	0	0	7	181	7	181
2007	17	186	0	0	0	0	17	186
2008	67	531	19	171	26	208	112	910
2009	24	273	0	0	0	0	24	273
2010	112	861	37	272	38	341	187	1474
2011	16	173	86	631	7	71	109	874
2012	19	185	5	55	0	0	24	239
Total	255	2209	147	1128	78	800	480	4137
Controls	498	2960	306	2846	180	2141	983	8889

Table 2. Number of railroad sections, and number of years since they were tree-cleared in the analyses. Year 0 is the year when the clearing was performed.

No. of years	Southern region	Central region	Northern region	Total
after clearance	Count	Count	Count	Count
0	255	147	78	480
1	236	142	78	456
2	220	56	71	347
3	108	19	33	160
4	84	19	33	136
5	17	0	7	24
6	0	0	7	7

Statistical analyses

I employed t-tests and ANOVA analyses (using JMP 10; SAS Institute Inc., 2012) to compare mean UTC frequencies between railroad sections before and after clearance and between cleared sections and control sections. Since UTC frequencies increased overall during the study period, I used the average increase in UTC on the control sections to estimate the expected UTC along the cleared railroad sections. Two-sample t-tests were used to evaluate the differences in accident frequencies over time. Accident data is usually Poisson distributed and highly overdispersed around a mean value. To avoid effects of overdispersion in the analysis, we calculated the mean UTC over all railroad sections with reported UTC during the study period of 2001–2012 for a given year and category, instead of using all individual railroad sections (N=1463). To reduce the risk of making a type 2 error, power tests was performed. In repeated statistical tests on the same dataset, the sequential Bonferroni correction, described in Holm (1979), was used to adjust the significance level and reduce the risk of type 1 error.

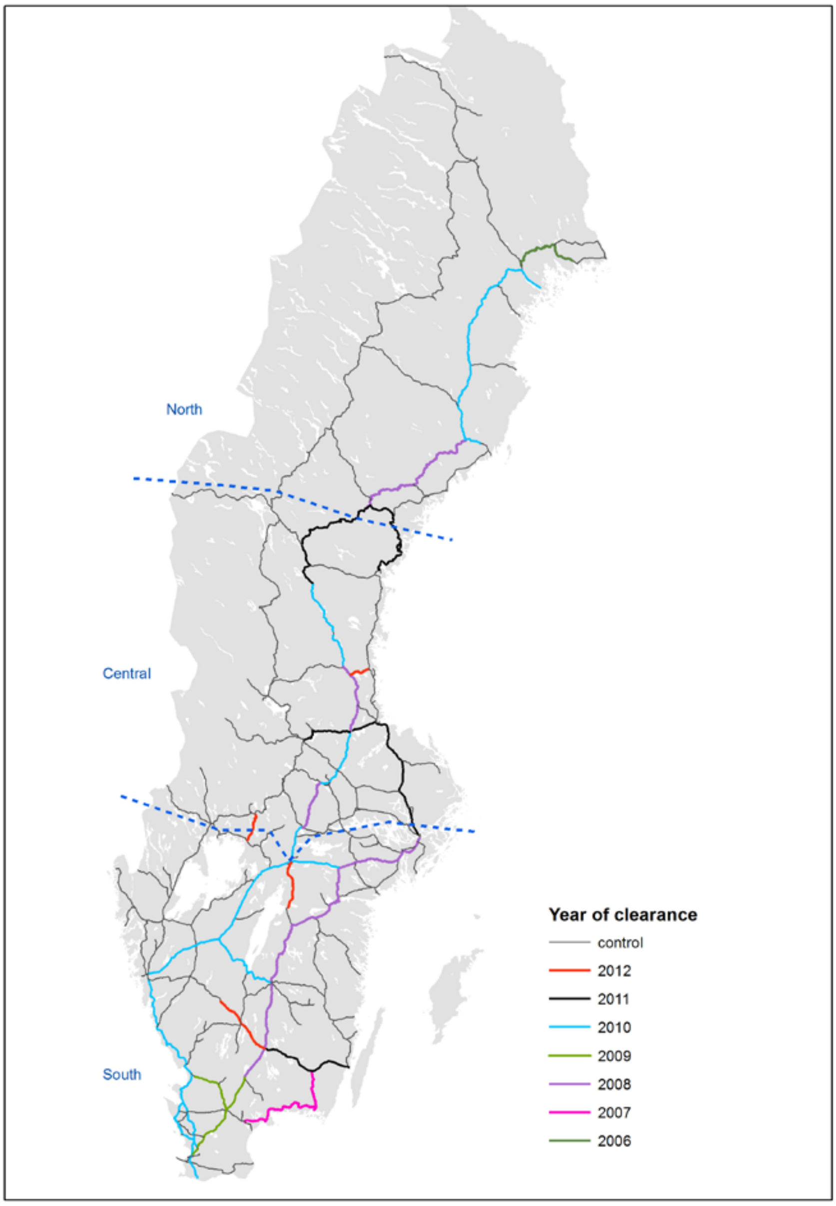


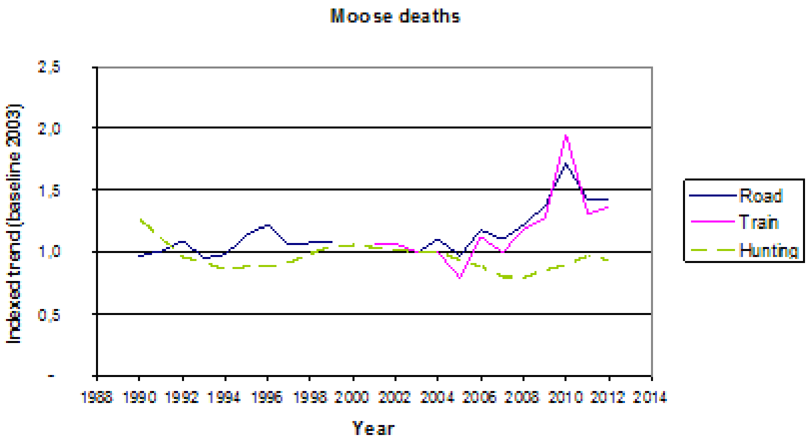
Figure 2. Map illustrating what year each railroad sections were cleared (in different colours) and the uncleared controls, in Sweden 2006–2012.

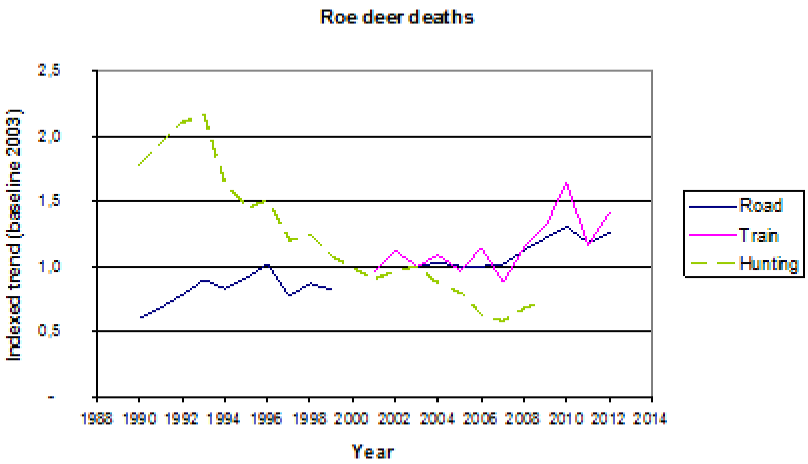
Results

Differences in ungulate collision frequencies (UTC) over time

During the study period from 2006 to 2012, train accidents with both moose and roe deer have become more frequent, with maximum values during the snow-rich winter of 2009/10 (Figs. 3a and b). There has been a significant increase in number of moose accidents ($N = 154$, $R^2 = 0.11$, $F = 18.37$, $p < 0.0001$), and roe deer accidents ($N = 154$, $R^2 = 0.04$, $F = 5.82$, $p < 0.02$), from 2001 to 2012. Figure 3 shows the number of moose and roe deer killed during hunting and also the reported collisions on both roads and railroads.

The tree-cleared sections has been found to have a higher traffic load then the controls (98.3 trains per day vs. 45.2 trains per day; two-tailed t-test, $t = 8.65$; $N = 456$ vs. 921, $p < 0.0001$). There has been an increase of UTC on both roads and railroads during the later years. However, this increase is not resembled in the hunting statistics for these species (Figs. 3a and b).





Figures 3a and b. The number of reported moose and roe deer collisions on roads, collisions on railroads and deaths by hunting. Data sources: Road: Swedish Road Administration (before year 2000), National council for wildlife-vehicle accidents (after year 2003), Railroad: Swedish Transport Administration; Hunting: Swedish Association of hunting and game management.

UTC along control versus cleared railroads

On average, moose collision frequencies (MTC) along tree-cleared railroad sections increased by 25% (±5.35% C.I. 95%) from 0.64 (per 10 km and year) before clearance to 0.80 after clearance. This was, in fact, somewhat smaller but not significantly different from the increase that occurred on uncleared control railroads (39% ±1.55% C.I. 95%; from 0.44 incidents per 10 km and year before clearance to 0.61 after clearance; Fig. 4, Table 3).
The analysis of variance (Table 3) revealed significant effects of time (before versus after clearance) and category (control versus tree-cleared railroads), with data from before tree clearance and from control railroads, which contained generally fewer accidents than data from tree-cleared railroads and later years. However, there was no effect of the interaction between time and category (Table 3). A power analysis of the interaction factor produced a power value of 0.052, which is very close to α (0.05).

Thus, we could not reject the null-hypothesis and must defer that tree clearance had no significant effect on MTC.

A similar result was obtained for roe deer. On average, roe deer collision frequencies (RTC) along tree-cleared railroad sections increased by 25% (±7.61% C.I. 95%) from 0.94 (per 10 km and year) before clearance to 1.17 after clearance. This was not significantly different from the increase that occurred on uncleared control railroads (24% ±1.61% C.I. 95%; from 0.77 incidents per 10 km and year before clearance to 0.95 after clearance; Fig. 5, Table 4). The analysis of variance (Table 4) revealed significant effects of time (before versus after clearance) and category (control versus tree-cleared railroads), with data from before tree clearance and from control railroads, which contained generally fewer accidents than data from tree-cleared railroads and later years. But, there was no effect of the interaction between time and category. A power analysis of the interaction factor produced a power value of 0.058, which is very close to α (0.05).
This implies that we cannot reject the null-hypothesis and must defer that tree clearance had no significant effect on RTC.

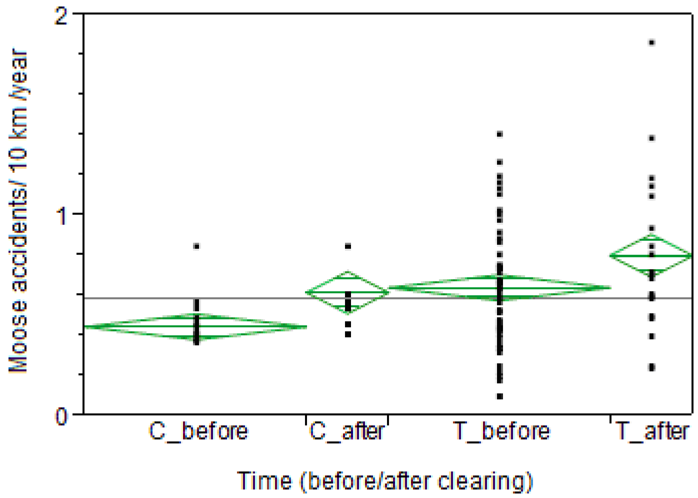


Figure 4. The number of accidents/km before and after clearing in both the control (C_) and the tree-cleared railroad sections (T_). The figure shows single values, mean value, group mean values, and 95% confidence intervals.

Table 3. Analysis of variation in moose-train collision frequencies before and after tree clearance (TIME) and between cleared and control sections (CATEGORY) during 2001 – 2012. ERROR denotes the residual variation. Differences over time and between categories significantly explain the observed variation, whereas tree-clearance, expressed as the interaction between the two factors, has not effect on collision.

Source of variation	DF	SS	MS	F Ratio	p-value
FACTORS	3	2.27	0.76	12.744	<0.0001
Error	150	8.91	0.06		
C. Total	153	11.18			

Factor	DF	SS	F Ratio	p-value
TIME (before/after)	1	0.84	14.10	0.0002
CATEGORY (control/tree cleared)	1	1.10	18.58	<0.0001
TIME*CATEGORY	1	0.00	0.02	0.89

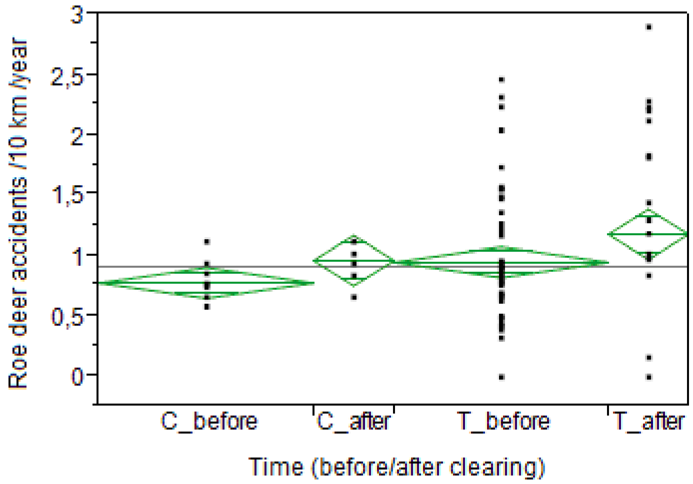


Figure 5. The number of accidents/km before and after clearing in both the control (C_) and the tree-cleared railroad sections (T_). The figure shows single values, mean value, group mean values, and 95% confidence intervals.

Table 4. Analysis of variation in roe deer-train collision frequencies before and after tree clearance (TIME) and between cleared and control sections (CATEGORY) during 2001 – 2012. ERROR denotes the residual variation. Differences over time and between categories significantly explain the observed variation, whereas tree-clearance, expressed as the interaction between the two factors, has not effect on collision.

Source of variation	DF	SS	MS	F Ratio	p-value
FACTORS	3	2.64	0.88	3.802	0.0116
Error	150	34.66	0.23		
C. Total	153	37.30			

Factor	DF	SS	F Ratio	p-value
TIME (before/after)	1	1.32	5.73	0.0179
CATEGORY (control/tree cleared)	1	1.15	4.97	0.0273
TIME*CATEGORY	1	0.02	0.07	0.7929

Seasonal and regional pattern

Train collisions with both moose and roe deer were reported significantly more often during winter (November–March) than during summer (mean MTC; summer 0.27, winter 0.33, two-tailed t-test, $t = 2.41$; $N = 168$, $p = 0.0163$; RTC; mean summer 0.41, mean winter 0.51, $t = 3.29$; $N = 168$, $p = 0.0011$), with an unusually high number of winter collisions in 2010. However, the summer in 2010 was normal, compared to the other years. There were no significant differences found between cleared and control railroads when comparing the accident frequencies for summer and winter separately (Table 5a and b).
The same pattern emerged when I divided accident statistics into regions (Table 5a and b), yet with a few deviances: during summer RTC were significantly higher after tree-clearing in the southern region, while MTC were significantly higher in the central region. In tables 5a and b; I tested 24 hypotheses (for each combination of region, seasons and species), which increases the probability of getting a rare result (type 1 error). A Bonferroni correction was performed to deal with this issue (Holm 1979). All p-values in table 5 were compared to the adjusted significance level ($K = 24$, $\alpha/(1/K) = 0.00208$). The p-values of the largest difference (MTC in central Sweden during summer and RTC in southern Sweden during summer; both $p = 0.002$), were very close to the adjusted significance level.

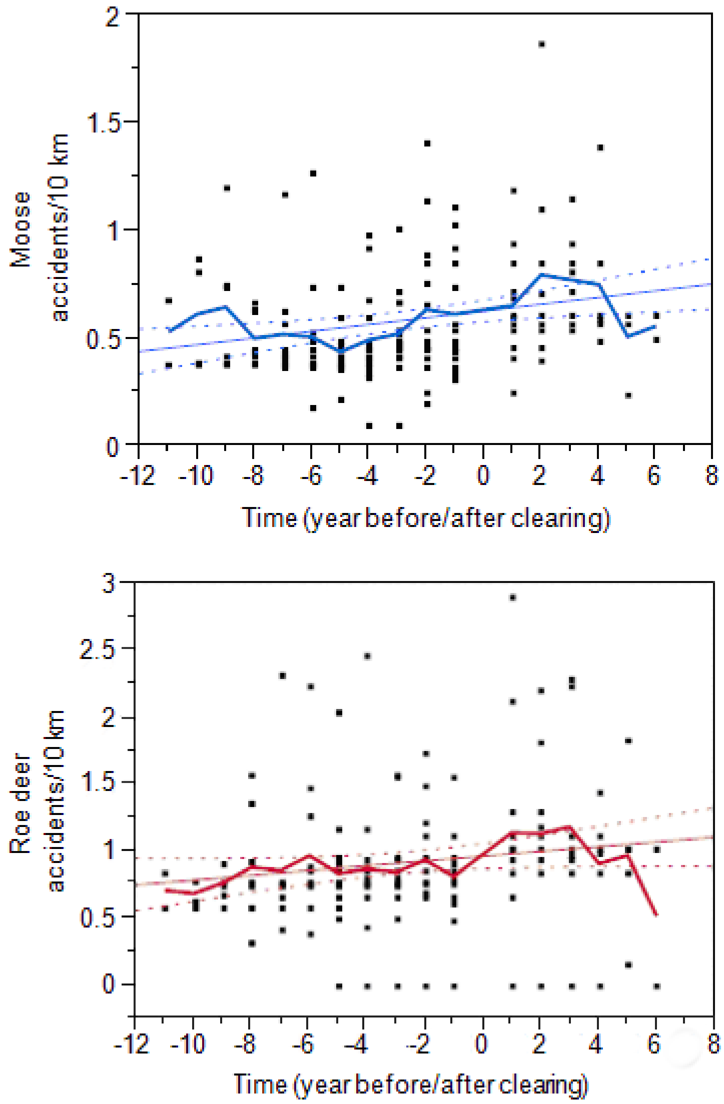
Table 5a and b. The result from a t-test where expected and observed accident frequencies are compared for moose and roe deer in three Swedish region. The table shows the t-value and p-value, and the percental change between observed and expected accident frequencies. Data based on 12 years of reported ungulate-train collisions.

Moose		Winter			Summer			Total		
	N (before/after)	%	p-value	t-value	%	p-value	t-value	%	p-value	t-value
North	**31 / 13**	6	0.737	-0.339	-16	0.533	0.629	-8	0.667	0.433
Central	**37 / 7**	-1	0.982	0.023	131	0.002	-3.401	46	0.213	-1.264
South	**51 / 15**	-24	0.353	0.936	13	0.492	-0.691	-8	0.632	0.482
Total	**56 / 21**	-14	0.362	0.916	-2	0.889	0.141	-10	0.400	0.846

Roe deer		Winter			Summer			Total		
	N (before/after)	%	p-value	t-value	%	p-value	t-value	%	p-value	t-value
North	**31 / 13**	-34	0.465	0.737	-54	0.441	0.778	-39	0.339	0.967
Central	**37 / 7**	11	0.716	-0.366	-29	0.360	0.926	-3	0.896	0.132
South	**51 / 15**	10	0.478	-0.713	44	0.002	-3.289	25	0.022	-2.344
Total	**56 / 21**	-11	0.503	0.673	16	0.438	-0.780	0	0.977	-0.029

Differences over time

Overall, UTC increased significantly over time, both with reference to the actual years 2001 – 2012 (Figs. 3a and b) and in relation to the year when clearing was conducted (Figs. 6a and b). While mean values were slightly increased 2–3 years after tree-clearing, the variation was too large to allow for any significance. Also, mean values tended to decrease again after the third year after clearing. With increasing time after clearance, however, sample sizes became too limited to reveal any long term effects.



Figures 6a and b. The number of train collisions with moose, resp. roe deer per 10 km and year relative to the year of clearance (year = 0). Although the increase is significant (moose: MTC = 0.6282+ 0.0157* YEAR; N=153;R^2 = 0.057; F=9.123; p=0,003; roe deer: RTC= 0.9587+0.0177*YEAR; N=153; R^2 = 0.0217; F=3.3715; p=0.0683) it is not an effect of tree-clearing since cleared and uncleared railroads showed the same trend. Data was provided by the Swedish Transport administration.

Discussion

The study suggests that tree clearance along railroads does not affect the risk for train collisions with ungulates. Even though ungulate-train collisions (UTC) increased throughout the study period and were more frequent during the years after tree clearance was conducted (Figs. 6a and b), this increase was also observed for the control railroads. The absence of effect, compared to the uncleared control railroads, was congruent among regions and seasons, with some exceptions: roe deer-train collisions (RTC) were found to increase in southern Sweden during the summer months, and moose-train collisions (MTC) also increased in central Sweden during the summer (but the increase was barely significant after the Bonferroni correction was applied).

The observed increase in UTC since 2001 is hence not a result of an increased number of cleared railroads, but is rather due to other factors. In fact, the continuous increase in accident numbers since 2001 could also be an effect of increasing traffic intensity on the railroads. During the study period, rail traffic loads have increased: human rail travel increased from 8 732 million person kilometres in 2001 to 11 792 million person kilometres in 2012, while freight transport increased from 19 547 millions of ton kilometres to 22 043 millions of ton kilometres (Rail traffic 2012, Trafa). Rail traffic loads differ between years, but on average, they reflect the increase in human rail traffic of 2.8% per year over the time period 2001–2012. The corresponding mean increase in freight transport was 1.1% per year (Rail traffic 2012, Trafa). This increase in rail traffic loads was largely possible due to a more efficient use of trains (more wagons) and only to a lesser part an effect of more trains in traffic. Detailed statistics were not available though.

For comparison, on roads during 2003 – 2012, the average annual increase in car traffic was 0.44% (Trafikarbetets utveckling för svenskregistrerade fordon 1999–2012, Trafa). Wildlife accident frequencies along roads however, increased with 4% per year in moose and 2.6% per year in roe deer over the same period (National Council for Wildlife Accidents, 2014). The increase in accident frequencies was hence higher than the corresponding increase in car traffic.

I observed a mean increase in accidents on railroads by 4.27% per year for moose, while the corresponding increase for roe deer was 3.07% per year for the time period 2001–2012 (Figs. 6a and b). Hence, as for roads, deer accident frequencies along railroads increased at a higher rate than rail traffic. This suggests that the observed increase in rail traffic can not be a major factor behind the observed increase in accident frequencies along railroads.

Another possibility is that the increase in UTC over time is an effect of growing deer populations, as observed before for roads (Seiler 2004). However, some other studies (Case 1978; Groot Bruinderink and Hazebroek 1996) have not found a consistent correlation between population size and number of animal-vehicle collisions. One method to assess the total animal population is to rely on game bag statistics (Jonas Kindberg, Swedish Association of hunting and game management, pers. comm.). Game bag statistics in Sweden suggest that the population of roe deer has had a major decrease during the observed time period, while the population of moose decreased only slightly (Figs. 3a and b). These decreasing game bags are in contrast to the increase in accident frequencies along railroads.

There are some other characteristics that differ between cleared and uncleared railroads in this study that should also be noted. One is that clearing along railroads was not carried out randomly. The railroads selected for clearing were those considered as strategically important (www.Trafikverket.se). It is further likely that the increase in railroad traffic mainly occurred along these cleared railroad sections, as they are carrying most of the traffic. Since the expected value for accident frequency after clearing on tree-cleared sections was calculated from the change in accident frequency on the control railroads (that are trafficked less), the expected accident frequency on cleared sections will be underestimated. If this applies, tree-clearing may rather lead to a reduction in accident risks and thus compensate for the increase caused by higher traffic flows.

This study did not consider potential differences between one-way and two-way railroads, but since the cleared railroad sections carried more traffic than the controls we can assume that two-way railroads were more common in this category. The two-way railroad, being wider, might result in a more pronounced barrier effect for the animals than a one-way railroad. This could possibly make the animals avoid the two-way railroad to a greater extent than the one-way railroad. Higher traffic volumes do not necessarily lead to higher accident frequencies, there is not a linear correlation between accident frequency and traffic volume. Von Celsing (2008) studied the correlation between the numbers of trains and UTC and found that most accidents occurred on railroads with intermediate traffic intensity. Seiler et al (2011) suggest that high traffic intensity may scare animals away more effectively from the railroad. High traffic intensity on the cleared railroad sections in my study would hence cause a greater barrier effect then on the control railroads, which could lower the number of UTC.

There are also different numbers and lengths of tree cleared railroad sections in the different regions. The highest number of cleared railroad sections are in southern Sweden, where also the proportion cleared sections/controls was highest. There is an interaction between year and region and UTC. The clearings were performed in different years in the different regions (Table 1), and the occurrence of moose and roe deer also vary between regions. Since there were only a few cleared railroad sections during year 2006, the accident frequencies year 6 after clearance (Figs. 6a and b) are based on a less data then the following years, when more railroad sections were cleared. The clearance during 2006 also only took place in the north region, which could explain the decrease in roe deer accident frequency six years after clearance, since roe deer are more common in southern and central Sweden.

The only observed effect of clearance on accidents with moose in central Sweden and with roe deer in southern Sweden was during the summer season, even though there is a higher accident frequency during winter. This suggests an effect of food availability: On roads, collisions with ungulates generally occur where roads cross favourable foraging habitat, and are generally highest on roads with a high traffic load, where there is low visibility for drivers or where roads intersect through levelled terrain or drainage corridors (Gunson et al 2011). Managed roadsides hold a relatively constant amount and quality of browse, since the roadsides are brush-cut to increase lines of sight and visibility for the driver. This practice increases the growth of early successional vegetation, which is attractive to moose (Rea 2003). On the other hand, a wide vegetation free zone could also decrease the number of accidents (Found and Boyce 2011). Accident frequencies for deer have been found to be higher where roadside vegetation is denser and more diverse, and collisions along roads decrease when the vegetation free zone is wider (Found and Boyce 2011). If vegetation is part of the explanation, differences should be expected mainly during summer, when the early successional species are attractive for ungulates. The observed differences in accident frequencies between controls and cleared sections in this study are in fact during summer, but the increases were barely significant after the Bonferroni correction was applied.

During the especially snow-rich winter in 2010, a peak of accident numbers was observed on both roads and railroads (Figs. 3a and b). This is supported by other studies (Gundersen and Andreassen 1998) and suggests that ungulates use railroads, and roads, more in snow-rich years because the areas are cleared of snow. The differences between the years made it necessary to use a BACI approach. When comparing accident frequencies on cleared railroads, with railroads that had not been cleared, these kinds of effects are then minimised.

Conclusions

According to my study, tree clearance did not change the risk for train collisions with moose and roe deer when compared to non-cleared controls and to before clearance. The observed overall increase in accident frequencies is most likely due to other factors such as increased traffic volume or snow depth.

Collisions with ungulates, especially with moose, are very expensive, and the newer trains (X2, X40 and X55) stand for a majority of the cost (155 000 kr/ accident for materials) compared to the older trains ((LoP, Motor and NT, 20 000/ accident for materials) Ann Malmborg, SJ).

As such modern and more sensitive train types are becoming more common, costs for repairs will probably increase even more in the future. To mitigate future accidents and the expected increase in accidents makes it fundamentally important to study also other potentially explanatory factors in more detail.

Acknowledgments

To my supervisor Andreas Seiler for all the support during the study. To the Swedish Transport Administration for supporting the study, Anders Goude and Sara McGowan for valuable advice, and Stefan Olaison, Jörgen Brännvall, Peter Söderberg, Lars Hedman, Hans Larsson, Tommy Söderström and Jan-Erik Lundh for information on when clearings were conducted. Without you, this study would not have been possible. Thank you!

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