



Sveriges lantbruksuniversitet  
Swedish University of Agricultural Sciences

Department of Economics

WORKING PAPER 03/2017

## **Costs of animal-vehicle collisions with ungulates in Sweden**

Ing-Marie Gren<sup>1</sup>, Annika Jägerbrand<sup>2</sup>

ECONOMICS

<sup>1</sup>Department of Economics, Swedish University of Agricultural Sciences, Box 7013, 750 07, Uppsala, Sweden

<sup>2</sup> Calluna, Hästholmsvägen 28, 131 30 Nacka, Sweden

---

Sveriges lantbruksuniversitet, Institutionen för ekonomi  
Swedish University of Agricultural Sciences,  
Department of Economics, Uppsala  
ISSN 1401-4068  
ISRN SLU-EKON-WPS-1305-SE

Working Paper Series 2017:03

Corresponding author:  
Ing-Marie.Gren@slu.se

---

## **Costs of traffic accidents with ungulates in Sweden**

*Abstract* Animal-vehicle collisions (AVCs) with ungulates pose a serious problem in many countries, and there is a need for predicting accidents and costs at a large scale for an efficient mitigation of the accidents. Based on the assumption that AVCs are determined by traffic volume and ungulate population sizes, this study provides a relatively simple method for calculating and predicting costs of current and future traffic accidents with moose, roe deer, and wild boar in Sweden. A logistic population model is assumed for all ungulates, and econometric methods are used for predicting vehicle accidents with panel data on traffic accidents, traffic load, bags, hunting licenses, and landscape characteristics for each county and year during 2003-2015. The calculated total discounted cost of AVCs over a period of 15 years is relatively stable around 1300 million SEK per year in present value (which corresponds to 0.03% of gross domestic product in 2015), but the allocation of costs among ungulates differs. Costs of AVCs with moose account for the largest share of the cost (44%), but collisions with wild boar show the most rapid increase over a 15 year period because of the estimated relatively high intrinsic growth rate and the recent establishment of this animal in several counties. The predicted costs are, however, sensitive to the assumption of future hunting pressure and traffic volume.

Key words: costs, traffic accidents, moose, roe deer, wild boar, econometrics, Sweden

JEL codes; Q29, Q57

## 1. Introduction

Wildlife vehicle collisions cause serious animal and human injuries and property damage throughout the world which increase with traffic and transport volume. In Sweden, the number of reported vehicle accidents with roe deer, wild boar, and moose has increased with 36% from approximately 33000 in 2003 to 45000 in 2015 (NVR, 2017). This is in contrast with the development of all traffic accidents with some personal injury which have decreased from 18365 in 2003 to 14672 in 2015 (Trafikanalys,2017). Similar to other traffic accidents, vehicle accidents with wildlife give rise to costs in terms of human injuries and fatalities, property damage, towing, accident attendance and investigation. Specific for accidents with wildlife are the cost of hunters' search for killed animal, lost animal (which can be threatened species), and disposal of animal carcass. A relatively early study showed that the property damage costs of deer vehicle collisions in USA can amount to approximately 16,000 million SEK/year (Conover et al., 1995). A more recent study indicated that cost of traffic accidents with deer, elk and moose in USA, which includes property damage, personal injury, and lost animal, can amount to approximately 75,500 million SEK/year (Huijser et al., 2008). For Sweden, property damage costs of traffic accidents with wild boar have been estimated which amounted to 10 million SEK/year (Hägström-Svensson, 2014), and accidents with roe deer to approximately 1,000 million (Jägerbrand, 2014).

Despite the national and international concern for wild life traffic accidents, and the scientific community's long term experience from ecological modelling of impacts of wild life on traffic accidents (see Gunson et al., 2011 for a review), there is, to the best of our knowledge, no study estimating and predicting costs of traffic accidents with wild boar, roe deer and moose in Sweden. In principle, it would be straightforward to calculate such costs by simply multiplying the number of traffic accidents with the ungulates with the cost per accident. However, this would not allow us to predict future cost from, e.g. expected increases in the population size of the ungulate species or in traffic load. Furthermore, such predictions require knowledge about the interdependency between population development and pressures on population such as traffic load and hunting. An increase in any of these pressures will reduce future population and hence traffic accidents when they depend on the size of the wild life populations. The dynamics of these populations are, in

turn, determined by, not only pressures, but also landscape characteristics. The purpose of this study is to calculate and predict dynamic and spatial allocation of costs from traffic accidents by estimating population sizes of each of the three ungulates, roe deer, moose, and wild boar. To this end we develop and estimate econometric regression models that account for hunting pressure and differences in land-scape characteristics among regions with panel data on different counties and years between 2003-2015.

Vehicle accidents constitute a part of the external costs of traffic, the literature of which is large with a relatively long tradition (e.g. Jansson, 1994), which rests on the literature on the valuation of life and injuries (e.g. Mishan, 1971). There are only a few studies on the estimation of costs of AVCs (Witmer and DeCalesta, 1991; Conover et al., 1995; Bisonette et al., 2008; Huijser et al., 2008; Häggmark-Svensson, 2014). All studies calculate costs in terms of repair costs, and all but Häggmark-Svensson are applied to AVCs with deer in USA. Bisonette et al. (2008) and Huijser et al. (2008) also include cost of human injuries and fatalities, and Huijser et al. (2008) calculate costs for large ungulates. Except for Häggmark-Svensson et al. (2014), who calculate costs of accidents with wild boar in Sweden, none of the studies predict costs of future traffic accidents. This would require models of the determination of accidents. Such models are used and developed by a related literature on costs and benefits of measures curbing traffic accidents with wildlife, such as fences, road tunnels, and warning signs (e.g. Schwabe et al., 2002; Seiler, 2004; Glista et al., 2009; Hussain et al., 2007; Huijser et al., 2009; Found and Boyce, 2011; Gagnon et al., 2015; Rytwinski et al., 2016). A common approach has been to derive the impact of mitigation measures on accidents by statistical analysis with AVC as the response variable and traffic load and landscape characteristics as explanatory variables.

However, most of these cost and benefit calculations of mitigation measures do not include wildlife population dynamics, which is a prerequisite when aiming to predict future costs of AVCs. There can be an interdependency between AVCs and population size where current increases in traffic volume and accidents decrease future populations and thereby associated accidents (see e.g. Fahrig et al., 1995). Population dynamics and size depend also on other pressures, such as hunting. To the best of our knowledge, there are only two studies predicting vehicle accidents with wildlife which account for the linkages between current and future accidents and other pressures such as

hunting (Schwabe et al., 2002; Gren et al., 2016). Schwabe et al. (2002) do this in a two-step approach where the first step is to estimate the explanatory power of different variables affecting traffic accidents (traffic and population density, mitigation strategies, and local landscape conditions). The next step is to use these results for parameterizing a function of the population dynamics, which is assumed to be logistic. In an application to deer accidents in Ohio, USA, they showed that benefits from accident mitigation measures, such as fencing of roads, occur by decreases in traffic accidents and increases in deer bags. Gren et al. (2016) used a slightly different approach when calculating and predicting costs of accidents with wild boar in Sweden. Similar to Schwabe et al. (2002) they assumed a logistic population growth function which accounts for the pressure from both traffic volume and hunting and landscape characteristics. Using econometric tools, they estimated a value of the traffic pressure coefficient, i.e. the impact on population growth from a unit increase in the traffic volume. Equipped with this numerical population growth function for wild boar in Sweden, they simulated effects of changes in traffic volume on future accidents when accounting for different hunting pressures.

In this paper, we will use the same approach for predicting traffic accidents for the three ungulates as Gren et al. (2016). Since population sizes are not known, we use changes in catch per unit effort as a proxy for changes in population sizes. This is a commonly applied method in bioeconomic modelling, in particular for estimating fish population (e.g. Schaefer, 1954; Clark, 1990). In our study, there are two effort variables, traffic volume and hunting, and any of these can be used as a proxy for the latent population variable. A problem in our case with using hunting statistics is the lack of appropriate effort variable, such as number of hunters and time spent on hunting. Instead, data on number of issued hunting licenses are available, but such a variable gives no information on actual hunting activity. An advantage with traffic volume as an effort variable is that it reflects actual driving activity. We will use both these approaches in this study, and account for eventual impacts of landscape characteristics on growth of ungulate populations.

In our view, the main contribution of this study is the calculation and prediction of costs of traffic accidents in Sweden when accounting for the dynamic interdependency in traffic accidents and bags. This has been made for wild boar (Hägmark-Svensson, 2014), but not for deer and moose.

The paper is organized as follows. We start with a preliminary analysis of cost of accidents with moose, deer, and wild boar in Sweden. Next, we present the theoretical framework for estimating ungulate populations based on traffic and hunting data. Section 4 presents data retrieval and results from the statistical analyses. Calculated and predicted costs of traffic accidents from the ungulates are presented in Section 5. The paper ends with a summary and conclusions.

## 2. Preliminary analysis

The total number of accidents with moose, roe deer, and wild boar in Sweden has increased from approximately 33 000 to 46 000 during the period 2003 to 2015 (NVR, 2017). These three ungulates account for 97% of the total number of vehicle accidents with wild life. Red deer, fallow deer, and carnivores account for the remaining 3%. Both the total number of accidents with the three ungulates and the increase over time differs among the species (Figure 1).

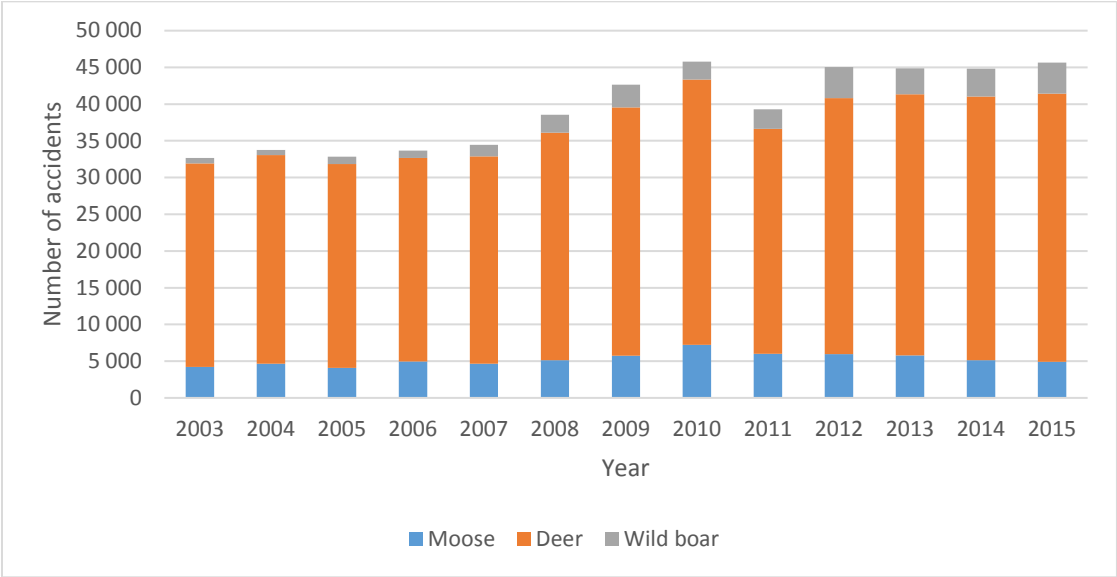


Figure 1: Number of vehicle accidents with moose, roe deer and wild boar in Sweden during the period 2003-2015 (NVR 2017).

The share of accidents with roe deer, which amounts to approximately 80%, has been relatively stable over the period, while that of wild boar has increased from 2% to 9%. One reason for the

increase in total number of accidents can be increase in traffic volume, which increased from approximately 53 000  $10^6$  km (driven km) to 57000  $10^6$  km during the same period (RUS, 2016). Accidents in relation to traffic volume has thus increased from 0.61/ $10^6$  km to 0.80/ $10^6$  km indicating the contribution of other factors affecting the number of accidents (Table A1).

The main costs of an accident with any ungulate are associated with personal injuries and/or property damage. In addition, there are costs associated with carcass removal, search for wounded or killed animal, and the value of lost animal. Unlike human injuries and property damages, there are no standardized values on these additional costs in Sweden (Bångman, 2016), and they are therefore excluded. Huijser et al. (2009) have shown that these cost account for a relatively small part of the total cost, less than 5%, for deer and moose in USA. If the relative shares are similar for Sweden our exclusion of these costs should thus not result in a significant underestimation of the costs

The personal injuries are divided into three categories; fatality, severe and mild injury (Bångman, 2016). As mentioned in the introduction, the assessment of these costs in monetary terms implies the valuation of a statistical life, health and wellbeing, on which there is a large body of literature with a long tradition in economics (see e.g. Miller 2000 for a meta-analysis). In this study, we use the costs recommended by the Swedish Transport Administration, according to which the calculated statistical cost of fatality is 25400 thousand SEK, serious injury 4700 thousand SEK, mild injury 230 thousand SEK, and property damage 15 thousand SEK (Bångman, 2016). Property damage is regarded to be larger for wild boar because of their compactness and heaviness and the average payment by insurance companies amounts to 23 thousand SEK (Gren et al., 2016). These costs assigned to different types of accidents are in the same order of magnitude as the estimates used by e.g. Huijser et al. (2008) for calculating cost of AVC with large ungulates in USA,

Expected cost for each ungulate depends on the probabilities of type of accidents. The probability of type of accident in Sweden is evaluated at different speed limits (Johansson, 2016), where a high speed implies larger probability for fatality and severe injury. In this study, we choose the estimates made for the speed of 90 km/h, since this is the average base speed limits on major roads

in Sweden (Trafiks akerhet, 2017). The calculated expected cost per ungulate is then calculated as the probability of each type of accident times the damage cost (Table 1).

Table 1: Allocation of different types of damages from 100 traffic accidents with moose, deer or wild boar in Sweden at an average speed of 90 km/hour, cost/accident and calculated expected cost/accident

	Personal injury % of total accidents <sup>a</sup> ;			Property damage % of total <sup>a</sup>	Estimated expected cost/accident, thousand SEK
	Fatality	Serious	Mild		
<b>Moose</b>	0.14	0.77	10.11	89	108
<b>Deer</b>	0.001	0.03	0.96	99	19
<b>Wild boar</b>				100	23
<b>Cost/accident, thousand SEK<sup>b</sup></b>	25400	4700	230	23	

<sup>a</sup>Johansson (2016); <sup>b</sup>B angman (2016)

Given the expected costs presented in Table 1, the total calculated costs of traffic accidents with the three ungulate species amount to 1372 million SEK in 2015, which corresponds to 0.03% of total GDP in the same year. Traffic accidents with deer accounts for the major part of the cost, see Figure 2.

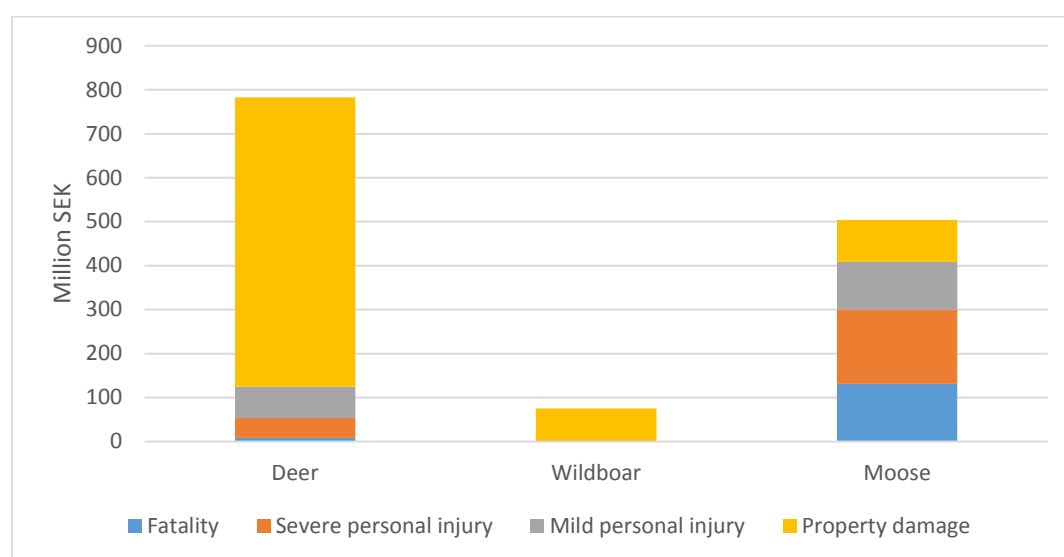


Figure 2: Allocation of calculated total cost of traffic accidents between ungulates and type of accidents in Sweden in 2015.



Vehicle accidents with deer and wild boar give rise to mainly costs of property damages, while cost of accidents with moose are more equally divided between the type of accidents. Because of the size of accidents with deer, costs of property damages accounts for 60% of total costs. This share of property damage is relatively high compared with results of cost estimates for USA, where the property damage accounts for 40% of the average collision cost with deer, elk and moose when including human injury and property damage cost (Huijser et al., 2008). The main reason for this difference is the higher probabilities of human injuries and fatalities in Huijser et al. (2008) compared with our study.

Sweden is an elongated country with different sizes of the 21 counties (Figure A1). Moose and deer are found in all counties but wild boar is not established in the most northern counties because of the cold climate, which the yearlings cannot survive (Gren et al., 2016). Given the same expected cost per accidents for the different ungulates, costs of traffic accidents depend only on the number of accidents with different ungulates (Figure A2). The calculated allocation of total costs of traffic accidents with the ungulates is unevenly distributed among counties (Figure 3),

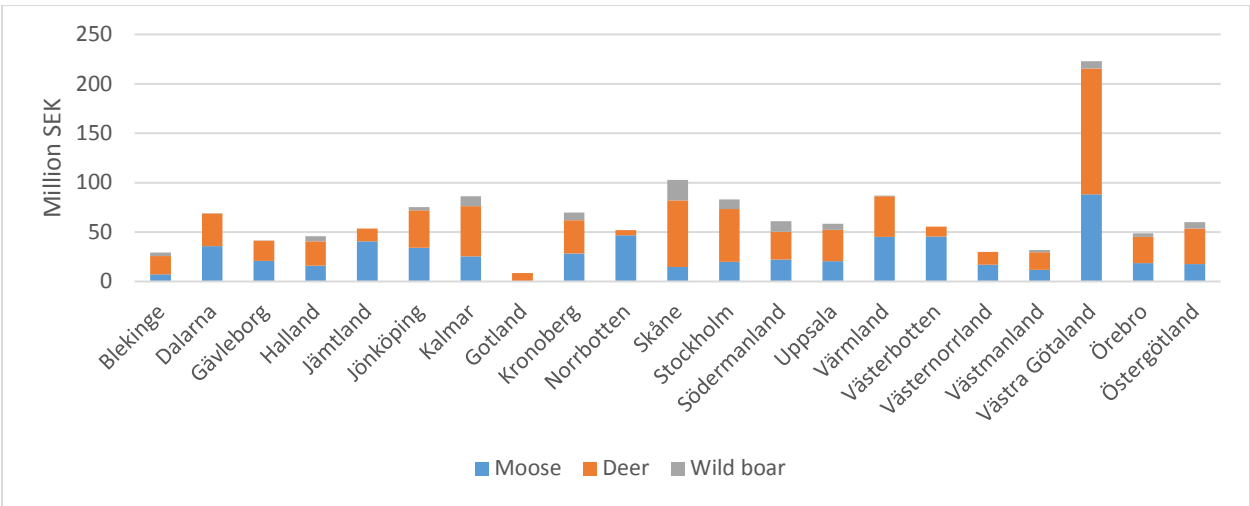


Figure 3: Allocation of costs of traffic accidents with ungulates among counties and species in 2015.

The calculated cost in Västra Götaland accounts for 16% of total costs, which is more than twice as large as for the county with the second highest cost (Skåne). The expected costs of both deer and moose are highest in this county because of the relatively large amount of accidents (Figure A2)

### 3. Derivation of econometric model for estimating traffic accidents with ungulates

As shown in the preceding section, the expected cost of traffic accidents depends on the type and probability of accidents, which differ between ungulates. In this study we make a simplification by not considering type of accidents, but instead only total number of accidents. We account for differences in traffic accidents among the included ungulates. A crucial assumption is that, for each ungulate,  $U$  where  $U = O, D, P$  ( $O$ =moose,  $D$ =roe deer,  $P$ =wild boar), the number of accidents at a specific point in time,  $A_t^U$ , depends on traffic effort e.g. traffic load,  $E_t^A$ , and ungulate population,  $X_t^U$ . However, for given levels of  $E_t^A$  and  $X_t^U$  the number of accidents are reduced if there are mitigation measures. In this study we include fences along roads,  $F_t$ , along the roads since this a common method in Sweden, We model the effect of fences as a linear decrease in the level of effort,  $\theta^U F_t$ , where  $\theta^U$  shows the marginal counteraction of  $F_t$  on  $E_t^A$ . The relation between  $A_t^U$  and  $X_t^U$  is then written as:

$$A_t^U = \beta^U (E_t^A - \theta^U F_t) X_t^U \quad (1)$$

where  $\beta^U$  is the ‘catchability’ coefficient which measures the change in traffic accidents from a marginal increase in either  $E_t^A$  or  $X_t^U$ , which is assumed to be constant over time. For a given  $\beta^U$ , traffic accidents can increase even if  $E_t^A$  decreases if there is a sufficiently large increase in  $X_t^U$ .

It is assumed that population growth is independent among the ungulates and depend on landscape characteristics,  $M_t^j$  where  $j=1, \dots, n$  characteristics, which provide suitable habitats for the ungulates. Wild boar is omnivore and there is no competition of food with the other ungulates. Moose and deer feed on the same trees such as birch, pine and aspen, but usually at different tree heights since moose is much larger than deer. The population of an ungulate in any period  $t+1$  is then assumed to depend on population in prior period, growth during the period, and pressures in terms of accidents  $A_t^U$  and animals killed by hunting,  $B_t^U$  which is written as:

$$X_{t+1}^U = X_t^U + G^U(X_t^U, M_t^1, \dots, M_t^n) - A_t^U - B_t^U \quad (2)$$

$$X_0^U = \bar{X}^U$$

where  $G^U(X_t^U, M_t^1, \dots, M_t^n)$  is the growth function of the species.

Another simplification is made by assuming that there is no within period interdependency between  $A_t^U$  and  $B_t^U$ . For example, there might be dynamic dependency when hunting takes place first in a period which reduces the population and thereby traffic accidents later in the same period, or vice versa. Such interdependency can be valid when there is a specific hunting season and traffic accidents are reduced after the hunting season, or when traffic accidents prior to the hunting season reduce the population available for hunting. In Sweden, the hunting of moose is regulated and allowed in autumn, but the season regulation for deer varies in different parts of Sweden. With respect to wild boar, they are allowed to be killed by hunting any time during the year. Our assumption could then be invalid for moose. However, AVCs in general increase in mating and hunting seasons, but also during dusk and dawn during a day, because of the animals' movements in these periods which make them more prone to traffic accidents (Thurfjell et al., 2015; NVR, 2017). Although  $A_t^U$  and  $B_t^U$  are assumed to be independent within the same period, equation (2) shows that there is a dependency among periods where higher hunting pressure in one period reduces future population and thereby accidents as shown in eq. (2).

We follow a large part of the literature in bioeconomics by assuming a logistic growth function (e.g. Schaefer, 1954; Schwabe et al., 2002; Kataria, 2007; Gren et al., 2016), which gives

$$G^U(X_t^U, M_t^1, \dots, M_t^n) = r_t^U X_t^U \left(1 - \frac{X_t^U}{K^U}\right) \quad (3)$$

where  $r_t^U = r^U(M_t^1, \dots, M_t^n)$  is the intrinsic growth rate and  $K^U$  is the maximum size of the population under conditions of no pressure. Following Gren et al. (2016) it is assumed that the landscape characteristics enter the intrinsic growth rate so that  $r_t^U = b^U + \sum_{j=1}^n d^{j,U} M_t^j$ . Given these assumptions and equations (1)-(3), the rate of change in the population during time can be written as

$$\frac{X_{t+1}^U - X_t^U}{X_t^U} = \left( (b^U + \sum_{j=1}^n d^{j,U} M_t^j) \left(1 - \frac{X_t^U}{K^U}\right) \right) - \beta^U (E_t^A - \theta^U F_t) - \frac{B_t^U}{X_t^U} \quad (2')$$

$$X_0^U = \bar{X}^U$$

However, (2') can not be subject to any regression analysis since time series population data are not available, which is a well-known problem in wildlife management. A common approach for estimating the latent population variable is to use catch per unit effort (CPUE) as a proxy for relative population abundance, and to assume that the growth rate in CPUE reflects the growth rate in the underlying population (e.g., Arreguín-Sánchez, 1996). In our study, the corresponding abundance construct based on traffic accidents is obtained from (1) and is defined as

$$x_t^{U,A} \equiv \beta^U X_t^U = \frac{A_t^U}{(E_t^A - \theta^U F_t)}, \text{ which shows the number of traffic accidents per unit traffic}$$

effort (TAPUE).

We can choose the rate of change over time in  $x_t^{U,A}$  or use a similar concept expressed in hunting bags per effort (BAPUE defined as  $x_t^{U,B} \equiv \alpha^U X_t^U = \frac{B_t^U}{E_t^B}$ ) as an approximation of the rate of

change in the population as defined in equation (2'). Irrespective of choice, we can obtain estimates of the intrinsic growth rate, carrying capacity, and catchability coefficients needed for

estimating the population function. The steps for obtaining this result is shown for  $x_t^{U,A}$ . By

replacing  $X_t^U$  with  $\frac{x_t^{U,A}}{\beta^U}$  (from the definition of  $x_t^{U,A}$ ) in equation (2') we obtain:

$$\frac{dx_t^{U,A}}{x_t^{U,A} dt} = b^U - \frac{r_t^U}{\beta^U K^U} x_t^{U,A} - \beta^U \left( E_t^A - \theta^U F_t + \frac{B_t^U}{x_t^{U,A}} \right) + \sum_{j=1}^n d^{j,U} M_t^j \quad (4)$$

From (4) we can derive a regression equation which can be estimated as:

$$Y_t^U = \gamma^{U,1} + \gamma^{U,2} x_t^{U,A} + \gamma^{U,3} E_t^A + \gamma^{U,4} F_t + \gamma^{U,5} \frac{B_t^U}{x_t^{U,A}} + \sum_{j=1}^n v^{U,j} L_t^j + \varepsilon_t^U \quad (5)$$

where  $Y_t^U = \frac{dx_t^{U,A}}{dt} / x_t^{U,A}$ ,  $\gamma^{U,1} = b^U$ ,  $\gamma^{U,2} = \frac{r_t^U}{\beta^U K^U}$ ,  $\gamma^{U,3} = \beta^U$ ,  $\gamma^{U,4} = \beta^U \theta^U / E_t^A$ ,

$\gamma^{U,5} = \beta^U \frac{A_t^U}{B_t^U}$ ,  $v^{U,j} = d^{U,j}$ ,  $r_t^U = \gamma_1^U + \sum_{j=1}^n v^{U,j} M_t^j$ , and the carrying capacity is calculated

as  $K_t^U = \frac{\gamma^{U,1} + \sum_{j=1}^n v^{U,j} M_t^j}{\gamma^{U,2} \gamma^{U,3}}$ . The expression for  $\gamma^{U,5} = \beta^U \frac{A_t^U}{B_t^U}$  is obtained by recognizing

that  $x_t^{U,A} = \frac{A_t^U}{E_t^A - \theta^U F_t}$  in the fifth term at the right hand side of (5) and that the impact of  $\frac{B_t^U}{x_t^{U,A}}$

in the parenthesis in eq. (4) is proportional to that of  $E_t^A - F_t$ .

However, if rate of changes in  $x_t^{U,A}$  show worse statistical performance than  $x_t^{U,B}$ , which is the case for one of the ungulates in our regression analyses presented in Section 4, we can still obtain a measure of the traffic catchability coefficient and predict accidents. Equation (4) is then changed to:

$$\frac{dx_t^{U,B}}{x_t^{U,B} dt} = b^U - \frac{r_t^U}{\beta^U K^U} x_t^{U,A} - \alpha^U \left( E_t^B + \frac{A_t^U}{x_t^{U,B}} \right) + \sum_{j=1}^n d^{j,U} M_t^j \quad (4')$$

and the associated regression equation is written as:

$$Y_t^U = \gamma^{U,1} + \gamma^{U,2} x_t^{U,A} + \gamma^{U,3} \frac{A_t^U}{x_t^{U,B}} + \gamma^{U,4} E_t^B + \sum_{j=1}^n v^{U,j} M_t^j + \varepsilon_t^U \quad (5')$$

where  $\gamma^{U,4} = \alpha^U$  and we can obtain an expression for  $\beta^U$  in equation (5') from the third term at the right hand side of (5') where  $\frac{A_t^U}{x_t^{U,B}} = \frac{\beta^U E_t^A}{\alpha^U}$  from which  $\beta_t^U = \alpha^U \frac{x_t^{U,A}}{x_t^{U,B}}$ .

## 4. Description of data and econometric results

As shown in Section 3 we can estimate a population function for an ungulate which is subject to pressure from traffic and hunting with data on traffic accidents and volume, hunting bags and efforts, fences, and landscape characteristics. In this study, we have access to a panel data set with these variables for each county in Sweden for the years 2003-2015. Estimation of a panel requires appropriate methods. Both data retrieval and estimation methods are described in this section before presenting the results.

### 4.1 Data retrieval

Data on ungulate bags and traffic accidents in the 21 different Swedish counties are available from 2003 until 2015 (Viltdata, 2017; NVR, 2017). When growth rate in BAPUE (hunting bags per unit effort) is used as dependent variable, an ideal effort variable would be number of hunters and their activities allocated on hunting the different ungulates. Unfortunately, such an effort variable is not available, but only number of issued hunting licenses in each county (Bladh, 2016). This variable might not fully describe the effort variables since some owners of the licenses do not hunt, and some others travel between counties in order to hunt. In this respect, traffic load as an effort variable and the use of growth rate in TAPUE as a proxy for changes in the population is more accurate since it shows the number of km by cars in each county (RUS, 2016). Data on traffic accidents with ungulates are obtained from NVR (2017), which is considered as relatively

accurate. Since 1987 drivers are obliged by §40 *Jaktförordningen* to report wildlife accidents and injured animals to the authorities. Traffic load is measured in millions of kilometers driven in each county (RUS, 2016).

Following the literature, we include data on landscape characteristics which are; areas of forest, agricultural and pasture land for each county (Swedish Statistics, 2016). Forest may provide some difficulties for drivers to detect movements of ungulates in the landscape and thereby, *ceteris paribus*, increasing the probability of an accident (Antonson et al., 2015, Jägerbrand and Antonson, 2016). On the contrary, arable and pasture land with a more open type of landscape tend to improve visibility thereby reducing the risk of an accident, but simultaneously however, drivers automatically increase their speed due to risk compensation when visibility is higher in open landscapes (Jägerbrand and Antonson, 2016). Although, open types of landscapes would be less attractive to certain ungulates since they tend to congregate in the intermittent area of forest and open landscape elements. Hence, we would expect a general negative sign for the variables arable and pasture land.

In addition to landscape characteristics, the presence of wildlife fences along certain roads can mitigate accidents and affect growth of ungulate populations (e.g. Almkvist et al., 1980, Erke and Elvik, 2006). The roads as such can affect population, not only through accidents, but also as barriers for ecological corridors and pathways for the animals. In this study we therefore include the length of fences and roads as explanatory variables (Bylund, 2017). In addition, the size of the county are included as a control variable.

Given all assumption, the descriptive statistics for the dependent and independent variables used in the regressions are as shown in Table 2

Table 2: Descriptive statistics, where U= O, D, P i.e. moose (o), deer (D), and pigs (P), and N=252 for moose and deer, and N=160 for pigs

Variable	Mean	Standard deviation	Min	Max
<b>BAPUE (Bags per hunting license), <math>x^{U,B}</math></b>	$S^{O,H}$ 0.31	$S^{O,H}$ 0.25	$S^{O,H}$ 0	$S^{O,H}$ 1.28
	$S^{D,H}$ 0.48	$S^{D,H}$ 0.40	$S^{D,H}$ 0.01	$S^{D,H}$ 2.41
	$S^{P,H}$ 0.36	$S^{P,H}$ 0.35	$S^{P,H}$ 0	$S^{P,H}$ 1.59
<b>TAPUE (Accidents per traffic load), <math>x^{U,A}</math></b>	$S^{O,A}$ 0.14	$S^{O,A}$ 0.13	$S^{O,A}$ 0	$S^{O,A}$ 1.22;
	$S^{D,A}$ 0.68	$S^{D,A}$ 0.36	$S^{D,A}$ 0	$S^{D,A}$ 1.79
	$S^{P,A}$ 0.08	$S^{P,A}$ 0.09	$S^{P,A}$ 0	$S^{P,A}$ 0.50
<b>Growth rate in BAPUE, <math>Y^{U,B}</math></b>	$Y^{O,H}$ 0.017	$Y^{O,H}$ 0.20	$Y^{O,H}$ -0.99	$Y^{O,H}$ 0.846
	$Y^{D,H}$ 0.028	$Y^{D,H}$ 0.33	$Y^{D,H}$ -0.77	$Y^{D,H}$ 1.67
	$Y^{P,H}$ 0.429	$Y^{P,H}$ 1.16	$Y^{P,H}$ -0.90	$Y^{P,H}$ 7.65
<b>Growth rate in TAPUE, <math>Y^{U,A}</math></b>	$Y^{O,A}$ 0.035	$Y^{O,A}$ 0.22	$Y^{O,A}$ -0.87	$Y^{O,A}$ 0.72
	$Y^{D,A}$ 0.058	$Y^{D,A}$ 0.23	$Y^{D,A}$ -0.94	$Y^{D,A}$ 1.25
	$Y^{P,A}$ 0.256	$Y^{P,A}$ 0.47	$Y^{P,A}$ -0.79	$Y^{P,A}$ 1.88
<b>Number of bags, <math>B^U</math></b>	$H^O$ 4280	$H^O$ 3973	$H^O$ 0	$H^O$ 15943
	$H^D$ 5604	$H^D$ 5226	$H^D$ 237	$H^D$ 33598
	$H^P$ 3742	$H^P$ 3771	$H^P$ 0	$H^P$ 19201
<b>Number of accidents, <math>A^U</math></b>	$A^O$ 253	$A^O$ 167	$A^O$ 0	$A^O$ 1025
	$A^D$ 1501	$A^D$ 1180	$A^D$ 0	$A^D$ 6696
	$A^P$ 172	$A^P$ 175	$A^P$ 0	$A^P$ 899
<b>Number of licenses</b>	12959	7219	1690	37401
<b>Traffic load, million km</b>	2631	2721	341	11380
<b>Forest, 1000 km<sup>2</sup></b>	1389	1505	147	6435
<b>Agriculture land, 1000 km<sup>2</sup></b>	127	117	31	488
<b>Pasture land, 1000 km<sup>2</sup></b>	23	21	2	78
<b>Area, 1000 km<sup>2</sup></b>	1539	1475	225	6476
<b>Fences, km</b>	228	195	0	1013
<b>Roads, 10 km</b>	4389	2594	592	12658

The average growth rate measured as BAPUE and TAPUE are relatively similar for the ungulates, but they differ among the ungulates considerably higher for wild boar than for the other included ungulates. The pressure on the populations from hunting is considerably higher than that from



traffic accidents. The number of bags are at least 3.5 times larger than number of accidents. For wild boar, this difference is even higher and amounts to approximately 22 times the number of accidents.

## **4.2 Econometric results**

Since the data set is a panel with observations for 21 counties over the period 2003-2015 we test for fixed or random effect model by a Hausmann test, and if a random effect model is statistically better than an ordinary least square estimate. The observed p-value of the Breusch-Pagan tests indicated that the null-hypothesis of no variances across the counties cannot be rejected, favoring a random effects model (Table A2). However, tests revealed the existence of contemporaneous correlation among counties (Table A2). Cross-sectional dependence is likely to occur in a relatively small country as Sweden where our units of analysis, counties, are subjected to the same type of national regulations and neighboring counties face similar weather conditions. If our independent variables do not reflect these cross-sectional dependencies the estimated standard errors will be affected. We therefore estimated our models with Driscoll and Kraay (1998) standard errors which are heteroscedasticity consistent and account for cross-sectional and temporal correlations. We also tested for the existence of multicollinearity and the VIF showed an acceptable value for all regressions ( $<2.63$  in average).

Recall from the theoretical Section 3 that we can use either growth rate in BAPUE or TAPUE as dependent variable with associated explanatory variables. It turned out the TAPUE gave the best statistical fit for deer and wild boar, and BAPUE for moose. We also made regressions with different constructs of road, total road length and in relation to the area of the county, but the inclusion of these constructs reduced the statistical performance of the regressions. On the other hand, fences as share of road length, and the landscape constructs turned out to be significant for some models (Table 3).

Table 3: Regression results from pooled OLS and Driscoll and Kray standard errors (p-values in parentheses).

	<b>Moose (Growth rate in BAPUE)</b>	<b>Deer (Growth rate in TAPUE)</b>	<b>Pig (Growth rate in TAPUE)</b>
<b>Constant</b>	0.064* (0.078)	0.346*** (0.001)	0.461** (0.013)
<b>Licens</b>	-0.0128-3*** (0.000)		
<b>Traffic load</b>		-0.033-3*** (0.001)	-0.004-3** (0.021)
<b>Bags/hunting licenses, <math>x^{U,B}</math></b>	-0.140** (0.013)		
<b>Accidents/traffic load, <math>x^{U,A}</math></b>		-0.282*** (0.000)	-1.635 *** (0.001)
<b>Accidents divided by <math>x^{U,B}</math>, <math>A^{U/x^{U,B}}</math></b>	0.066-3*** (0.003)		
<b>Bags divided by <math>x^{U,B}</math>, <math>B^{U/x^{U,A}}</math></b>		0.005-3*** (0.001)	0.001-3 (0.287)
<b>Forest</b>	0.056-3*** (0.000)	-0.021-3 (0.368)	0.262-3* (0.071)
<b>Agricultural land</b>	-0.164-3 (0.162)	-0.220-3 (0.277)	0.312-3 (0.225)
<b>Pasture land</b>	0.836-3 (0.274)	1.128-3 (0.401)	-3.604-3* (0.082)
<b>Fence/ road length</b>		-0.459* (0.082)	-1.311** (0.021)
<b>R<sup>2</sup></b>	0.15	0.17	0.13
<b>Prob&gt;F</b>	0.000	0.000	0.000

All constants, which are used to calculate the intrinsic growth rates as shown in eq. (2'), are significant and positive. We also obtain significant and expected signs of the effort variables *Licens* for moose and *Traffic load* for deer and pig. Similarly, the estimated coefficients of  $x^{U,B}$  and  $x^{U,A}$  are negative as expected, and significant. The estimated positive signs of the impact of the effort variable not included in the dependent variable,  $A^{U/x^{U,B}}$  for moose and  $B^{U/x^{U,A}}$  for moose and deer, may seem counterintuitive. However, as shown in Section 3 equation (5), these coefficients should be multiplied with the coefficient estimates of  $x^{U,B}$  for moose and with  $x^{U,A}$  for deer and pigs in order to obtain an expression for the effect of the second pressure. These coefficients are negative, and hence the pressure of traffic load on moose and hunting licenses on roe deer and pigs are negative as expected. Similarly, the negative coefficient of *fence/road length* are expected since, from Section 3, the counteracting impact of mitigation measures are calculated as  $\theta^U = \frac{\gamma^{U,4}}{\beta^U}$ .

This gives  $\theta^D=1.628$  and  $\theta^O=0.802$

With respect to landscape characteristics, forests contribute positively and significantly to the growth rate of moose and pigs, and grassland has a significant and negative effect on the growth rate of wild boar. We calculate the intrinsic growth rate for the ungulates at the mean values of the coefficient of these landscape variables, which gives 0.15, 0.34 and 0.47 for moose, deer and wild boar respectively. The intrinsic growth rate for wild boar is close to that obtained by Gren et al. (2016) and Jansson et al (2012). Gren et al. (2016) used the same method and data for calculating wild boar population dynamics as in current study but with data for a three year shorter time period. Their result showed an intrinsic growth rate of 0.48, which is the same as that obtained from age-structured models of a single local population by Lemel and Truvé (2008) and Jansson et al. (2012).

,

## 5. Predictions of costs of traffic accidents

We test the estimated regression functions by comparing the predicted and actual traffic accidents for the year 2015. The calculated population of moose, deer, and wild boar amount to, in average per county, 20801, 22381, and 18301, respectively. The associated total populations for Sweden then amounts to 416020, 470001, and 238177. Except for wild boar it is difficult to compare these estimates with results from other studies since similar calculations have not been carried out. Using the same approach as in this study, Gren et al. (2015) estimated a total wild boar population of approximately 127000 in 2011 and Jansson et al. (2012) reported a population level of 150000 for the same year. The number of accidents with wild boar increased by 91% from 2011 to 2015 (Table A1), and the traffic volume by 3% (RUS 2016). The population of moose is estimated to vary between 300000 and 400000 animals (Svenska Jägarförbundet, 2017b), and our estimate of 416020 is then slightly higher than the upper range. Our estimate of a population level of 238177 in 2015 thus seems reasonable. With respect to roe deer, Svenska Jägarförbundet (2017a) reports a population density, roe deer/1000 ha productive forest land, ranging between 20 and 60 animals. Our estimate shows an average of 44 animals/1000 ha, which is thus within the reported range.

When predicting the traffic accidents with deer and wild boar we use the estimated with accidents divided by traffic volume,  $x_i^{U,A}$ , in Table 3. Since the regression results for moose with rates of

changes in  $x_t^{U,A}$  as dependent variable were poor relative to the estimates with bag per hunting license,  $x_t^{U,B}$ , we can not use the coefficients directly but derive the traffic accident catchability coefficient as shown in eq. (4) in Section 3. Except for two counties, the deviations from the actual number of accidents do not deviate by more than 1% from the actual number for any county and ungulate (Tables A3-A5).

We calculate costs of traffic accidents over a period of 15 years, which is the planning period used by the Swedish Transportation Administration (Trafikverket, 2014). As shown in Section 3, the population and thereby traffic accidents depend on the forecasted traffic volume and hunting efforts. Trafikverket has (2014) predicted an average annual increase in traffic volume by 1%. In the base scenario we therefore assume this increase in the traffic volume, and an unchanged level of hunting pressure, which currently amounts to approximately 20% of the calculated population in 2015. In this scenario, the predicted accidents for the three ungulates are as displayed in Figure 5.

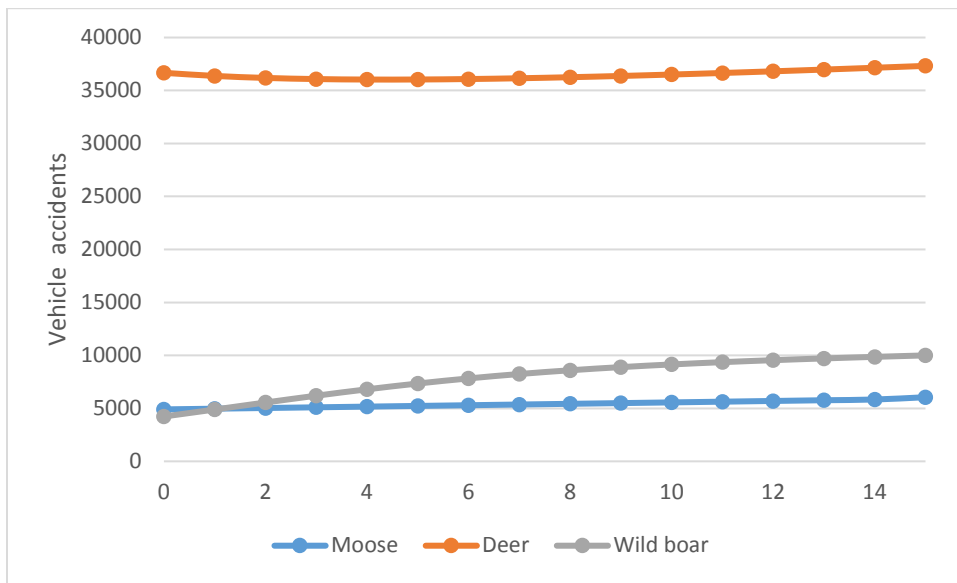


Figure 5: Predicted vehicle accidents with different ungulates with unchanged hunting pressure and an average increase in traffic volume by 1% per year

The relatively small increase for deer is explained by the relatively large number of traffic accidents which reduces growth in the population, which, in turn, decreases future accidents. This

is, in turn, explained by the share of traffic accidents with deer in relation to the calculated population level (Table A1), and the associated estimated traffic volume coefficient. On the other hand, accidents with wild boar are predicted to increase with approximately 136%, which is due to the estimated high intrinsic growth rate. Accidents with moose show a slight increase by approximately 23% from 2015 level.

The expected costs per accident and ungulate are assumed to be constant during the period and correspond to the costs presented in Table 1 in Section 2. We assign a social discount rate of 1.5%, which is the level recommended in cost-benefit analysis (Boardman et al., 2012). The calculated total discounted cost in the base scenario then amounts to 22344 million SEK in the base scenario. Despite the increase in traffic accidents with moose and wild boar shown in Figure 5, the annual cost of traffic accidents in present value remains relatively unchanged over time (Figure 6).

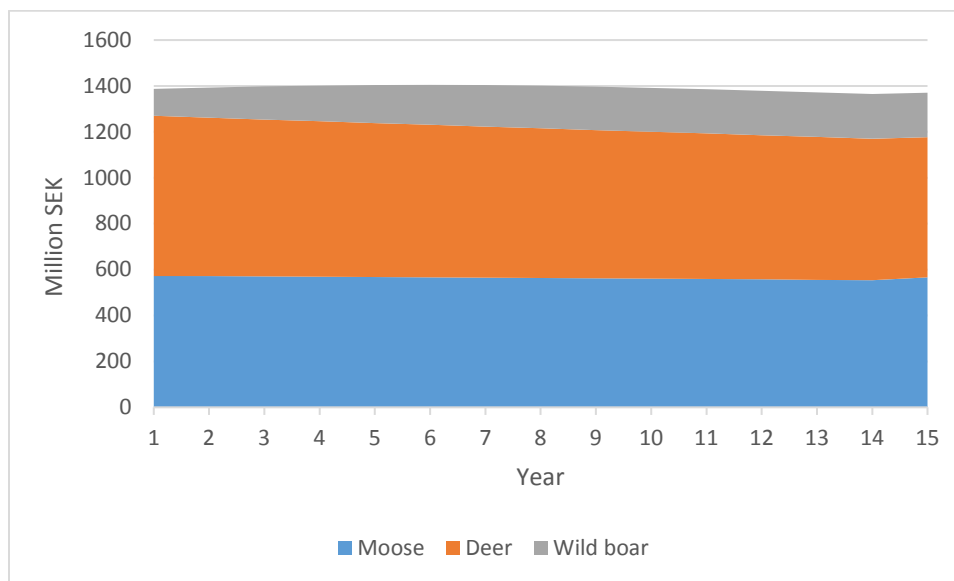


Figure 6: Development of discounted total costs of traffic accidents with ungulates in Sweden with unchanged hunting effort and increased traffic volume with 1% per year.

The monotonic decrease in costs of traffic accidents is due to the discount rate since the number of accidents is relatively stable over time. The discount rate also explains the lower increase in costs for wild boar and moose than corresponding increases in accidents.

However, the development of cost of traffic accident for a county can deviate considerable from the total development. For example, in Västra Götaland the county with the largest number of traffic accidents with ungulates, the expected total discounted cost of accidents increases by 15%. (Figure 7).

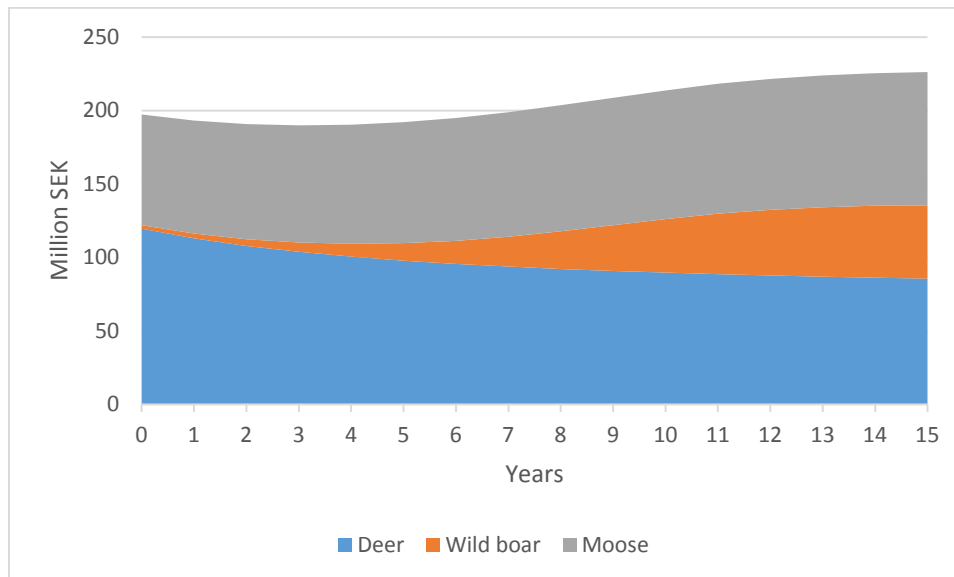


Figure 7: Development of discounted costs of traffic accidents in Västra Götaland county with unchanged hunting effort and increase in traffic volume by 1.2% per year.

The increase in costs is due to the increase in traffic volume, which is expected to raise by 1.2% per year, and the increase in the populations of wild boar and moose. As shown in Figure 7, the cost of accidents with wild boar shows a tenfold increase. This is explained by the recent establishment and associated low population of the animal in Västra Götaland, and the high calculated intrinsic growth rate for the animal in this county (Table A5).

This pattern of increasing costs of traffic accidents with wild boar is applicable to all counties where the animal is established. The relative increase is smaller for counties where wild boar has resided for several decades, such as in Skåne (Figure A4). The traffic volume increases by 1.3% in this county but the calculated total cost of accidents decreases by 24% because of the decrease in accidents with deer and moose. On the other hand, calculated costs of traffic accidents with deer or moose increase in the northern counties, such as Jämtland, where the calculated intrinsic growth rate of the animals is high.

However, the estimated total costs are affected by the assumptions of increases in traffic volume and hunting pressure. Without any increase in the traffic volume, total cost decrease to approximately 21 000 million SEK. On the other hand, if hunting pressure is reduced by 50%, the predicted total costs increase to approximately 28000 million SEK (Figure 8).

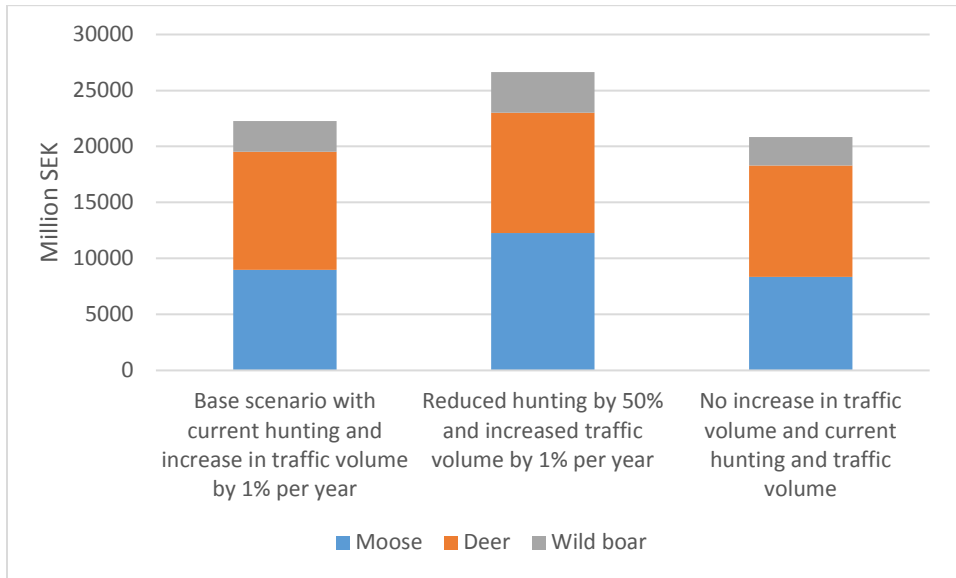


Figure 8: Calculated discounted total costs of traffic accidents with ungulates in Sweden during 15 years under different combinations of future hunting effort and traffic volume.

Total costs increase by approximately 25% from the base scenario when hunting efforts are reduced, which is mainly due to the increase in traffic accidents from moose and wild boar. The effect of an avoided increase in traffic volume is a decline in total costs by approximately 7%, which is of the same order of magnitude for all ungulates.

## 6. Discussion and conclusion

The main purpose of this study has been to calculate and predict costs of traffic accidents with ungulates, moose, roe deer and wild boar, in Sweden. The tool rests on the assumption that traffic accidents is determined by traffic volume and wild life populations, and populations, in turn, are

determined by pressure from traffic volume and hunting and from landscape characteristics including composition of land use and fences along major roads. A specific challenge is to estimate the population sizes, on which there is no data. This study used a method proposed by Gren et al. (2016) which was developed with respect to the consideration of two types of pressures. The method has been much used in fishery economics where the latent population variable is derived from changes in the growth rate of catch per unit effort. Two effort variables, or pressures on ungulates, were identified; traffic load and hunting. Both these variables were used for estimating population functions for moose, deer, and wild boar with panel data for counties in Sweden for the years 2003-2015.

The regression results showed intrinsic growth rate of 0.14, 0.33, and 0.47 for moose, deer and wild boar respectively when evaluated at the mean values of the explanatory variables. Differences in these growth rates explain to a large extent the predicted costs of traffic accidents over a period of 15 year, which decline for moose and deer but increase for wild boar. However, the total discounted cost ranges between 21 000 and 28 000 million SEK, or 1400 million SEK and 1870 million SEK annually, depending on assumptions of future hunting pressure and changes in traffic volume. AVCs with roe deer and moose account for approximately 45% each, but wild boar shows the most rapid increase in costs because of its high intrinsic growth rate and recent establishment in several counties. A decrease of hunting bags from about 20% of the calculated population sizes to 10% increased the total cost of accidents by approximately 25%. This result support the suggestion by other studies to consider hunting as a measure for combating traffic accidents (e.g. Schwabe et al., 2002).

However, we have not accounted for underreporting of traffic accidents, which can be severe where actual accidents can be more than twice as high as the reported number (e.g. Helldin, 2013). This will undoubtedly affect the level of accidents and thereby the calculated costs. It is not clear whether it will affect our predictions of costs. Snow et al (2015) analyse the effect of this factor for large ungulates in US but find that the predictive power of the models of accidents are not significantly affected. One reason can be the randomness in underreporting, i.e. it is not biased towards specific spatial or dynamic patterns.



Another simplification has been the neglect of eventual behavioral adaptation of the animals to pressure, including hunting and traffic. The animals may learn the spatial allocation of risks of being killed and avoid these areas. This has been shown for elk (Cuite et al., 2012), and for wild boar in Sweden (Thurfjell et al., 2015). Thurfjell et al. (2015) point out the role of animal behavior and show that wild boar in Sweden learn to avoid crossing roads with heavy traffic, resulting in higher accidents at roads with intermediate traffic. If so, the relation between population size, traffic volume and accidents is more complex and time dependent than in our model where it is assumed to be constant.

The choice of a logistic growth function has been criticized because of the neglect of composition of population cohorts, and disregard of stochastic shocks to the population (e.g. Clark, 1990). Other functions, such as age or stage structured models, might give other predictions of population developments. On the other hand, such models are quite data demanding with respect to biological parameters such as reproduction and survival strategies for different cohort. Such data are most often non-existent at the large scale level. Nevertheless, our estimates of populations of moose, deer and wild boar come relatively close to the few known estimates of these ungulates, and the associated predicted accidents are within a small range from actual number of accidents for all included ungulates.

## Appendix: Tables A1-A5, Figures A1-A4

Table A1: Accidents with ungulates and traffic volume in Sweden during 2003-2015.

<b>Year</b>	<b>Accidents;</b>			<b>Total</b>	<b>Traffic volume, mill km</b>	<b>Accidents/mill km</b>
	<b>Moose</b>	<b>Deer</b>	<b>Wild boar</b>			
<b>2003</b>	4 204	27720	755	32 679	53062	0.617
<b>2004</b>	4 641	28430	670	33 741	53557	0.630
<b>2005</b>	4092	27761	987	32 840	53915	0.609
<b>2006</b>	4957	27706	1020	33 683	54548	0.617
<b>2007</b>	4635	28243	1583	34 461	53886	0.639
<b>2008</b>	5118	30982	2464	38 564	56314	0.684
<b>2009</b>	5761	33798	3085	42 644	55832	0.763
<b>2010</b>	7227	36107	2445	45 779	55100	0.830
<b>2011</b>	5994	30654	2647	39 295	55456	0.708
<b>2012</b>	5963	34866	4198	45 027	54922	0.819
<b>2013</b>	5771	35552	3551	44 874	54978	0.816
<b>2014</b>	5141	35914	3783	44 838	55996	0.801
<b>2015</b>	4914	36513	4229	45 656	57013	0.801

Table A2: Regression results with random effect model with robust standard errors (p-values in parentheses).

	<b>Moose (Growth rate in BAPUE)</b>	<b>Deer (Growth rate in TAPUE)</b>	<b>Pig (Growth rate in TAPUE)</b>
<b>Constant</b>	0.064* (0.078)	0.335*** (0.037)	0.462*** (0.000)
<b>Licens</b>	-0.0128-3*** (0.000)		
<b>Traffic load</b>		-0.031-3*** (0.004)	-0.044-3*** (0.000)
<b>X<sup>B</sup></b>	-0.140** (0.013)		
<b>x<sup>A</sup></b>		-0.296*** (0.000)	-1.635 *** (0.000)
<b>A/x<sup>B</sup></b>	0.066-3*** (0.003)		
<b>B/x<sup>A</sup></b>		0.005-3** (0.046)	0.001-3** (0.032)
<b>Forest</b>	0.056-3*** (0.000)	-0.019-3 (0.201)	0.262-3*** (0.001)
<b>Agricultural land</b>	-0.164-3 (0.162)	-0.310-3 (0.204)	0.312-3 (0.252)
<b>Pasture land</b>	0.836-3 (0.274)	1.445-3 (0.351)	-3.604-3** (0.024)
<b>Fence/road area</b>		-0.175(0.592)	-1.311** (0.010)
<b>Breusch-Pragan test of random effects</b>	p=1.00	p=0.127	p=1.000
<b>Pesaran<sup>a</sup> test of cross sectional dependence</b>	p=0.000	p=0.000	p=0.000
<b>Wald test</b>	272.01	68.71	197.26
<b>Prob&gt;F</b>	0.000	0.000	0.000

<sup>a</sup> Pesaran (2004)

Table A3: Calculated intrinsic growth rate, population, accidents, maximum population size, and deviation in calculated accidents from actual accidents with moose, all numbers are evaluated at the mean values over the years for each county

	<b>Intrinsic growth rate</b>	<b>Population</b>	<b>Accidents</b>	<b>Maximum population</b>	<b>Deviation in pred. accidents<sup>a</sup></b>
<b>Blekinge</b>	0.06	5567	76	33334	-0.04
<b>Dalarna</b>	0.17	32324	306	97240	-0.01
<b>Gävleborg</b>	0.14	33011	174	78965	-0.01
<b>Halland</b>	0.05	8931	167	28277	-0.02
<b>Jämtland</b>	0.24	81028	389	136327	-0.01
<b>Jönköping</b>	0.06	17083	406	32109	-0.01
<b>Kalmar</b>	0.03	29503	277	15228	0.02
<b>Gotland</b>					
<b>Kronoberg</b>	0.08	22719	312	42722	-0.01
<b>Norrbottn</b>	0.40	39104	396	223484	0.01
<b>Skåne</b>	0.04	1783	157	19938	-0.04
<b>Stockholm</b>	0.06	4399	205	32871	-0.03
<b>Södermanland</b>	0.05	15083	201	27343	-0.04
<b>Uppsala</b>	0.05	15324	146	26979	0.01
<b>Värmland</b>	0.12	35399	474	69330	-0.02
<b>Västerbotten</b>	0.28	50092	377	158359	-0.01
<b>Västernorrland</b>	0.16	45274	223	89751	-0.03
<b>Västmanland</b>	0.06	18298	104	33314	-0.01
<b>Va Götaland</b>	0.02	13570	698	83205	-0.01
<b>Örebro</b>	0.07	25820	200	41306	-0.01
<b>Östergötland</b>	0.03	19224	151	17957	0.00
<b>Total average</b>	0.11	20801	272	60711	-0.01

Table A4: Calculated intrinsic growth rate, population, accidents, maximum population size, and deviation in calculated accidents from actual accidents with deer, all numbers are evaluated at the mean values over the years for each county

	<b>Growth rate</b>	<b>Population</b>	<b>Accidents</b>	<b>Maximum population</b>	<b>Deviation in pred. accidents<sup>a</sup></b>
<b>Blekinge</b>	0.31	29354	867	35195	0.01
<b>Dalarna</b>	0.28	27687	1562	31633	0.00
<b>Gävleborg</b>	0.25	16286	870	28894	0.01
<b>Halland</b>	0.28	17589	1064	31931	-0.01
<b>Jämtland</b>	0.28	22475	600	31591	0.00
<b>Jönköping</b>	0.32	29315	1956	36413	0.00
<b>Kalmar</b>	0.38	33973	2050	43823	-0.01
<b>Gotland</b>	0.33	12377	135	37624	0.02
<b>Kronoberg</b>	0.31	32019	1550	35748	0.00
<b>Norrbottn</b>	0.21	3908	199	23881	0.05
<b>Skåne</b>	0.27	14983	3321	30623	-0.01
<b>Stockholm</b>	0.31	7491	2511	34893	-0.01
<b>Södermanland</b>	0.28	27687	1381	32122	-0.01
<b>Uppsala</b>	0.27	26710	1545	31118	0.00
<b>Värmland</b>	0.26	34527	1943	30408	0.01
<b>Västerbotten</b>	0.22	6840	321	25594	0.02
<b>Västernorrland</b>	0.27	12052	576	31071	0.00
<b>Västmanland</b>	0.27	19869	935	30818	0.00
<b>Va Götaland</b>	0.20	22149	6696	23312	-0.07
<b>Örebro</b>	0.27	26058	1330	31288	0.00
<b>Östergötland</b>	0.31	22475	1695	34389	0.00
Average in total	0.30	22182	1543	33912	-0.01

<sup>a</sup>(Predicted accidents-actual accidents)/actual accidents

Table A5: Calculated growth rate, population, accidents, maximum population size, and deviation in calculated accidents from actual accidents with wild boar, all numbers are evaluated at the mean values over the years for each county

	<b>Growth rate</b>	<b>Population</b>	<b>Accidents</b>	<b>Maximum population</b>	<b>Deviation in pred. accidents<sup>a</sup></b>
<b>Blekinge</b>	0.43	23863	100	58994	0.01
<b>Halland</b>	0.37	13181	113	51953	-0.01
<b>Jönköping</b>	0.44	9091	86	61503	-0.01
<b>Kalmar</b>	0.43	37951	251	59329	0.00
<b>Kronoberg</b>	0.51	54771	287	71342	0.00
<b>Skåne</b>	0.46	17500	551	63829	0.00
<b>Stockholm</b>	0.52	4091	195	72422	0.01
<b>Södermanland</b>	0.39	36591	259	53809	0.00
<b>Uppsala</b>	0.46	11818	97	64106	-0.03
<b>Västmanland</b>	0.36	4773	32	49443	0.00
<b>Va Götaland</b>	0.67	2500	101	92227	-0.03
<b>Örebro</b>	0.52	8409	61	72634	-0.02
<b>Östergötland</b>	0.48	13409	144	66695	0.00
<b>total</b>	0.46	18304	175	64484	-0.01

Svenska län/  
Swedish counties  
1998



Figure A1: Counties in Sweden

Source: [http://www.hhogman.se/swe\\_counties\\_map\\_eng.htm](http://www.hhogman.se/swe_counties_map_eng.htm)

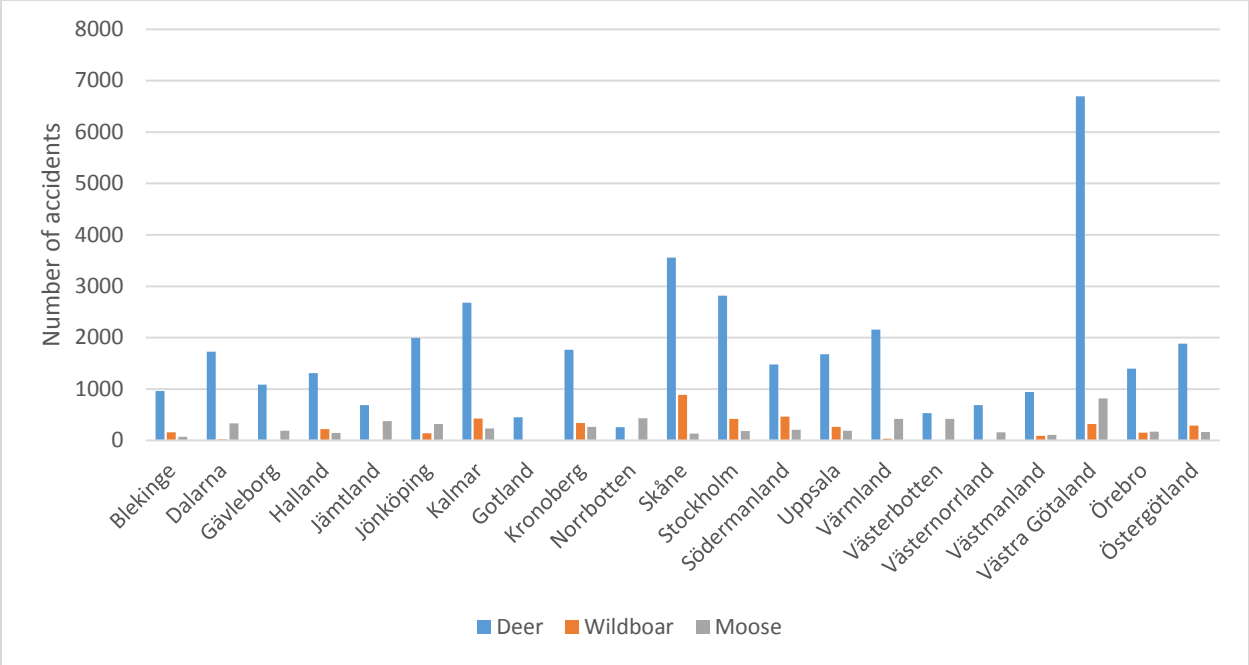


Figure A2: Allocation of traffic accidents with ungulates among counties and ungulates in 2015

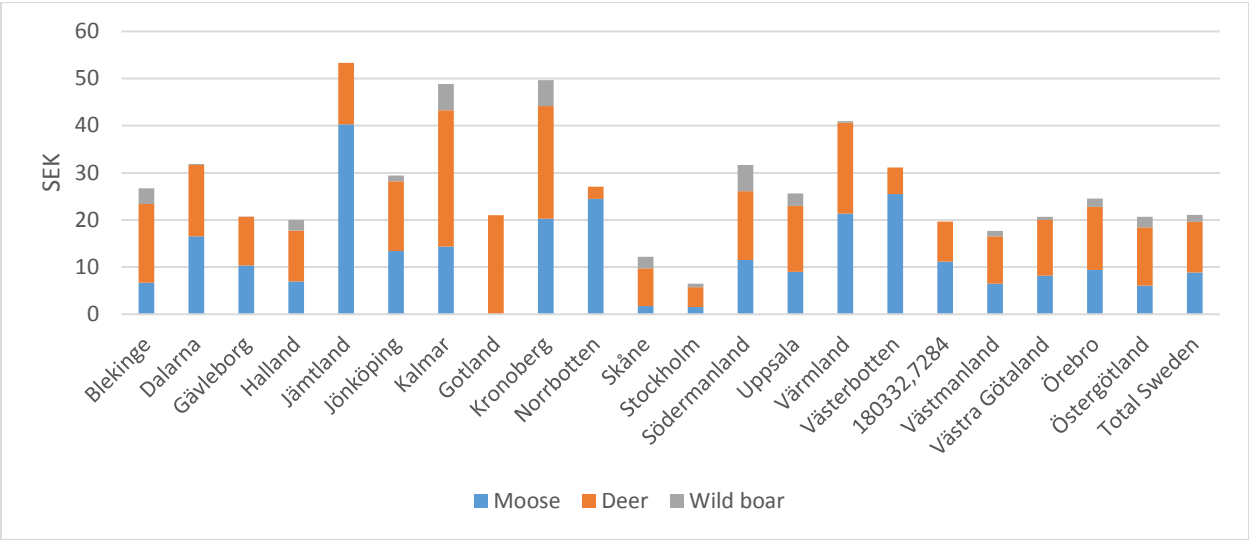


Figure A3: Expected costs of traffic accidents with ungulates among counties and ungulates in 2015, SEK/km traffic volume



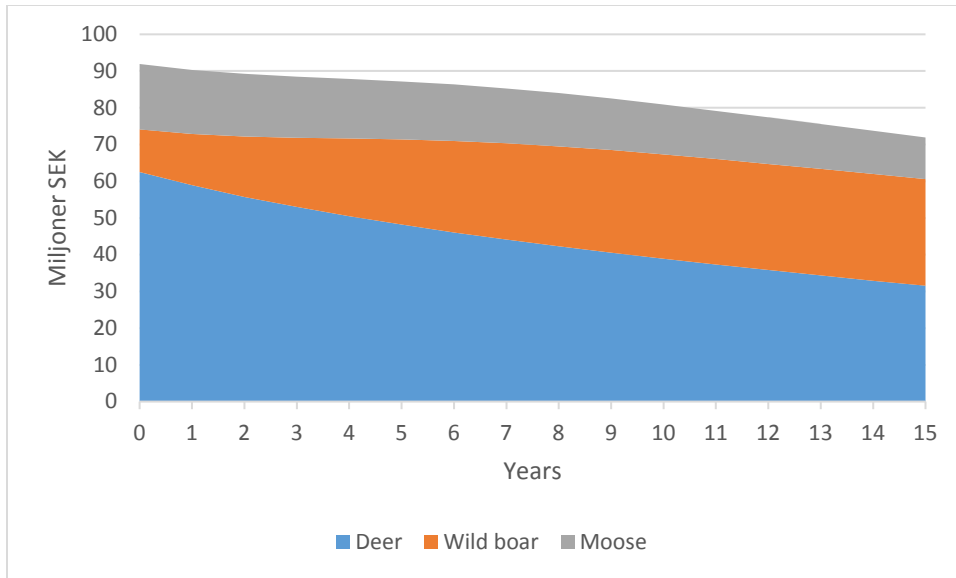


Figure A4: Development of discounted costs of traffic accidents in Skåne county with unchanged hunting effort and increase in traffic volume by 1.3% per year.

## References

- Antonson, H., Jägerbrand, A., Ahlström, C. 2015. Experiencing moose and landscape while driving: A simulator and questionnaire study. *Journal of Environmental Psychology* 41, 91-100.
- Almkvist, B., T. André, S. Ekblom and S.-A. Rempner. 1980. Viltolycksprojektet (VIOL) Slutrapport Maj 1980. TU 145. Statens vägverk Utvecklingssektionen 1980-05.
- Arreguín-Sánchez, F. 1996. Catchability: a key parameter for fish stock assessment. *Reviews in Fish Biology and Fisheries* 6. 221-242.
- Bissonette J, Kassar CA, Cook LJ. 2008. Assessment of costs associated with deer-vehicle collisions: human death and injury, vehicle damage, and deer loss. *Human-Wildlife Conflicts* 2, 17-27.
- Bladh, D. 2016 Statistik på jaktkort. Swedish Environmental Protection Agency.
- Boardman A., Greenberg D., Vining A., Weimer D. 2012. Cost benefit-analysis. Concepts and practice. Fourth edition. Pearson International Edition.
- Bylund, T. 2017. Data on fences and road length in different counties 2003 to 2015. Trafik Analys, Stockholm, Sweden.

- Bångman, G. 2016. Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.0. Kapitel 20 English summary of ASEK recommendations. T. S. T. Administration. Trafikverket.
- Clark C.W. 1990. Mathematical bioeconomics: the optimal management of renewable resources. 2<sup>nd</sup> edition. John Wiley and Sons, Inc., New York.
- Conover, M.R., Pitt, W.C., Kessler, K.K., DuBow, T.J., Sanborn, W.A. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Society Bulletin 23, 407–414.
- Driscoll, J., Kraay, A. 1998. Consistent covariance matrix estimation with spatially dependent panel data. Review of Economics and Statistics, 80, 549-560.
- Erke, A., Elvik, R. 2006. Road safety measures: A catalogue of estimated effects. TØI rapport 851/2006. Norwegian Centre for Transport Research, Institute of Transport Economics (TOI).
- Fahrig, L., Pedlar, J. H., Pope, S. E., Taylor, P. D., Wegner, J. F. 1995. Effect of road traffic on amphibian density. Biological Conservation 73,177–182.
- Found, R., Boyce, M. 2011. Predicting deer-vehicle collisions in an urban area. Journal of Environmental Management 92, 2486-2493.
- Gagnon, J., Loberger, C., Sprague, S., Ogren, K., Boe., S., Schweinsburg, R. 2015. Cost-effective approach to reducing vehicle collisions with elk by fencing between existing highway structures. Human-Wildlife Interactions 9, 248-264.
- Glista, D., DeVault, T., DeWoody, A. 2009 A review of mitigation measure for reducing wildlife mortality on roadways. Landscape and urban planning 91, 1-7.
- Gren, I-M., Häggmark.Svensson, T., Andersson, H., Jansson, G., Jägerbrand, A. 2016. Using traffic data to calculate wild life populations. Journal of Bioeconomics, 18, 17-31.
- Gunson, K., Mountrakis, G., Quackenbush, L. 2011. Spatial wild-life vehicle collision models: A review of current work and its application to transport mitigation projects. Journal of Environmental Management 92. 1074-1082.
- Helldin, J-O. 2013. Påkörda djur – trafikdödlighet ett växande naturvårdsproblem. Rapport, Centrum för Biologisk Mångfald, Sveriges Lantbruksuniversitet, available at <http://media.triekol.se/2013/10/Triekol-CBM-skrift-77-lowres.pdf>.
- Huijser, MP., McGowen, P., Fuller, J., Hardy, A., Kociolek, A., Clevenger, A.P., Smith, D., Ament, R. 2008. Wildlife-Vehicle Collision Reduction Study: Report to Congress. Western Transportation Institute, Montana State University. Available at <https://www.fhwa.dot.gov/publications/research/safety/08034/08034.pdf> (access date July 27, 2017) .

Huijser, MP., Duffield, J., Clevenger, A., Ament, R., McGowen P. 2009. Cost benefits analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. *Ecology and Society* 14, 15.

Hussain, A., Armstrong, J., Brown, D., Hogland, J. 2007. Land-use pattern, urbanization, and deer-vehicle collisions in Alabama. *Human-Wildlife Conflicts* 1, 89-96.

Hägström-Svensson T., Gren I-M., Ankdersson H., Jansson G., & Jägerbrand A. 2014. Costs of traffic accidents with wild boar in Sweden. Working Paper 2014:05. Department of Economics, Swedish University of Agricultural Sciences, Uppsala, Sweden. At [https://ideas.repec.org/p/hhs/slueko/2014\\_005.html](https://ideas.repec.org/p/hhs/slueko/2014_005.html) (access date July 3 2017).

Jansson, J. O. 1994. Accident externality charges". *Journal of Transport Economics and Policy* 28, 31-43.

Jansson G., Månsson J., Nordström J. 2012. GPS-märkta vildsvin hjälper oss att förstå deras beteende. *Svensk Jakt* 9, 96-98.

Johansson, Ö. 2016. Sannolikheter för trafikolyckor med klövdjur i Sverige. Väg och Transport institutet, Borlänge, Sweden.

Jägerbrand, A.K. 2014. Collisions and accidents with roe deer in Sweden during 10 Years (2003-2012). Variation in time, geographical patterns and costs. Report 818 (in Swedish with English summary). Available at <http://vti.diva-portal.org/smash/get/diva2:717176/FULLTEXT01.pdf> (access date August 15, 2017).

Jägerbrand, A. K., Antonson, H. 2016. Driving behaviour responses to a moose encounter, automatic speed camera, wildlife warning sign and radio message determined in a factorial simulator study. *Accident Analysis and Prevention* 86, 229-238.

Lagos, L., Picos, J. Valero, E. 2012. Temporal pattern of wild ungulate-related traffic accidents in northwest Spain. *European Journal of Wildlife Research* 58, 661-668.

Lemel J., Truve J. 2008. Vildsvin, jakt och förvaltning – Kunskapssammanställning för LRF. Svensk Naturförvaltning AB, Rapport 04.

Miller, T. 2000. Variations between countries in values of statistical life. *Journal of Transport Economics and Policy* 34, 169-188.

Mishan, E.J. 1971. Evaluation of life and limb: a theoretical approach. *Journal of Political Economy* 79, 687-705.

NVR (Nationella Viltolycksrådet) 2017. Viltolyckor under de senaste 5 åren. Available at <http://www.viltolycka.se/statistik/viltolyckor-de-senaste-5-aren/> (access date March 21, 2017).

Pesaran, M.H. 2004. General diagnostic tests for cross section dependence in panels. Cambridge Working Paper in Economics, 0435, University of Cambridge.

RUS (Regional Utveckling och Samverkan) 2016 Körsträckedata. Available at <http://extra.lansstyrelsen.se/rus/Sv/statistik-och-data/korstrackor-och-bransleforbrukning/Pages/default.aspx> (access date August 21, 2016).

Rytwinski, T., Soanes, K., Jaeger, J., Fahrig, L., Findlay, S., Houtalan, J., van der Ree R., van der Griff E. 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. PLOS ONE 21, 1-25.

Seiler, A. 2004. Trends and spatial patterns in ungulate-vehicle collisions in Sweden. Wildlife Biology 10, 301-310.

Schaefer M. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bulletin of the Inter-America Tropical Tuna Commission 1, 25-56.

Schwabe, K.A., Schuhmann, P.W., Tonnikov, M. 2002. A dynamic exercise in reducing deer-vehicle collisions: Management through vehicle mitigation techniques and hunting. Journal of Agricultural and Resource Economics 27, 261-280.

Snow N., Porter, W., Williams, D. 2015. Underreporting of wildlife-vehicle collision does not hinder predictive models for large ungulates. Biological Conservation 181, 44-53.

Swedish Statistics 2016. Land use in Sweden. Available at [http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START\\_MI\\_MI0803\\_MI0803A/MarkanvLan/?rxid=f45f90b6-7345-4877-ba25-9b43e6c6e299](http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START_MI_MI0803_MI0803A/MarkanvLan/?rxid=f45f90b6-7345-4877-ba25-9b43e6c6e299) (access date November 18, 2016).

Svenska Jägareförbundet 2017a. Rådjur, population. Available at <https://jagareforbundet.se/vilt/vilt-vetande/artpresentation/daggdjur/radjur/radjur-population/> (access date May 21 2017).

Svenska Jägareförbundet 2017b. Älgar, population. Available at <https://jagareforbundet.se/vilt/vilt-vetande/artpresentation/daggdjur/alg/alg-population/> (access date May 22 2017).

Thurfjell, H., Spong, G., Olsson, M., Ericsson, G. 2015. Avoidance of high traffic levels results in lower risk of wild boar-vehicle accidents. Landscape and Urban Planning 133, 98-104.

Trafikanalys 2017. Road traffic injuries 2015, Table 6.1 pp. Available at [http://www.trafa.se/globalassets/statistik/vagtrafik/vagtrafikskador/vaegtrafikskador\\_2015.pdf](http://www.trafa.se/globalassets/statistik/vagtrafik/vagtrafikskador/vaegtrafikskador_2015.pdf) (access date March 23 2017).

Trafikverket 2014. Prognos för personresor 2030. Report no 2014:071, Borlänge, Sweden.

Trafiksäkerhet 2017. Hastighetens betydelse for trafiksäkerheten. Available at <http://www.trafiksakerhet.se/hastighet.htm> (date of access July 25, 2017).

Viltdata 2017. Statistics on wild life populations. Available at <http://www.viltdata.se> ((access date February 13, 2017).

Witmer G.W., DeCalesta D.S. 1991. The need and difficulty of bringing the Pennsylvanian deer herd under control. Fifth Eastern Wildlife Damage Control Conference (1991), paper 45, at <http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1044&context=ewdcc5> (access date July 13, 2017).