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Costs of traffic accidents with wild boar populations in Sweden

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Abstract: Traffic accidents with wild boar have increased rapidly over the last years in Sweden. This paper calculates and predicts costs of current and future accidents, totally and for different Swedish counties, based on estimates of wild boar populations. A logistic population model is assumed, and econometric methods are used for calculating populations with panel data on traffic accidents, traffic load, and landscape characteristics for each county. The results show an average growth rate of 0.48, which varies between 0.39 and 0.52for different counties. This, together with predictions on changes in traffic load, forms the basis for calculations of costs of traffic accidents for a 10 year period. In total, the predicted costs can increase from 60 million SEK in 2011 to 135 or 340 million SEK in 2021 in present value depending on hunting pressure. The variation in cost increases is, however, large among counties, increasing by tenfold in Stockholm and Södermanland where the wild boar populations are relatively small and by approximately 50% in counties with mature populations.

Key words: traffic accidents, costs, wild boar, econometrics, land scape characteristics, Sweden.

JEL codes: Q29, Q57

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1.Introduction

The numbers of wild boar traffic accidents in Sweden have increased continuously during the latest decade. For example, between 2003-2011 the reported number of traffic accidents increased by approximately 250% (Nationella Viltolycksrådet, 2013; Jägerbrand, 2012). Due to the relatively low height of wild boars drivers seem to have difficulties in detecting the animals on or close to the road. Wild boars often travel in groups and vehicle collisions with several animals may cause more damages. Furthermore, the low angle of impact at collision and the heavy weight of wild boars give, in general, rise to more serious vehicle damage than compared to e.g. deer collisions. 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, among other, traffic accidents, there is, to the best of our knowledge, no study estimating costs of traffic accidents with wild boar in Sweden. In principle, it would be relatively easy to calculate such costs by simply multiplying the number of traffic accidents from wild boar with the cost per accident. However, this would not allow us to predict future cost from expected increases in the size of the wild boar population. Furthermore, the expected increases of the populations differ among regions in Sweden because of varying landscape and climate characteristics. The purpose of this study is to calculate and predict dynamic and spatial dispersion of costs from traffic accidents by estimating wild boar population using a model that accounts for differences in land-scape characteristics among regions.

Naturally, one important reason for the increase in traffic accidents is the rapid increase of the wild boar population. The hunting bag statistics show an annual mean increase of ca 30% during 2000-2010 in Sweden, and the biological growth rate was estimated to ca 48% in the same period (Lemel and Truvé, 2008; Jansson et al., 2011). However, according to Tham (2004) wild boars have existed in Sweden over thousand years. They were eradicated in the end of the seventeenth century but reinstated in 1723 for hunting purposes on the island Öland. This caused protests among farmers and they were again eradicated in the end of 1770. Once again minor populations were kept in enclosures but some individuals escaped in the 1970's, and the wild boar population reestablished itself. The wild boar population was accepted as part of the Swedish fauna by the parliament in 1988 (SFS 1987: 905).

There is a relatively large body of literature on costs and benefits of measures curbing traffic accidents with wildlife, such as fences, road tunnels, and warning signs (e.g. Seiler, 2004; 2005; Hussain et al., 2007; Huijser et al., 2009). A common approach has been to derive the impact of mitigation measures on accidents by statistical analysis. The role of landscape characteristics for traffic collisions with deer has been investigate by Hussain et al. (2007), who used a panel data set for explaining collisions in different counties in Alabama, USA. A similar study using landscape attributes, traffic load etc. to assess and predict risk zones for ungulate-vehicle collisions in Sweden was conducted by Seiler (2004, 2005). Huijser et al. (2009) calculated costs and benefits from measures such as fences along motor ways and speed limits which reduce the number of collisions with large ungulates (elk, moose, and deer) in USA and Canada.

However, these cost and benefit calculations of mitigation measures do not include wildlife population dynamics, which is necessary when aiming to predict future costs of traffic accidents. Wildlife population models are numerous in the ecological literature, with a variety of scopes and methods. Commonly used background data or methods are, for example; hunting statistics, capture-recapture, indirect indices, line-transect surveys of tracks or pellets and direct observation at feeding sites (Avecedo et al., 2007). The most common approach to estimate ungulate populations of extensive areas, like counties or nations, has been to use bags statistics. This was used to estimate the Swedish wild boar population in 2005, resulting in ca 40 000 animals (Svenska Jägarförbundet 2010), which was believed to exceed 150 000 animals 2010 (Jansson et al. 2011).

Boitani et al. (1995) employed a catch per unit of effort method in an attempt to estimate the wild boar population in Tuscany (Italy). This approach requires good information regarding the amount of effort put in to capturing the animals and that the population is closed during capturing events. It is not plausible to enclose the population or to conduct a capture-recapture study at a larger scale. Geisser and Reyer (2005) studied the wild boar population density in Thurgau (Switzerland), where hunting statistics, road accidents and various ecological factors were analysed by principal component analysis and stepwise regression to obtain a population density index. Their study showed that an increased population density is correlated to traffic accidents, and that the population density to some extent depends on, and in some cases significantly related to, ecological factors.

The problem in our case with using hunting statistics is the lack of appropriate effort variables, such as number of hunters and time spent on hunting wild boars. Such an effort variable is not available at the county level, in Sweden. Therefore, this study makes use of data on traffic accident for different counties during the period 2003-2012 with different formulations of traffic load as a measure of effort. The relationship between traffic load and wildlife accidents has previously been described (Seiler, 2004), who also pointed out the role of landscape characteristics. Our approach and dataset also allows for the estimation of the impacts of landscape characteristics on growth of wild boar populations in different counties. The theoretical basis rests on long term experiences from estimation of fish populations, with a common assumption of a logistic functional form (Schaefer, 1954). To the best of our knowledge, the approach of using road kills to estimate population development and costs of traffic accidents involving wildlife has not been applied by any earlier study. In our view, a contribution of this paper is thus the development and application of data on traffic accidents for approximating wildlife populations. In addition, we estimate and predict costs of traffic accidents with wild boars in Sweden accounting for differences in landscape characteristics among counties, which has not previously been carried out.

The paper is organized as follows. First, we present the theoretical framework for estimating wild boar populations based on data on traffic accidents and traffic load. Section 3 shows data retrieval and results from the statistical analyses. Calculated and predicted costs of traffic accidents from wild boars are presented in Section 4. The paper ends with a summary and conclusions.

2. Theoretical background for calculations and predictions of wild boar populations

Following the literature in fishery economics (e.g. Shaefer, 1954; Kataria, 2007), it is assumed that the development of wild boars over time in each county *i*, where *i =1,..n* counties, depends on population growth, traffic accidents, and hunting. The population growth is assumed to follow a logistic function, which is written as:

$$\frac{\partial P_t^i}{\partial t} = r^i P_t^i \left(1 - \frac{P_t^i}{K^i}\right) - V_t^i - H_t^i \qquad (1)$$

where P_t^i is population in period *t*, r^i is the intrinsic growth rate, K^i is the maximum population without hunting and traffic accidents, V_t^i is individuals killed in traffic accidents, and H_t^i is hunting.

Traffic accidents, in turn, are assumed to depend on traffic load, T_t^i, and a coefficient, a^i, relating accidents to the traffic load and P_t^i, which is written as

$$V_t^i = a^i T_t^i P_t^i \qquad (2)$$

Equation (2) thus shows that the number of killed animals from traffic accidents can be calculated when P_t^i, a^i, and T_t^i are quantified. Since we don't have information on P_t^i and a^i they are estimated by assuming that accident per unit of traffic load, S_t^i, is proportional to the population where

$$\frac{V_t^i}{T_t^i} = S_t^i \qquad (3)$$

which is used to derive regression equations that can be estimated with statistical tools.

However, landscape characteristics, L_t^i, are not accounted for in (1). In principle, these can enter the population dynamics in two ways; directly as an additional variable in a similar way as V_t^i and H_t^i, or indirectly on the impact on the intrinsic growth parameter, r^i.

Direct impacts of landscape characteristics are formulated as effects on population growth according to

$$\frac{\partial P_t^i}{\partial t} + H_t^i = r^i P_t^i \left(1 - \frac{P_t^i}{K^i}\right) - V_t^i + f^i L_t^i \qquad (4)$$

where f^i reflects the marginal impact on population growth of landscape characteristics L_t^i.

It is now assumed that a proportional change in population can be approximated by a proportional change in accidents per unit traffic load. The latter is obtained by replacing P_t^i in equation (4) with $S_t^i \equiv a^i P_t^i = \frac{V_t^i}{T_t^i}$ in equation (3), writing the left hand side of (4) accordingly as $a^i(\frac{\partial P}{\partial t} + H_t^i)$, and dividing by S_t^i, which gives

$$\frac{\partial S_t^i}{\partial t} \Big/ S_t^i = r^i - \frac{1}{a^i K^i} S_t^i - a^i (T_t^i + \frac{H_t^i}{S_t^i}) + f^i \frac{L_t^i}{S_t^i} \quad (5)$$

The derivative in the dependent variable is obtained by making a finite difference approximation according to

$$\frac{\partial S_t}{\partial t} = \frac{S_{t+1} - S_{t-1}}{2} \quad (6)$$

The regression equation for population growth with direct impacts of landscape characteristics is then specified as

$$Y_t^i = \alpha^{i1} + \alpha^{i2} S_t^i + \alpha^{i3}(T_t^i + \frac{H_t^i}{S_t^i}) + \alpha^{i4} \frac{L_t^i}{S_t^i} + \varepsilon_t^{iD} \quad (7)$$

where the correspondence of coefficients in equation (7) with those in equation (5) are

$$Y_t^i = \frac{S_{t+1}^i - S_{t-1}^i}{2} \Big/ S_t^i, \quad r^i = \alpha^{i1}, \quad \alpha^{i2} = \frac{1}{a^i K^i}, \quad \alpha^{i3} = a^i, \quad \alpha^{i4} = f^i$$

We can now calculate carrying capacity as the population level where eq. (5) equals zero without any hunting and accidents and recognizing that $S_t^i = a^i P_t^i$, which gives

$$K^i = \frac{r^i + \alpha_{i4} L_t^i}{\alpha^{i2} \alpha^{i3}} \tag{8}$$

With respect to the indirect specification, it is assumed that the intrinsic growth rate shows a linear dependence on landscape characteristics, $r^i = b^i + c^i L_t^i$. The wild boar population growth equation can then be written as

$$\frac{\partial P_t^i}{\partial t} = (b^i + c^i L_t^i) P_t^i \left(1 - \frac{P_t^i}{K^i}\right) - V_t^i - H_t^i \tag{9}$$

Following the same assumption and steps as for the direct specification gives population unit growth rates as

$$\frac{\partial S_t^i}{\partial t} \Big/ S_t^i = b^i + c^i L_t^i - \frac{1}{a^i K^i} S_t^i - a^i (T_t^i + \frac{H_t^i}{S_t^i}) \tag{10}$$

The regression equation is then specified as

$$Y_t^i = \alpha^{i5} + \alpha^{i6} L_t^i + \alpha^{i2} S_t^i + \alpha^{i3} (T_t^i + \frac{H_t^i}{S_t^i}) + \varepsilon_t^{iID} \tag{11}$$

$$r^i = \alpha^{i5} + \alpha^{i6} L_t^i$$

and Y_t^i, α^{i2}, and α^{i3} are defined in the same was as for the direct specification. The intrinsic growth rate, $r^i = \alpha^{i5} + \alpha^{i6} L_t^i$, varies over time and among counties because of L_t^i. Carrying capacity is calculated for the population level where (9) equals zero without any hunting or traffic accidents, i.e. $0 = r^i - \alpha^{i2} S_t^i$ and $S_t^i = a^i P_t^i$, which gives

$$K^{il} = \frac{r^i}{a^i \alpha^{i2}} \tag{12}$$

Predictions of future accidents requires forecasts of future populations, and they are, for both the direct and indirect models, found by integrating the logistic population growth model in (1) with respect to time. However, traffic accidents and hunting may give create difficulties in finding solutions, and we therefor transform equation (1) into a more simple representation where traffic accidents and hunting are expressed in terms of a proportion, z^i, of the population, which is written as

$$\frac{\partial P_t^i}{\partial t} = r^i P_t^i \left(1 - \frac{P_t^i}{K^i}\right) - z^i P_t^i \tag{13}$$

where z^i is the combined relative decline in population from both accidents and hunting. We can then use one form of solution for a non-linear first-order differential equation (e.g. Matthews, 2014), which gives

$$P_t^i = \frac{(r^i - z^i)K^i}{r^i + \left(\frac{r^i(K^i - P_0^i) - z^i K^i}{P_0^i}\right)e^{-(r^i - z^i)t}} \tag{14}$$

where $P_t^i \to K^i\left(1 - \frac{z^i}{r^i}\right)$ when $t \to \infty$.

Thus, future populations can be determined for different levels of pressures z^i when estimates of intrinsic growth rates, carrying capacity, a base year population, i.e. P_0^i , are available.

3. Data retrieval and estimation of regression equations

The two regression models in eq. (7) and (11) constitute the basis for the numerical approximation of wild boar populations, and subsequent calculations of costs of traffic accidents in different counties in Sweden. In this section we therefore give backgrounds with respect to data collection, and estimation of these regression equations.

3.1 Data retrieval

The data needed for estimating regression equations specified in equation (7) and (11) are; traffic accidents, traffic load, animals killed by hunting, and landscape characteristics. In this study we make use of a panel date set on these variables which includes 13 counties with wild boar populations during the period 2003-2012 (Nationella Viltolycksrådet, 2013). During this period the number of traffic accidents with wild boar has increased six fold from approximately 750 to 4100 (Figure 1).

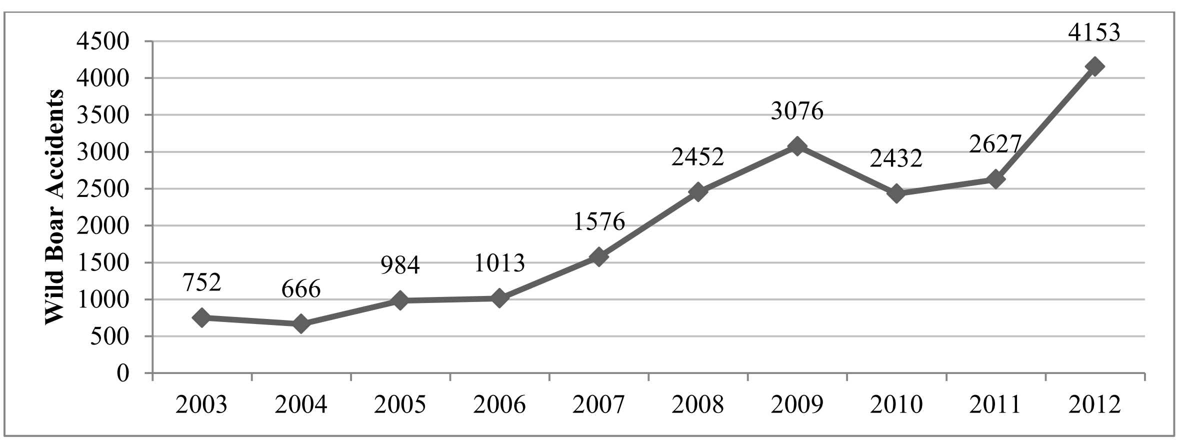


Figure 1: Traffic accidents from wild boar over 2003-2012
Source: Nationella Viltolycksrådet (2013)

The data on wild boar accidents, as collected by the Nationella Viltolycksrådet (2013),are to be considered as relatively accurate. Since 1987 drivers are obliged by §40 *Jaktförordningen* to report to the authorities if they are involved in a wildlife accident and injuring the animal. Further, since 2010 it is compulsory for vehicle drivers to report the accident to the police even if the animal is not hurt. However, according to Leisner and Folkesson (2006) the non-reported number of accidents may be significant, the consequences of which are discussed in Section 4 where we present the population calculations.

Traffic accidents are distributed heterogeneously among the counties, and the highest levels are found in the southern county Skåne (Figure2).

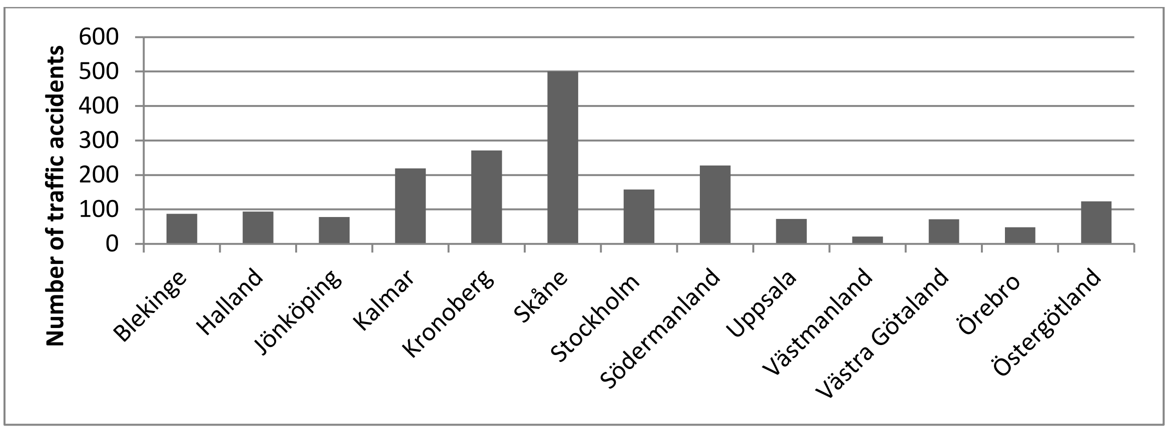


Figure 2: Average number of traffic accidents over 2003-2012 in different Swedish counties Source: Nationella Viltolycksrådet (2013)

The number of animals killed by traffic accidents corresponds to approximately 5% of those killed by hunting, which increased during the period 2003-2012 from approximately 17000 to 97000 (Viltdatabasen, 2014). The relative change is thus in the same order of magnitude as the relative increase in traffic accidents. The allocation of killed animals by hunting among counties also follows the same pattern as that of traffic accidents (Figure 3).

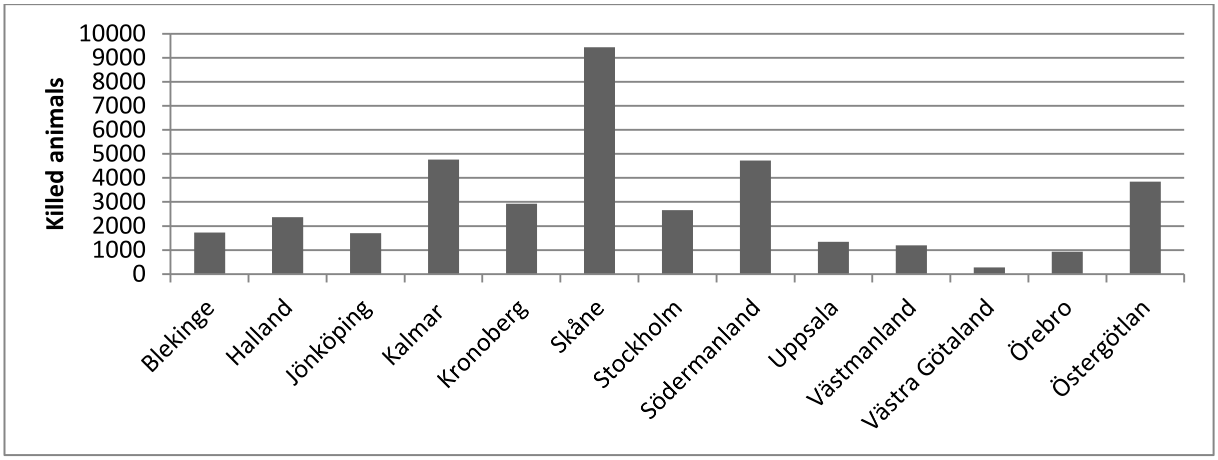


Figure 3: Average number of killed animals from hunting over 2003-2012 in different Swedish counties
Source: Viltdatabasen (2014)

However, when we relate the number of animals killed by traffic accidents presented in Figure 2 to traffic load the pattern changes (Figure 4). Traffic load is measured in millions of kilometers driven in each county (Trafik Analys, 2013a,b). This statistical measure does unfortunately not include foreign traffic, which will underestimate the true amount of kilometers driven, and thereby overestimate the accident intensities presented in Figure 4.

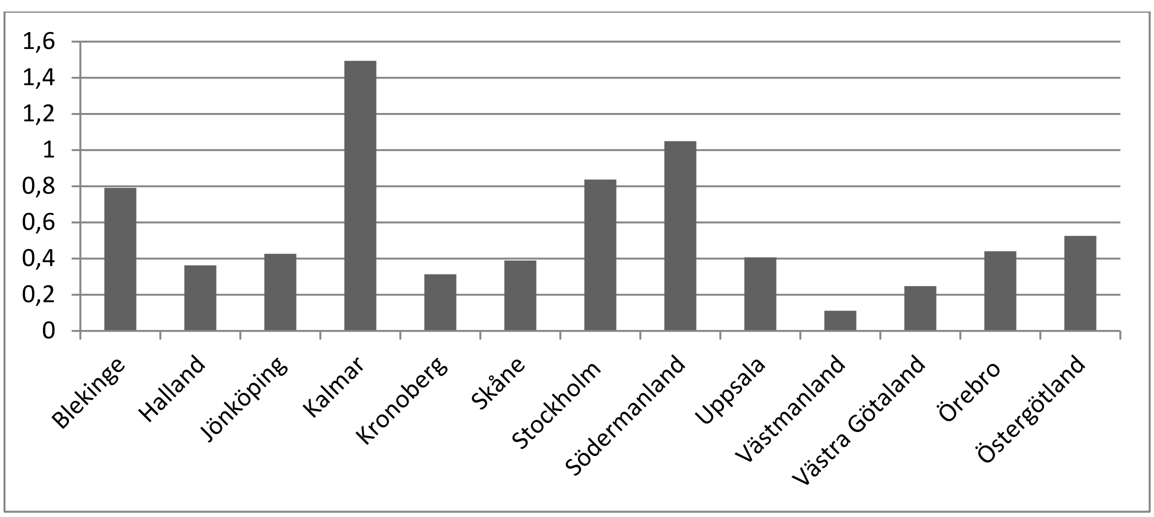


Figure 4: Traffic accidents per traffic load in million driving km.
Source: Nationella Viltolycksrådet (2013), Trafik Analys (2013a,b)

The largest number of accidents per traffic load occurs in Kalmar county, where it is almost 50% higher than in the county with the second largest number of accidents per traffic load. The Skåne county has the largest number of wild boar accidents but shows a relatively low accident intensity. The variations in intensities can be explained by the presence of wildlife fences along certain roads but also by landscape characteristics which promote growth of wild boar population.

In this study we therefore include the length of fences as explanatory variable measured as the length of the fences in relation to the road kilometers in the county i.e. a ratio between the two. Included landscape characteristics are: areas of deciduous and boreal forests, pasture, and arable land. A deciduous component, specially beech (Fagus) and oak (Quercus), of the forest is appreciated by wild boars, and generally regarded to promote population development (Markström & Nyman, 2006). Detailed data on tree species composition, i.e. here to discern the occurrence of these broadleaved stands, are however not available for the period under study why we confine the forest habitat parameter to separate only between deciduous and coniferous forest. Both pastures and arable land constitute important feeding sites for wild boar (Markström & Nyman, 2006), and the distribution of such habitats may naturally influence their movements, especially crop fields in late summer (Jansson et al., 2012). However, although these habitats are attractive per se, the size and shape of such fields are also important, where small and narrow fields are preferred by wild boars rather than large open areas (Jansson et al., 2011).

It should also be recognized that deciduous forest, as well as other types of forest, may provide some difficulties for drivers to detect movements of wild boars in the landscape and thereby, *ceteris paribus*, increasing the probability of an accident but the problem is less accentuated for deciduous forest. 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. However, a more open type of landscape would be less attractive to the wild boars that often tend to congregate in the intermittent area of forest and open landscape elements. Hence, we would expect a negative sign for the variables arable and pasture land.

In Sweden, supplemental feeding of wildlife, mainly ungulates, is allowed and extensively applied in many areas. For wild boar, this is part of the management (for hunting and/or to lure them from crop fields) and feeding stations are often frequently utilized and generally believed to promote its reproduction (Bergqvist & Pålsson, 2010). Thus, we are well aware of that the extent (volumes and frequency) and distribution of supplemental feeding stations may confound the otherwise expected relationship between population development and habitat/landscape type, as well as influencing the local movements of wild boar. However, neither the number of feeding stations nor their positions are registered, why we in this study are not able to include them in our estimates. The estimates of the population dynamics will then be biased upwards for counties with relatively much feeding.

We construct two different specifications of the effort variable in terms of traffic load, $T_i, i = 1{,}2$, where $T_1$is specified as $\frac{Traffic\ load}{Road\ area\ in\ ha}$, and T_2 as $\frac{Traffic\ load}{County\ sizein\ 1000\ ha}$. Because of these two specifications of traffic load we will have two constructs of S_t^i and Y_t^i respectively. We add fences as a control variable which affects number of accidents but not population per se. Descriptive statistics of all variables are presented in Table 1.

Table 1: Descriptive statistics (n=130 number of observations)

	Mean	Standard deviation	Min	Max
Dependent variables				
Y_1	0.3019	0.3566	-0.3604	1.5275
Y_2	0.2517	0.2923	-0.3604	1.0293
Independent variables				
T_1	23 822	18573	8 567	95618
T_2	462995	466156	151141	2046202
S_1	0.0084	0.0101	0.00008	0.0455
S_2	0.0004	0.0005	0.000007	0.0024
H, animals killed by hunting	2913	2923	0	13339
Ara, arable land/total area	0.1898	0.0967	0.0597	0.4637
Dec, decidious forest/total area	0.0037	0.0032	0.0003	0.0131
Pas, pasture land/total area	0.0345	0.0160	0.0056	0.0615
For, forest land/total area	0.5817	0.1137	0.3236	0.7667
Fenc, fence length/ road length	0.0126	0.0081	0.0001	0.0347

3.2 Regression equations and results

The data set is a panel with observations for 13 counties over the period 2003-2012. We therefore test for fixed or random effect model, and if a random effect model is statistically better than an ordinary least square estimate. In order to verify that the relationship should be represented by a random effects model, compared to a fixed effects model, the Hausman test is used (appendix A, Table A2). The observed p-value for the tests indicated that the null-hypothesis cannot be rejected, favoring a random effects model. However, according to the

Breusch-Pagan-Lagrange multiplier test the model can be reduced to an ordinary least squares (OLS) regression model, instead of a random effects model. Hence the produced result is estimated using OLS regression models.

Tests indicated the presence of heteroscedasticity and we therefore estimated all four models, i.e. the two models specified in equations (7) and (11) with two different effort variables, with robust standard errors. However, all variables on landscape characteristics presented in Table 1 could not be included in the estimation due to multicollinearity. By removing some variables we managed to get an acceptable mean variance inflation factor of 1.11 and 1.10 for model 1 and model 2 respectively. The regression equations were then specified as:

Indirect model:

$$Y_{it}^{k} = \alpha^{k1} + \alpha^{k2}(T_{it}^{k} + H_{it} / S_{it}^{k}) + \alpha^{k3} S_{it}^{k} + \alpha^{k4} Ara_{it} + \alpha^{k5} Dec_{it} + \alpha^{k6} Fenc_{it} + \varepsilon_{it}^{k} \quad (15)$$

Direct model:

$$Y_{it}^{k} = \beta^{k1} + \beta^{k2}(T_{it}^{k} + H_{it} / S_{it}^{k}) + \beta^{k3} S_{it}^{k} + \beta^{k4} Ara_{it} / S_{it}^{k} + \beta^{k5} Dec_{it} / S_{it}^{k} + \beta^{k6} Fenc_{it} + \upsilon_{it}^{k} \quad (16)$$

where $k=1,2$ for the two measures of T_{it}.

In order to make statistical comparisons of the model specifications the Akaike Information Criterion, *AIC,* is used where the model with the lowest *AIC* value (AIC_{min}) is to be considered preferable. Table A6 in appendix A shows the information relevant for Model 1 and Model 2. According to delta *AIC,* Δ_i, which is less than 2, the models which have $AIC > AIC_{min}$ can be considered to have a satisfactory fit and there exists substantial evidence for the model specifications, i.e. the difference between the models is small and it is not possible to distinguish between the two. However when computing the parameters relevant for the wild boars and the population size, the indirect model produces the most plausible result, and we therefore present this model in the main text. The relative information loss between the models is to be considered small.

Table 2: Regression results of the logistic models

	Model 1; dependent variable Y^1		Model 2; dependent variable Y^2	
	Coefficient	**p-value**	**Coefficient**	**p-value**
Intercept, r	0.569	0.000*	0.547	0.000*
S^1	-9.365	0.002*		
S^2			-166.282	0.001*
T^1**+H**	-6.83-8	0.055		
T^2**+H**			-5.69-9	0.032**
Ara	-0.323	0.104	-0.352	0.030**
Dec	-2.707	0.753	-0.531	0.945
Fenc	-8.592	0.000*	-7.511	0.010*
R^2	0.085		0.118	
Prob.>F	0.002		0.003	

Significance Level: *=p<0.01, **=p<0.05, ***=p<0.1

All statistically significant estimates show expected signs; the traffic effort variable including hunting (T^1+H, T^2+H) is negative, the accident intensity (S^1, S^2) is negative, *Fenc* is negative, and the intercepts, the intrinsic growth rates, are positive. The landscape characteristics could have either sign, the significant negative coefficient of the share of arable land, *Ara*, can be explained by relatively large areas without hiding opportunities in the landscape, which is avoided by the wild boar. It is interesting to note that the construction of fences has, in average, decreased the annual increment in accidents by approximately 8-9%. Without the fences, the accidents in relation to traffic load would thus have increased by approximately 30% more than the averages of 0.30 and 0.25 presented in Table 1.

Unfortunately the models do not have a high R^2 value indicating that some variation has not been accounted for. On the other hand, the F-values are significant at the 5% confidence level. Since almost all coefficients are significant in Model 2, and the R^2 is somewhat larger than that for Model 1, we use results from Model 2 in the subsequent calculations. Furthermore, since only share of arable land is significant we use this when calculating the intrinsic growth rates, totally and for each county. In average for total Sweden, this corresponds to the value of the intercept of Model 2 in Table 2, 0.547, minus the estimated coefficient of -0.352 times the average share of arable land, which from Table 1 is 0.1898. This gives an average intrinsic growth rate of 0.48, which is the same as that obtained by Lemel and Truvé (2008) and Jansson et al. (2011).

The estimated coefficient for the effort variable allows for the calculation of populations for the years 2004-2011 for which we have data on traffic accidents. The calculations are made according to

$$P_{it} = \frac{V_{it}}{a(T_{it} + H_{it} / S_{it})} + H_{it} = \frac{(V_{it})^2}{aT_{it}(V_{it} + H_{it})} + H_{it} \quad (17)$$

The calculated results are presented in Table 3.

Table 3: Calculated populations in different counties over the years 2004-2011

	2004	2005	2006	2007	2008	2009	2010	2011
Blekinge	1451	1349	1429	2730	3177	8267	5870	3681
Halland	1806	2268	2107	2980	4079	6539	5560	4481
Jönköping	1602	1483	1587	2557	6087	6839	5445	5387
Kalmar	3630	4518	3864	9325	18985	26361	17277	18310
Kronoberg	8995	11903	20638	25445	30416	30750	20712	28416
Skåne	7945	8689	8169	12889	19202	21130	19537	21067
Stockholm	1271	1940	2282	2874	4907	5118	4855	5591
Södermanland	5220	7803	6390	9845	12893	14010	12396	14199
Uppsala	903	1467	2841	2982	3682	6454	3226	4986
Västmanland	328	506	2480	1541	1858	3243	3673	4648
Västra Götaland	254	714	149	499	1804	2923	2022	2841
Örebro	1121	1558	2194	2516	3321	6406	2792	4773
Östergötland	1511	3151	2635	4399	9738	12369	8651	8231
Total	36037	47349	56765	80582	120149	150409	112016	126611

According to our calculations, the total population shows an almost fourfold increase during the period 2004 to 2011, and amounted to approximately 126 000 animals in 2011. The relative increases have been particularly large in Västmanland and Västra Götaland where the population has increased more than ten times. When comparing the estimates with the few existing other estimates, it can be noted that the number for 2005 is close to the level of 40000 suggested by Swedish Jägarförbundet (2010), but a little bit lower for the year 2011 than the report of 150000 by Jansson et al. (2011).

However, our estimates can be biased because of the existence of unreported accidents. According to Seiler and Folkesson (2006) the factor relating unreported to reported accidents involving damage to property amounts to 0.6 for moose and deer. Similar estimates are not carried out for wild boar. If the factor is in the same order of magnitude as for moose and deer, our calculations of wild boar population can be considerably underestimated.

4. Cost of traffic accidents from wild boar populations

Costs of traffic accidents from wild boar accidents for each county are calculated as unit cost per accidents times the number of accidents. There exist no official statistics on unit cost of traffic accidents. In this study, data on average costs of accident including a wild boar have been obtained from an insurance company (Länsförsäkringar, 2014). These data indicate that the cost for a wild boar accident is roughly 23 000 SEK. Relating this to costs of accidents with other animals, the cost for roe deer and elk is 22000 and 38000 SEK respectively, it is apparent that a collision with wild boars can cause a lot of damage to the car. Fortunately it is rare to see damage to the people traveling in the car, and will thus not be included in this study.

The predicted number of accidents is estimated based on equation (2) in Section 2, i.e. $V_t^i = aT_t^i P_t^t$, which implies a need for predictions of traffic load, T_t^i, and wild boar populations,

P_t^t. Traffic loads by cars are expected to increase by 2% per year for all counties, but the deviations from the mean can be large (Trafikverket, 2014). The highest annual increase, 2%, is expected to occur in Stockholm , and the smallest, approximately 0.1%, in Gotland, see Table B5 in appendix.

Predictions of future wild boar populations are based on equation (14) in Section 2, which requires estimates of carrying capacity, K^i, intrinsic growth rates, r^i, and base year populations, P_0^i. Intrinsic growth rates are calculated by using equation (11) in Section 2 and the results presented in Table 3 in Section 3. Carrying capacity is calculated by recognizing that the a^i coefficient includes both effort and animals killed by hunting. The effort is approximately 1/12 of the total reduction in each year, and we have therefore adjusted the a^i coefficient in order to capture this effect. The results are presented in Table 4.

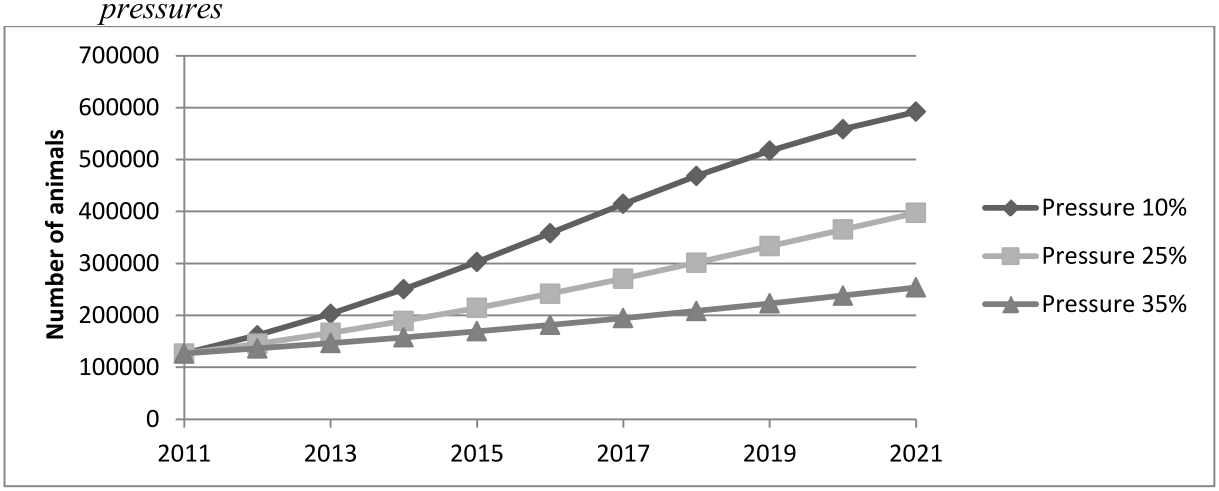
Table 4: Intrinsic growth rate, and max population from regression results of Model 2

Counties	Intrinsic Growth Rate	Max population
Blekinge	0.501	53042
Halland	0.471	49866
Jönköping	0.511	54100
Kalmar	0.502	53148
Kronoberg	0.524	55477
Skåne	0.389	41184
Stockholm	0.498	52724
Södermanland	0.470	49760
Uppsala	0.464	49124
Västmanland	0.468	49548
Västra Götaland	0.471	49866
Örebro	0.494	52301
Östergötland	0.478	50607
Total	0.48	660745

According to our calculations, the wild boar population has a potential to grow by approximately 260% from the 2011 level. The intrinsic growth rates differ, being lowest for Skåne and highest for Kronoberg county.

Assigning P_0^i at the population levels in 2011 (Table B1 and B2 in appendix B) and using the intrinsic growth rates and carrying capacities in Table 4 we can predict P_t^i and total population in Sweden, P_t, for future years (see equation (14) in Section 2). There is also a need for assumptions on hunting pressure on the population. In order to compare the results with respect to these pressures, we present calculations for three different pressures; 10%, 25% or 35% of the population is reduced every year. Given these assumptions, the predicted development of total populations over the 10 subsequent years are as displayed in Figure 4.

Figure 4: Calculated and predicted total wild boar population under different hunting pressures

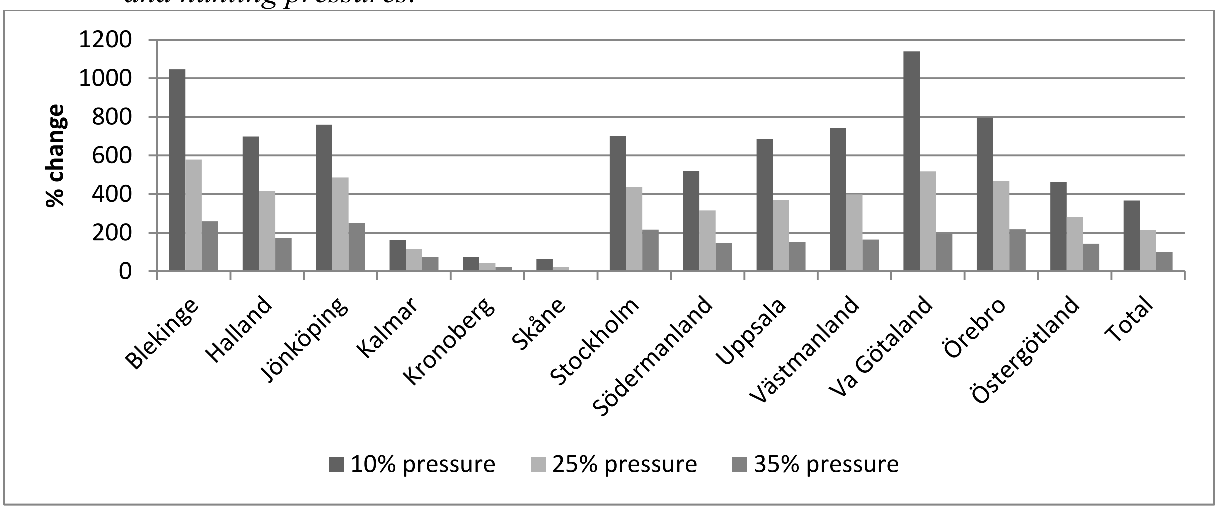


Source: Tables B1-B3 in appendix B

The prediction is done for the years 2012 and 2013 as well due to the loss of observations in the estimation procedure. The total increase in the population over the 10 year period ranges between 50% and 390% depending on hunting pressure. However, exogenous factors can cause this prediction to become inaccurate i.e. extremely harsh winters will cause the population to deviate from the prediction.

The forecasted developments of the population in different counties show considerable differences (Figure 5).

Figure 5: Predicted increases in population from the 2011 level to 2012 for different counties and hunting pressures.

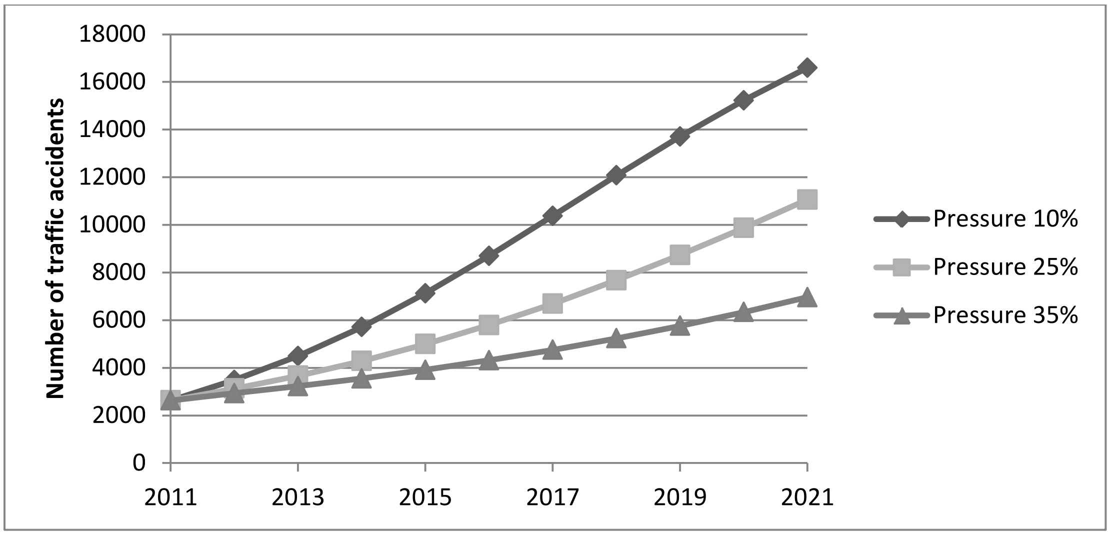


Source: Tables B1-B3 in appendix B

Irrespective of hunting pressure, the largest increases as measured in percent from the 2011 level occur in counties with relatively low population levels in this year, e.g. Blekinge and Västra Götaland, where the populations can show a tenfold increase. For these counties the level of hunting pressures has large effect of the population and its growth. When the hunting pressure corresponds to 35% of the population level each year, the predicted increases are reduced to a doubling of the population.

The predictions of population increases presented in Figure 5 provide the basis for the determination of future traffic accidents. We also need to consider expected changes in traffic load, the annual increase of which varies between 0.001 and 0.02 between different counties (Table B5 in appendix). The combined effect of growths in wild boar populations and traffic load on total traffic accidents is presented for different years in Figure 6.

Figure 6: Predicted development of total traffic accidents over 2011-2021

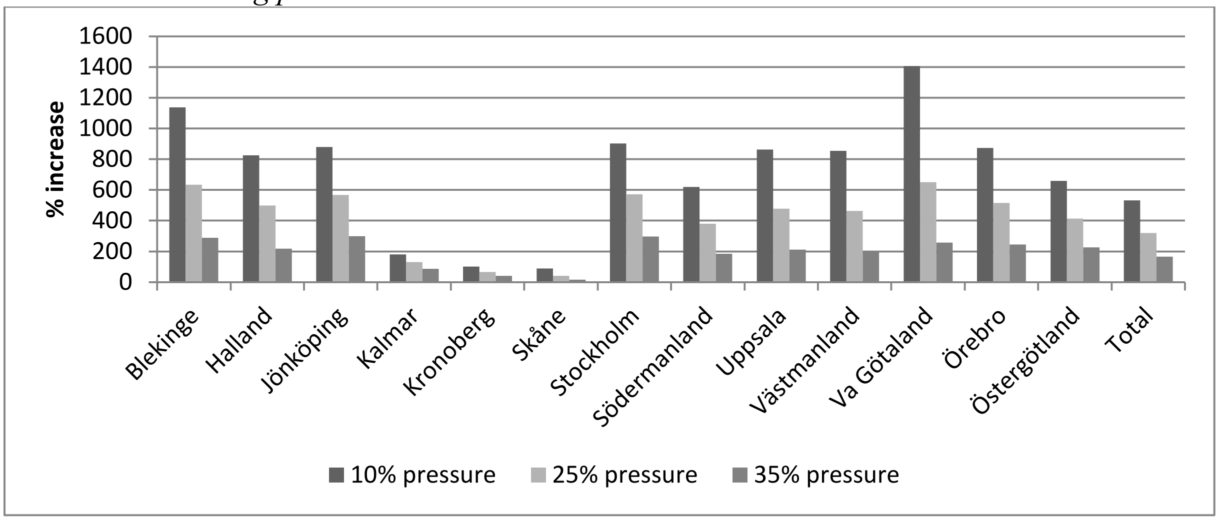


Source: Tables B5-B7 in appendix B

The predicted number of total accidents in 2012 and 2013 under the assumed low pressure corresponds to, respectively, 3483 and 4493 (Table B5). These figures can be compared with the actual number of 4170 in 2012 and 3551 in 2013 (Nationella Viltolycksrådet, 2014). The average number of predicted accidents between these years, 3988, is then relatively close to the actual average of 3860, although the precision in prediction for each year is not so high.

The difference is large between the predicted number of traffic accidents depending on assumption of hunting pressure; it can very between approximately 6900 and 16300. The variation is also considerable between different counties (Figure 7).

Figure 7: Predicted increases in traffic accidents from 2011 level in % for different counties and hunting pressures

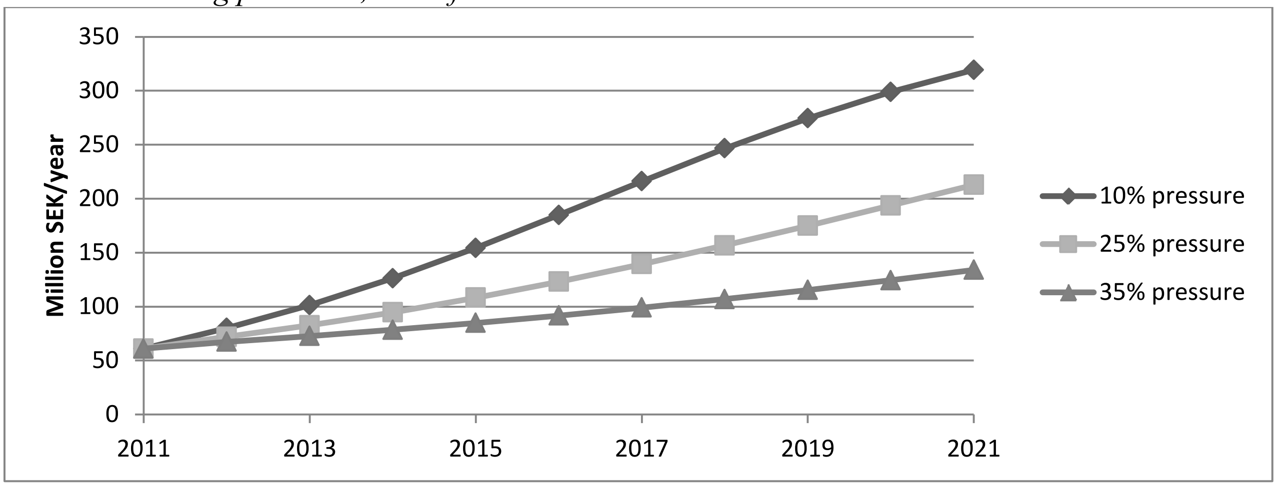


Source: Tables B5-B7 in appendix B

The predicted increases in traffic accidents follow to some extent those in populations, but can be either reinforced or counteracted by the increases in traffic load. For Blekinge, population has the largest increase but traffic load increase is relatively low and the combined effect show that the increase can range between 210% and 1150%. The reverse is the case for Stockholm county, and the percent increase in accidents is then predicted to be larger than the corresponding increase in the wild boar population. However, the corresponding range in the total increase is considerably lower, between approximately 100% and 500%, because of the low increases in counties with relatively large populations, Kalmar, Kronoberg, and Skåne.

When calculating costs of the traffic accidents presented in Figures 6 and 7 we also have to assign a value of the discount rate. There is a large debate on the correct level of the social discount rate, but recommendations range between 1% and 5% depending on time perspective (e.g. Boardman, 2010). We use the level on 2% in our calculations and assign the cost of SEK 23000 per accident, which give the development of costs under different pressures as shown in Figure 8.

Figure 8: Predicted development of costs in present value of traffic accidents under different hunting pressures, total for Sweden

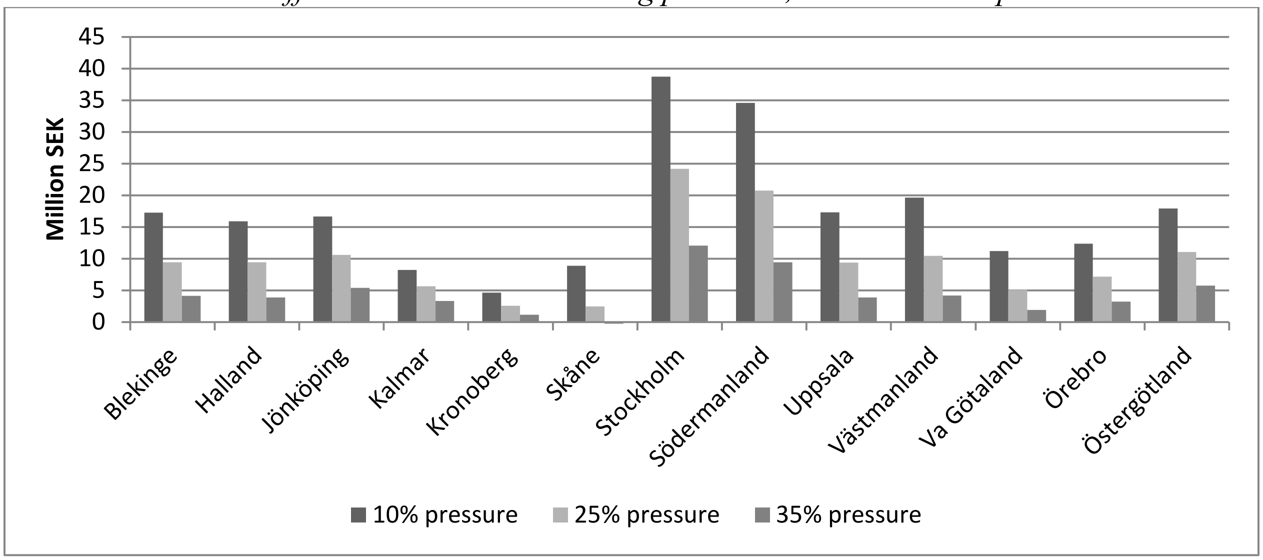


Source: Calculations based on Table B5-B7 in appendix B, 2% discount rate, and a cost of SEK 23000/accident

In 2011 the total number of traffic accidents was 2627, and with an average cost of 23000 per accident the total cost amounted to approximately 60 million SEK. Depending on hunting pressure this cost can increase to 135 or 320 million SEK in 2021. Each of the three different cost paths corresponds to a sum of discounted annual costs which amounts to 0.9, 1.4, or 2 billion SEK over the 10 year period. Recall that the cost is calculated as the expenses for insurance companies. Hunting pressures of 25% or 35% would then save expenses for the companies corresponding to 0.5 or 1 billion SEK compared with a pressure of 10%. The insurance companies would thus have an incentive to pay for increased hunting.

A further investigation of where these predictions of total cost increases occur, show that they are unevenly divided among counties (Figure 9).

Figure 9: Predicted increases in annual costs of traffic accidents from 2011 to 2021 in different counties and hunting pressures, million SEK in present value.



Source: Calculations based on Table B5-B7 in appendix B, 2% discount rate, and a cost of SEK 23000/accident

The largest annual costs increases occur in Stockholm and Södermanland county where they can amount to approximately 35-40 million SEK, which is explained by the relatively large increase in population or traffic load. The results in Figure 9 thus give some insights into the spatial targeting of hunting if reduction in traffic cost is an objective for wild boar management. The largest cost savings from a given increase in hunting in early years are likely to be obtained for the two counties with the largest predicted cost increases.

5. Summary and conclusions

The purpose of this study has been to estimate and predict costs of traffic accidents with wild boar in Sweden. The aim of predicting traffic costs required information on the development of the wild boar population over time. Such population models were estimated for different counties by means of data on traffic accidents and traffic load. A crucial assumption in this estimation was that of a logistic function of the population dynamics. Another important assumption was that the population growth rate can be derived from the growth rate in traffic accidents per unit traffic load. Given these assumptions and a panel data set over the period 2003-2012 for 13 counties we estimated population growth functions which accounted for differences in landscape characteristics among the counties. The calculated average intrinsic growth rate for Sweden amounted to 0.48, and it varied between 0.39 (Skåne) and 0.52 (Kronoberg). The calculated maximum population is approximately five times larger than current (2011) population levels.

In order to predict future wild boar populations we also needed to make assumptions of hunting pressure, and three levels were assigned; 10%, 25% or 35% of the population killed by hunting each year. Given the estimated growth rates and expected increases in traffic load, the predicted costs can increase from approximately 60 million SEK in 2011 to 135 or 340 million SEK in 2021 depending on hunting pressure. The relative increases are highest in counties with relatively low populations in 2011, high population and traffic load growth rates. The county facing the highest increase is Stockholm, which amounts to approximately 40 million SEK in 2021 under low hunting pressure. This is almost as high as the total cost of 60 million SEK in 2011.

The cost increases may put burden on the insurance companies which can transfer such costs by charging a higher premium for having a vehicle insured. This will in the end affect more people than the ones actually involved in accidents. On the other hand, the costs can decrease considerably, by approximately 60% under higher hunting pressure. The results also give some indication on the targeting of measures reducing the population where, for a given mitigation effort, the largest decrease is obtained in Stockholm and Södermanland county.

However, the logistic functional form on the population dynamics assumed in our study has been criticized because of the neglect of composition of population cohorts, and the assumption of a constant intrinsic growth rate (e.g. Clark, 1990). Choices of other functional forms or models, such as age-structured models, might give other predictions of population developments. On the other hand, it would not be possible to estimate such functions based on data on traffic accidents, which instead need data on biological parameters such as reproduction and survival rates for different cohorts. Another factor affecting the results is the existence of unreported accidents. Although there is an incentive to report in order to obtain compensation from insurance companies, not all accidents might be reported (Leisner and Folkesson, 2006). Our population estimates are affected if the share of unreported accidents has changed over the included period; if it has increased there is an overestimation and vice versa.

Appendix A: Regression results

Table A1: Regression Results of the Direct Model

Variable	Model 1	Model 2
Effort	-0.000000122	-0.00000000833**
Accident per unit of effort (S_t)	-5.573927**	-78.05831**
Arable Land	0.0008024**	0.0000545**
Deciduous Forest	-0.0068416	-0.0004208
Fences	0.00342	0.0002431
Intercept	0.3595199***	0.3071112***
Prob. > F	0.000	0.000
	$R^2 = 0.079$	$R^2 = 0.1252$
Significance Level: *=p<0.1, **p=<0.05, ***=p<0.01		

Table A2: Hausman Test for Fixed or Random Effect, Model 1 Indirect Specification

Variable	Fixed	Random	Difference	S.E
Effort	0.0000000289	-0.0000000683	0.0000000971	0.000000111
Accident per unit of effort (S_t)	-8.981529	-9.365629	0.3840993	4.556775
Arable Land	-2.567309	-0.3239128	-2.243396	4.617424
Deciduous Forest	33.31048	-2.706631	36.01711	68.66425
Fences	-12.28954	-8.592073	-3.697468	11.61849
Test: H_0: $\boldsymbol{Difference\ in\ coefficients\ is\ not\ systematic}$			$p = 0.9781$	

Table A3: Hausman Test for Fixed or Random Effect. Model 2 Indirect Specification

Variable	Fixed	Random	Difference	S.E
Effort	-0.0000000062	-0.00000000569	0.00000000051	0.00000000587
Accident per unit of effort (S_t)	-157.3535	-166.2829	8.929406	85.42251
Arable Land	-1.736539	-0.35192	-1.384619	3.755898
Deciduous Forest	42.73184	-0.5319168	43.26376	55.34918
Fences	-14.70066	-7.511348	-7.189311	9.109928
Test: H_0: $\boldsymbol{Difference\ in\ coefficients\ is\ not\ systematic}$			$p = 0.9233$	

Table A4: Hausman Test for Fixed or Random Effect. Model 1 Direct Specification

Variable	Fixed	Random	Difference	S.E
Effort	-0.0000000211	-0.000000122	0.000000101	0.000000115
Accident per unit of effort (S_t)	-8.650386	-5.573927	-3.076458	3.949366
Arable Land	0.0004249	0.0008024	-0.0003774	0.0003947
Deciduous Forest	-0.0201474	-0.0068416	-0.0133057	0.0094
Fences	0.187597	0.0034221	0.0153375	0.0108743
Test: H_0: $\boldsymbol{Difference\ in\ coefficients\ is\ not\ systematic}$			$p = 0.4819$	

Table A5: Hausman Test for Fixed or Random Effect. Model 2 Direct Specification

Variable	Fixed	Random	Difference	S.E
Effort	-0.00000000470	-0.00000000833	0.00000000364	0.00000000589
Accident per unit of effort (S_t)	-137.177	-78.05831	-59.11876	76.19104
Arable Land	0.0000444	0.0000545	-.0000101	0.0000203
Deciduous Forest	-0.001231	-0.0.0004208	-0.00008102	0.0006
Fences	0.0010882	0.0002431	0.0008451	0.0006724
	Test:		$p = 0.4378$	
H_0: $Difference\ in\ coefficients\ is\ not\ systematic$				

Table 6: AIC tests of Model 1 and Model 2

	Number of Parameters	AIC	Delta AIC (Δ_i)	Akaike Weight
Model 1:				
Indirect Specification	6	82.397	0	0.588
Direct Specification	6	83.112	0.71545	0.411
Model 2:				
Indirect Specification	6	37.188	0.81682	0.399
Direct Specification	6	36.371	0	0.601

Appendix B: Tables on population calculations, predictions of traffic load, wild boar populations, and traffic accidents

Table B1: Predicted number of animals with 10% pressure

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Blekinge	5314	7556	10534	14309	18827	23877	29103	34102	38534	42208
Halland	5670	7772	10443	13690	17429	21477	25576	29455	32897	35784
Jönköping	7728	10853	14828	19583	24871	30295	35416	39885	43527	46331
Kalmar	23136	28088	32782	36908	40302	42943	44913	46334	47337	48032
Kronoberg	33407	37745	41251	43920	45863	47229	48169	48804	49229	49511
Skåne	23490	25705	27658	29327	30715	31845	32746	33456	34008	34433
Stockholm	7906	10951	14772	19294	24287	29396	34234	38488	41993	44729
Södermanland	19346	25806	33542	42301	51610	60862	69463	76977	83193	88107
Uppsala	6862	9293	12326	15943	20025	24360	28673	32696	36228	39168
Västmanland	6441	8787	11750	15327	19418	23818	28249	32423	36116	39208
Va Götaland	4014	5611	7736	10472	13853	17824	22220	26776	31190	35192
Örebro	6718	9365	12754	16872	21568	26552	31452	35923	39732	42792
Östergötland	11780	15560	19947	24724	29577	34174	38247	41648	44351	46415
Total	161811	203093	250323	302670	358347	414653	468460	516967	558334	591909

Table B2: Predicted number of animals with 25% pressure

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Blekinge	4637	5810	7233	8937	10942	13256	15866	18737	21806	24992
Halland	5464	6627	7990	9568	11368	13388	15611	18008	20536	23141
Jönköping	6783	8473	10485	12832	15506	18471	21661	24985	28335	31597
Kalmar	21049	23818	26531	29108	31485	33618	35488	37091	38440	39559
Kronoberg	30794	32886	34677	36175	37404	38395	39185	39807	40294	40672
Skåne	21739	22359	22928	23448	23919	24345	24728	25072	25378	25651
Stockholm	6945	8565	10470	12669	15152	17888	20823	23879	26969	29998
Södermanland	17078	20396	24164	28370	32977	37919	43101	48412	53724	58912
Uppsala	6021	7233	8638	10245	12055	14060	16242	18567	20994	23472
Västmanland	5645	6821	8193	9775	11570	13576	15775	18137	20619	23170
Va Götaland	3492	4279	5223	6345	7666	9201	10961	12945	15144	17531
Örebro	5885	7272	8919	10843	13049	15523	18232	21119	24110	27119
Östergötland	9889	11777	13889	16201	18676	21263	23897	26513	29044	31433
Total	145420	166315	189340	214515	241769	270902	301568	333272	365395	397247

Table B3: Predicted number of animals with 35% pressure

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Blekinge	4231	4854	5558	6350	7236	8224	9317	10519	11831	13253
Halland	4998	5564	6184	6862	7601	8402	9268	10199	11195	12256
Jönköping	6214	7145	8191	9356	10646	12060	13599	15256	17021	18881
Kalmar	19838	21371	22891	24380	25823	27206	28518	29750	30897	31955
Kronoberg	29460	30396	31230	31967	32614	33178	33667	34089	34453	34764
Skåne	21110	21151	21190	21228	21265	21300	21334	21367	21399	21429
Stockholm	6368	7233	8193	9252	10413	11677	13042	14504	16056	17689
Södermanland	15710	17343	19105	20996	23017	25166	27437	29825	32319	34909
Uppsala	5517	6094	6721	7400	8134	8923	9768	10670	11629	12642
Västmanland	5166	5733	6352	7026	7758	8549	9402	10316	11291	12327
Va Götaland	3183	3561	3981	4446	4958	5522	6141	6818	7557	8358
Örebro	5386	6116	6928	7828	8820	9907	11090	12370	13744	15205
Östergötland	9125	10089	11123	12226	13394	14623	15907	17239	18611	20011
Total	136305	146650	157646	169317	181677	194736	208490	222923	238003	253681

Table B4: Predicted annual rates of increases in traffic load

County	Rate
Blekinge	0.007
Halland	0.015
Jönköping	0.010
Kalmar	0.005
Gotland	0.001
Kronoberg	0.014
Skåne	0.013
Stockholm	0.020
Södermanland	0.010
Uppsala	0.017
Västmanlnad	0.012
Va Götaland	0.011
Örebro	0.007
Östergötland	0.012

Source: Trafikverket (2014), Table 5

Table B5: Predicted number of traffic accidents with a pressure of 10% of the population

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Blekinge	127	195	293	429	608	830	1090	1375	1674	1974
Halland	135	187	256	340	439	550	664	776	880	972
Jönköping	150	213	295	394	507	626	741	846	935	1008
Kalmar	370	479	596	716	833	946	1055	1160	1264	1367
Kronoberg	373	427	473	511	541	565	584	600	614	626
Skåne	803	891	972	1045	1110	1167	1216	1260	1299	1333
Stockholm	339	480	662	884	1137	1407	1674	1924	2145	2335
Södermanland	431	583	767	980	1211	1447	1673	1878	2056	2206
Uppsala	154	213	288	380	486	604	725	843	952	1050
Västmanland	176	243	329	434	557	691	829	963	1086	1193
Va Götaland	65	92	129	177	238	310	392	479	566	647
Örebro	108	153	210	280	361	448	536	617	689	749
Östergötland	251	337	438	551	669	785	891	985	1065	1131
Total	3483	4493	5707	7120	8697	10374	12071	13707	15224	16591

Table B6: Predicted number of traffic accidents with a pressure of 25% of the population

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Blekinge	111	150	201	268	353	461	594	756	947	1169
Halland	130	160	196	238	287	343	405	475	549	628
Jönköping	131	166	208	258	316	382	453	530	609	687
Kalmar	337	407	483	565	651	741	834	929	1026	1126
Kronoberg	343	372	398	421	441	459	475	489	502	514
Skåne	743	775	806	835	864	892	919	944	969	993
Stockholm	298	376	469	580	710	856	1018	1194	1378	1566
Södermanland	381	460	553	657	774	901	1038	1181	1328	1475
Uppsala	135	166	202	244	293	348	410	479	552	629
Västmanland	154	189	229	277	332	394	463	539	620	705
Va Götaland	57	70	87	107	131	160	193	231	275	322
Örebro	95	118	147	180	218	262	311	363	418	475
Östergötland	211	255	305	361	423	488	557	627	697	766
Total	3126	3663	4283	4991	5792	6687	7671	8736	9870	11056

Table B7: Predicted number of traffic accidents with a pressure of 35% of the population

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Blekinge	101	125	155	190	234	286	349	424	514	620
Halland	119	134	151	170	192	215	241	269	300	333
Jönköping	120	140	163	188	217	249	285	323	366	411
Kalmar	318	365	416	473	534	600	670	745	825	909
Kronoberg	329	344	358	372	385	397	408	419	429	439
Skåne	721	733	745	756	768	780	792	805	817	830
Stockholm	273	317	367	424	488	559	638	725	820	924
Södermanland	350	392	437	486	540	598	661	728	799	874
Uppsala	124	139	157	176	198	221	247	275	306	339
Västmanland	141	159	178	199	222	248	276	306	339	375
Va Götaland	52	59	66	75	85	96	108	122	137	154
Örebro	87	100	114	130	148	167	189	213	238	266
Östergötland	195	218	244	272	303	336	371	408	447	488
Total	2930	3224	3551	3913	4312	4752	5234	5762	6337	6961

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