The Economic Impact of Wolves on the Moose Harvest in Sweden

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Abstract

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Chapter 1 - General introduction

Among all Scandinavian game species, the moose is the most relevant one for local economies in terms of yield from cervid species (Nilsen et al. 2005). With having one of the highest moose densities and harvest rates in the world, the annual harvest of moose meat of 8.5 million kg amounts to a value of 14.5 billion SEK (Malmsten 2014). Apart from the high economic value, hunting is also an important recreational activity (Lavsund et al. 2003; Wikenros 2011).
Moose numbers were increasing throughout the 19th century because of different reasons. Wikenros (2011) named for example the absence of predators, new hunting laws, and a different forest management which created better conditions for moose. However, an initial number of 314,000 in the early 1980s was reduced to 225,000 in the beginning of the 1990s. Hörnberg (2001) found that this change was mostly caused by increased hunting. Nevertheless, the recolonization of the wolf, a large predator on moose, could also have played a part. The wolf population has been growing considerably since the 1990's and since then has caused increasing awareness in Sweden (Ericsson et al. 2004). Whereas wolves are still listed as an endangered species, they are perceived as a disruptive factor to the moose hunt, because hunters see the wolf as a competitor for game species. There have furthermore been reports of wolves predating on dogs used for moose hunting. The attitude towards the return of the wolf is therefore critical (Darpö 2011). Eriksson (2013) described the situation as a conflict between conservation goals and economic and cultural concerns.

We have two hypotheses concerning this conflict. The first hypothesis regards the direct effect of wolves on the moose population. Wolves hunt moose and by that negatively affect the moose stock's natural growth. Hence, the moose population decreases. The second hypothesis is that wolves have an impact in terms of a cost as a result of the lower moose harvest caused by the decreasing moose population. The assumption is that effort adjusts quickly when there is a change in the number of moose. So if the number of moose decreases, effort is decreased in order to keep the moose population constant. Accordingly, the entailing effect of wolves is a reduction in harvest and possibly effort respectively. Consequently, both the direct effect on the moose population and the entailing effect on the harvest need to be accounted for, when analyzing the impact of wolves.

The purpose of this paper is the attempt to answer whether wolves have a significant economic impact on the moose harvest shot by hunters. We try to calculate the impact of wolves on the moose harvest value and how it depends on the hunters' effort adjustment.
More precisely the aim is to identify first the marginal product of one wolf which gives its monetary impact under no adjustment. In addition, the paper will also give more insight with regard to the relation between effort and harvest, e.g. how the harvest changes for an additional unit of effort.

Then, we will also look at the comparative statics of a harvest change due to wolves assuming an associated effort adjustment.

We will use a production function approach to value the impact of wolves on hunting. Although this approach has been used for fisheries before (Barbier and Strand 1998; Foley et al. 2010), it has never been applied to a predator-prey context. Besides, there have not been many studies which account for monetary predation losses due to wolves in the Swedish hunting sector. First, we develop a steady state model for moose harvesting in the presence of wolves. Based on this economic model, we derive a harvest function which can be estimated econometrically. With this harvest regression, we will identify the marginal product of wolves and the impact on the harvest. We will use the model to quantify the marginal effect of one additional wolf on the moose harvest from 2002 to 2011. We also include the traffic load to make sure to account for possible effects of traffic accidents on the harvest. The study will evaluate secondary balanced panel data of moose and wolves for different counties in Sweden.

The remainder of this paper is organized as follows: Chapter 2 provides background information about moose and hunting management as well as a review of studies which tried to measure wolf predation impacts before. Chapter 3 explains the methodology, and chapter 4 explains the data used; chapter 4 discusses empirical results and chapter 5 summarizes and concludes.

Chapter 2 – Background and Existing Literature

About Moose Management – Regulations and Institutions

Throughout the last century, moose hunting had mostly been unrestricted. There had been increasing problems with over-exploitation due to unlimited hunting and open access in the 1980s and 1990s. The development in recent years has gone more towards an organized management with abundant moose (Hörnberg 2001; Lavsund et al. 2003; Sandström, Di Gasper, and Öhman 2013). The main goal today is to maintain a population which can endure high harvest rates with an overall low natural mortality. It should also keep an operational sex ratio which helps to stabilize the size of the population (Nilsen et al. 2005). Changes in the moose population are of interest to hunters, but they also raise concerns in forestry companies, as moose cause browsing damage on trees (Hörnberg 2001; Sandström, Di Gasper, and Öhman 2013). Besides, moose have a negative impact on highway traffic safety (Lavsund et al. 2003). Since moose also incur costs, the population should not exceed a certain limit (Månsson et al. 2011).

In Sweden, it is necessary to obtain a national hunting license to be able to purchase weapons and receive the right to hunt. A hunting license incurs an annual management fee of 300 SEK and includes an examination. Hunting licenses count for the time between July 1st in one year and June 30th in the following year (Naturvårdsverket, 2015). From now on, if we talk about the hunting year 2002, it refers to the period 2002/2003. If hunters want to hunt moose, they need to obtain additional local licenses (“lokalt jaktkort”) (Svenska Jägareförbundet 2014). Furthermore, hunters are obliged to report each moose shot to the county administrative board and pay a fee for it to the landowner (“älgavgift”). The fee can vary between 200 and 400 SEK for an adult, whereas calves entail no fee (Apollonio, Andersen, and Putman 2010).

The county administrative boards decide about periods for the moose hunt in each hunting area. The minimum of scheduled days amounts to 70 days per year. The hunting period for moose starts on the second Monday in October in all parts of the country, apart from a few communes in Värmland, Dalarna and Gävleborg where it begins on the first Monday of September. The hunting year continues until February 28th (29th). After that date, no more moose are allowed to be harvested (Jaktförordning (1987:905), 2015)[1]. A special hunting period in order to protect damage by moose already begins on August 16th. However, the county administrative boards can intervene with this (Jaktförordning (1987:905), 2015)[2].

[1] Svensk Jaktförordning Bilaga 2
[2] Svensk Jaktförordning Bilaga 4 § 12

To better organize the moose hunt, every county in Sweden is divided into moose management units, so called Ä*lgförvaltningsområden* (ÄFOs). ÄFOs are organized by a group containing six representatives. Three are elected by the landowners' and three by the hunters' association. Since January 1st 2012, they decide on an administration plan for the moose population. Guidelines for the management are provided by the county administrative board (Naturvårdsverket 2013). The board also examines and approves of the administration plans (Apollonio, Andersen, and Putman 2010). An administration plan determines a harvest quota which decides how many moose can be hunted in an area. According to this goal, local licenses are issued (Naturvårdsverket 2013; Plahn 2015). However, such quotas can create problems when chosen too high (Levin and Hallam 1984) or when not adjusted quickly enough, which can increase the risk of collapse of a population system (Fryxell et al. 2010). They are determined according to the knowledge of moose's birth rates, density and damage level (Apollonio, Andersen, and Putman 2010).

ÄFOs are divided into smaller areas for which hunters have to apply for a number of moose (local licenses) that they can harvest (Apollonio, Andersen, and Putman 2010). According to Plahn (2015) there are two different types of hunting areas. First, there are license areas ("Licensområden"). The quota mechanism is still decided by the AFÖ. If the ÄFO proposes for instance that one calf should be shot in every one-hundred hectares, the quota will be adjusted to the size of the license area. Second, there are moose management areas ("Älgskötselområden – ÄSOs") (Plahn 2015). Area representatives develop a three-year plan for the ÄSO (Månsson et al. 2011) which determines annual harvests and has to be adhered to by the hunters with a tolerance of +-10% (Plahn 2015). If more moose are shot than agreed on with the county administrative board, hunters have to pay a fine. It amounts to 7000 SEK for a grown moose and 3000 SEK for a calf. However, it does not have to be paid, either if the value of the killed moose is declared to be useless, or if it obviously is unreasonable to demand a fee. No regulations can be found for the case when less moose are shot than agreed (Jaktförordning (1987:905), 2015)[3].

Despite the fines in order to prevent excessive harvesting in Sweden, local quotas which are supposed to regulate the number of harvested moose seem not to be adhered to. When looking at recent statistics on algdata.se, as suggested in a conversation with a responsible (Plahn, 2015), we can observe that hunters still shoot mainly irrespective of the quotas. There are a few hunt areas where harvest quotas are reached or even exceeded. In general, if this is the case, it is because of the harvest of more adult moose than agreed. However, the calf quotas are barely ever reached and thus the overall quota is principally below the target. We need to understand that there are use rates, in Swedish called *nyttjandegrader*, for each ÄFO. They represent how much of the agreed quota was

[3] Svensk Jaktförordning 52 c §

actually harvested. We can calculate them, dividing the number of moose harvested by the agreed quota. The use rates on ÄFO-level confirm the observations of the unmatched quotas. They often lie well below 100% and in 2013 the average use rate accounted for 84.1% (compare figure [sammanställd statistik sverige]). This is emphasized by Zimmermann et al. (2015) who state that quotas are set higher than the number of moose harvested. According to them, the difference has been increasing over time. To conclude, the above mentioned regulations and findings let room to believe that present-day sanctions do not seem to make harvest quotas binding.

Because of this, we assume a market for moose hunt which is characterized by open access with respect to the resource. An open-access resource is defined as a resource which everybody can harvest and which is in no way protected against exploitation (Clark, 1990). Especially resources which entail recreational activities, such as hunting, are commonly based on an open-access philosophy (Fryxell et al. 2010). In wildlife hunting, it is often difficult to control harvest efforts or the number of people that use such resources (Fryxell et al. 2010).

Table 1: Quotas, harvest and use rates in Sweden in 2013

County	**Quota**		**Harvest**		**Use Rate (%)**
	Adults	Calves	Adults	Calves	
Blekinge län	215	336	208	286	89.7
Dalarnas län	3891	3315	3555	2853	88.9
Gävleborgs län	3888	3430	3517	2966	88.6
Hallands län	659	692	795	845	121.4
Jämtlands län	11235	8556	9599	6001	78.8
Jönköpings län	1616	2430	1464	2084	87.7
Kalmar län	1411	1698	1232	1440	85.9
Kronobergs län	1361	1799	1335	1686	95.6
Norrbottens län	8208	7814	7239	4885	75.7
Skåne län	331	673	294	320	61.2
Stockholms län	696	932	589	602	73.2
Södermanlands län	667	898	603	763	87.3
Uppsala län	1092	1176	1008	1084	92.2
Värmlands län	4023	3782	3265	2448	73.2
Västerbottens län	8149	7634	7871	5366	83.9
Västernorrlands län	2824	2025	3092	1819	101.3
Västmanlands län	662	884	595	654	80.8
Västra Götalands län	3491	4186	3345	3914	94.6
Örebro län	1210	1353	1133	1178	90.2
Östergötlands län	1604	2180	1492	1657	83.2
Sum	57233	55793	52231	42851	84.1

Source: author’s creation with data from algdata.se

To sum up the characteristics of the market, hunting licenses and with it the right to hunt can be obtained by everybody fulfilling the requirements. There is the necessity of additional local licenses which have to be purchased for the moose hunt and are linked with the quota. Harvested moose have to be communicated and a one-time payment per animal is made to the landowners. Hunters hunt as long as their benefits from hunting, such as leisure and/or monetary output by selling the meat, outweigh their costs. If this is not the case, hunters decide to either reduce their time spent hunting, or in the worst case they drop out of hunting and follow other engagements.

Factors Affecting the Size of the Moose Population

The population of moose and therefore the moose harvest in Sweden is influenced by different factors, such as traffic, diseases, predation and the harvest by hunters. All of these factors have a direct impact on the mortality of moose. Especially younger animals are affected by several factors. Moose calves are for instance exposed to winter mortality. Additionally, in the summer there is the risk of neonatal mortality for newborns (Nilsen et al. 2005). In an observation in Southern Sweden, twelve out of forty-nine calves were found dead due to a subnormal body condition, and two were killed by dogs (Malmsten 2014, p.45). Moose calves were also found to be affected by bacterial infections which decrease their health as well as increase the risk of summer mortality. Yet, there is a need for further studies to measure the significance of diseases on the mortality of moose. Moreover, climate change may also have an impact on moose mortality. Moose are for instance exposed to heat stress (Malmsten 2014). According to Eriksen et al (2009), traffic accidents are a significant mortality factor. Over the time span from 2003 to 2012, moose which died in traffic accounted for an average share of almost 6% of the total moose harvest each year.

Predators to moose are bear and wolves (Dahle et al., 2013; Sand, Wikenros, Ahlqvist, Strømseth, & Wabakken, 2012 b). Again, younger moose are more exposed to predation risk compared to adults. Bear predation is only of local importance during the winter, when there are good snow conditions for the species, such as crusty snow (Dahle et al 2013). As claimed by Dahle et al. (2013), bear predation does not account for an important mortality factor. Wolves (Canis lupus), on the other hand, have a very large hunting territory and mainly predate on moose (Eriksen et al. 2009). Their main breeding areas are located in central Sweden and eastern Norway (Zimmermann et al. 2015). They predate on different species, such as roe deer, beaver and wild reindeer in Sweden. However, their diet consists with 95% of biomass (winter estimates) mostly of moose (Sand, Wikenros, et al. 2012 b). In contrast to predation risk, which was found to be low for moose individuals due to a high prey-to-predator ratio, hunting success (resulting in the killing of the prey) was very high, whenever a wolf encountered a moose (Wikenros et al. 2009). One wolf was found to kill on average 0.061

moose per day (Zimmermann et al., 2015). Wolves show a preference for calves[4], and also prey upon a few older females and yearlings (Nilsen et al. 2005). Besides, cases occurred where wolves were found killing hunting dogs that are commonly used for the moose hunt (Darpö 2011). The wolf is often seen as a disturbing factor and a main competitor to the hunters harvesting moose (Sand et al. 2008; Zimmermann et al. 2015).

However, human hunting activity is the most important factor which kills about 100,000 moose annually (Dahle et al. 2013). The annual hunting harvest is usually dominated by calves and males (Nilsen et al. 2005). The total number of moose shot by hunters will from now on be referred to the moose harvest or simply the harvest.

In summary, the three most important factors influencing moose mortality, which will be considered in this work, are human hunting activity, traffic accidents and wolf predation.

Literature Review

The impact of wolves has been analyzed in different fields in literature. Whereas many ecological studies exist which measure demographic impacts of the recolonizing wolf on the moose population and the moose management (Nilsen et al. 2005; Sand et al. 2005; Wikenros 2009; Gervasi et al. 2012; Sand, Vucetich, et al. 2012 a), there have only been a few studies about the economic impact of the wolf in general which account for the actual costs of wolves either with respect to hunting or livestock (Boman et al. 2003, Skonthoft 2006 and Bostedt and Grahn 2008).

A common way of measuring the demographic impact in ecology studies is to show wolf-moose relations through the estimation of numerical or functional responses. Numerical responses, for instance, show how the reproduction rate of the predator changes following a change in the prey density (Lester and Harmsen 2002). According to Nilsen et al. (2005), because of the intensive wolf management[5], the Scandinavian wolf does not have a numerical response when the prey density changes (Nilsen et al. 2005). Hence, numerical responses can be neglected in impact measurements of wolves in Sweden. Functional responses, on the other hand, are a common measure (Bostedt and Grahn 2008; Zimmermann et al. 2015). They show how the per capita kill rate of the predator follows a change in prey density (Zimmermann et al. 2015). The Per capita kill rate, also called the predation rate (Lester and Harmsen (2002), is often measured by the number of animals killed per predator per unit time (Sand, Vucetich, et al., 2012 a). Zimmermann (2015) for example used functional responses

[4] Almost 90% of all moose killed by wolves were calves (Sand et al., 2008).
[5] The goal for wolf management in 2009 and 2010 was to maintain 210 individuals in the wolf population (Wikenros et al. 2009).

to estimate per capita kill rates which were found to increase with increasing moose availability. They were also discovered to even off above a threshold. The threshold represents a point of saturation at which higher prey densities do not affect the number of moose killed per wolf anymore (Zimmermann et al. 2015). There are furthermore ecological studies on how the age structure of the moose population affects the kill rate. In fact, it was found to be the crucial factor determining the per capita impact of wolf predation (Gervasi et al. 2012; Sand, Vucetich, et al. 2012 a).

Among the ecological studies, there are, furthermore, studies about the impacts of wolf predation on the Swedish moose management. For instance, Nilsen et al. (2005) claimed that harvesting strategies would have to be adjusted under wolf predation. Managers would have to keep in mind that predation has a stronger effect on smaller populations. Therefore, in order to minimize the loss to wolf predation, managers should aim for both a high number of female moose and a high density locally (Nilsen et al 2005). A study by Wikenros (2011) showed that hunters and managers immediately adjusted harvest rates during the first season under which wolves were present. During this season, female moose harvest decreased. The quick reaction by the management, however, pointed towards a precautious change in harvest, rather than a wolf-caused loss (Wikenros 2011). Harvest was hence not reduced because of predation, but by the management's initiated harvest adjustment. This fact verifies the necessity to account for effort adjustments when studying the impact of wolves on the moose harvest. Wikenros et al. (2015) reinforced the assumption of a precautious change by showing that hunters reduced the number of female moose killed in wolf territories.

As noted before, even today the number of studies on monetary losses due to wolf predation seems to be limited. A Norwegian study by Skonhoft (2006 a) measured a landowner's costs and benefits in the presence of wolves. The economic loss was calculated by the profit when wolves predated subtracted from the profit when there were no wolves. Profit with predation included the license payments for hunted moose, and the profit without predation included tree damage costs by moose measured relative to the size of the moose population (Skonhoft 2006 a). Yet, Skonhoft (2006 a) analyzed benefits only in terms of license payments to the landowners, but missed to include other benefits. For example, there is literature available on the use of wolves, in terms of food provision to other animals in the form of prey leftovers (Wikenros 2011; Wikenros et al. 2013). The wolf also has existence and tourist values, which means that some people value the knowledge of the presence of the wolf and some may like to go and see the wolf in the countryside (Boman et al. 2003; Skonhoft 2006 b).

Marginal costs of conserving a wolf were estimated by Boman et al. (2003). They linked the costs to wolf population densities as well as prey abundance (including reindeer, roe deer and moose). High prey abundance means that there is a large number of moose per hunter. Hence, the more moose per hunter exist, the less strong the impact of wolf predation, and the lower the marginal cost of a wolf in terms of harvest losses. Because of high prey abundance in counties with at the same time high wolf densities (Västernorrland and Gävleborg), marginal costs in these counties were comparatively lower than in counties with low prey abundance. Consequently, northern counties experienced high marginal costs due to depredation on reindeer. Costs are, thus, also affected by the spatial distribution of wolves (Boman, Bostedt, and Persson 2003).

Bostedt and Grahn (2008) studied the social costs of four Swedish carnivores, among others wolves, under the use of functional responses. In contrast, their data focused on the costs in terms of compensation for livestock losses. One group for damage compensation were made of the owners of domesticated animals such as sheep, horses, cows etc. and the other group were made of herders of semi-domesticated reindeer. However, when it comes to compensation of predation losses, there is consent that analyses do not take indirect costs (such as stress which can cause weight loss in livestock) into account. Therefore, actual costs of wolves may be higher for livestock losses (Steele et al. 2013; Ramler et al. 2014). Looking at the costs, Bostedt and Grahn (2008) found that cost functions were much lower for wolves compared to the other species. This result came about mainly because predation costs of wolves have been limited over the last years by solving some problems with livestock farming (Bostedt and Grahn 2008), for instance through certain measures such as electric fencing (Darpö 2011). Besides, wolf numbers are kept low in the northern part of Sweden due to the fact that wolves are not compatible with reindeer herding (Bostedt and Grahn 2008). Bostedt and Grahn (2008) accounted for the marginal cost of a wolf which was significant at the 5% level and calculated at 7,480 SEK. In comparison, the cost was 1.5 times higher than that of bears which was due to the fact that bear prey on a wider range of animals than wolves (Bostedt and Grahn 2008).

Chapter 3 - Conceptual Framework

Our model is based on Barbier and Strand (1998) and Foley et al. (2010) who included the influence of a habitat in the population function of fish stocks to measure the value of that habitat in terms of harvest revenues. The concept of habitat factors, as mentioned by Foley et al (2010), refer to one or several factors that have a positive impact on the species, such as in their case for instance cold water coral. The original model by Clark (1990), however, can also include habitat factors which influence a population negatively. It applies mainly to open-access fisheries, but is easily usable in other biological resource settings (Clark 1990). As mentioned above, we analyze the situation of the moose hunt in the context of an open access model**.**

The two most important factors, which influence moose habitat and the moose harvest simultaneously, are the number of wolves and the traffic load. Both factors have an affect on the moose population in terms of growth and carrying capacity and on moose mortality. Different to Foley et al. (2010) who assume positive habitat impacts, but similar to Clark (1990), we assume that our habitat factors have negative impacts on the species. One would expect that the more wolves, the more predation occurs and the more traffic load, the more deadly accidents happen. However, the precise mechanism is not specified in the model (leaving it optional if the effect is positive or negative), but the model is defined such that both habitats influence the moose population.

Following the assumption of negative impacts, both factors would decrease the moose's natural growth and thus the moose harvest. The factors are also assumed to have a negative impact on the moose's carrying capacity ($K(W,T)$ is reduced to a lower carrying capacity $K(W,T)^{new}$; compare figure 1). Nilsen et al. (2005) showed that the moose population decreases, when wolves recolonize and the harvest is not adjusted. Especially the growth rate r(W,T) is affected, as wolves mainly predate on calves. Therefore, harvest rates of calves in particular need to be reduced under the presence of wolves (Nilsen et al. 2005).

The moose's natural growth function $F(X,W,T)$ is then affected by wolves W as well as by traffic load T, such that

$$F_W = \frac{\delta F}{\delta W_t} < 0 \text{ and } F_T = \frac{\delta F}{\delta T_t} < 0$$

Foley et al. (2010) introduced the assumption of a facultative habitat. Facultative habitat use means that a species can use features, such as covers from predators or focal points for reproduction, but even if the factors are not provided, the species can continue to exist. It is assumed that it finds another (second best) habitat where the growth of the species continues. In this study, wolves and traffic are both considered to be a facultative habitat factors, as moose exist independent of them.

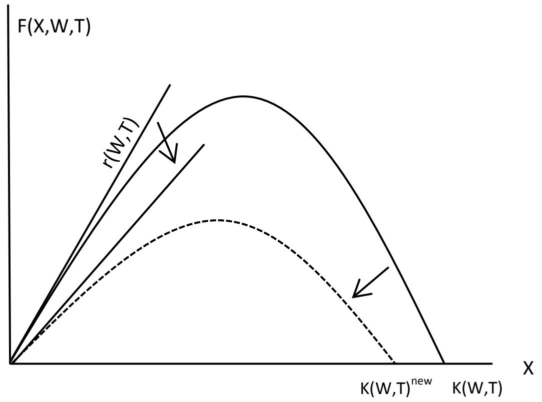

Figure 1: Effect on the logistic growth function by an increase in the number of wolves or in the traffic load (compare Foley et al. 2010)

As mentioned before, an increase in W and T presumably decreases the carrying capacity of moose. In the context of prey-predator relationships (Clark 1990), the carrying capacity K can then be described as

$$K_t(W_t, T_t) = K^0 - g * W_t - k * T_t$$

where g and k respectively are a coefficients that are used to describe the effect of W and T on the moose stock, its carrying capacity and the intrinsic growth rate. Due to the facultative habitat, the carrying capacity K will be positive if $W = 0$ and $T = 0$, so that we get $F(X, 0{,}0) > 0$. If the carrying capacity is a function of the habitat, then it is essential that $g > 0$ and $k > 0$. If it is not affected by the habitat factors, g and k will be equal to zero.

The change in moose stock

The moose stock X is affected by a biological logistic growth function $F(X, W, T)$ and the hunting harvest $h(X, E)$. The change in moose stock, in accordance with Foley et al. (2010), is consequently

$$X_{t+1} - X_t \; = \; F(X_t, W_t, T_t) - h(X_t, E_t). \qquad (1)$$

The logistic growth function $F(X, W, T)$ describes the net expansion of X influenced by the biological growth, the number of wolves and the traffic load. It can be described as follows:

$$F(X, W, T) = r(K^0 - gW - kT)\, X \left(1 - \frac{X}{K^0 - gW - kT}\right),$$

with r describing the intrinsic growth rate of the stock and K the carrying capacity, such that

$$F(X, W, T) = rX[(K^0 - gW - kT) - X]. \qquad (2)$$

The harvest can be described by a Schaefer production function (Clark 1990, Barbier and Strand 1998), such as

$$h(X_t, E_t) = qE_tX_t. \quad (3)$$

The function shows the impact of hunting effort on the stock. Harvest h can be denoted as a function of a catchability coefficient q, the hunting effort E and the stock of the moose. The harvest increases, if the number of moose increases, and if the effort increases respectively.

Representing equation (1) with equation (2) and substituting equation (3) into it produces the change in moose stock

$$X_{t+1} - X_t = X_t \{r[(K^0 - gW_t - kT_t) - X_t] - qE\}. \quad (4)$$

Effort in an open-access condition adjusts over time. It is described by Barbier and Strand (1998) as

$$E_{t+1} - E_t = \phi[ph(X_t, E_t) - cE_t], \quad (5)$$

where ϕ represents the effort adjustment coefficient, p the value of moose and c the real cost. The effort adjustment coefficient measures how the effort adjusts in response to the profits.

To fully understand equation (5), we need to know the following definitions: Total revenue from hunting is described as in Clark (1990) by

$$TR = ph(X_t, E_t),$$

with p corresponding to the unit value for the Swedish moose hunt. TC is the total cost of hunting and can be written as:

$$TC = cE_t.$$

The equilibrium cost can then be calculated as in Barbier and Strand (1998):

$$c = \frac{ph}{E}. \quad (5.1)$$

In an open-access situation effort will tend towards an equilibrium where effort is such that total revenues equal total costs (Clark 1990). The profit from hunting activity is $\pi = TR - TC$, but as it is assumed to be equal to zero in equilibrium, we can write $ph = cE$ (Barbier & Strand, 1998).

There are two scenarios that cannot indefinitely be supported and thus lead to a long run equilibrium effort. First, in the case, where effort is above the equilibrium effort, total costs would exceed revenues. Some hunters would make losses and reduce their time spent on the hunting activity, which decreases the equilibrium effort. Second, if effort is below the equilibrium effort, total revenues would exceed total costs. Hunting then becomes attractive and hunters spend more time hunting such that equilibrium effort would increase (Clark, 1990). The adjustment of effort towards equilibrium can be assumed to occur quickly, since, according to Wikenros (2011), the harvest was modified flexibly when conditions changed. Now, equation (5) shows that if costs of hunting are greater than benefits in period t, the effort decreases in the next period due to hunters reducing their time spent on hunting or, in the worst case, leaving the sector. Hence, the effort adjusts. On the other hand, if revenues increase, effort will also increase in $t + 1$.

Open access equilibrium

In the open access equilibrium, hunting effort and moose stock are presumed to be constant over time, thus $E_{t+1} = E_t = E$ and $X_{t+1} = X_t = X$, and the equilibrium level of wolves is assumed to be $W_{t+1} = W_t = W$, as is the traffic load $T_{t+1} = T_t = T$. We will look at the long run equilibrium of a change in the number of wolves and traffic load on moose hunting harvest.

The steady-state levels of effort E and moose stock X can be derived from equation (4) and (5) respectively, such that

$$X = \frac{c}{pq}\text{, and} \qquad (6)$$

$$E = \frac{r[(K^0 - gW - kT) - X]}{q} \quad \leftrightarrow \quad E = \frac{\mathrm{r}(K^0 - gW - kT)}{q} - \frac{r}{q}\mathrm{X}. \qquad (7)$$

Since effort is assumed to be in steady state, the effort curve is vertical for a certain level of stock (see figure 29. The slope of the stock curve is described by $\frac{dE}{dX} = -\frac{r}{q}$, which is derived from the equilibrium effort in equation (7).

Figure 2 depicts possible equilibrium conditions for a change in the number of wolves. As we know from figure 1, wolves negatively affect the moose's intrinsic growth rate as well as their carrying capacity. Therefore, if the number of wolves increases, the moose stock would decrease and thus shift the stock curve downwards. In order to reach the same level of stock, the equilibrium steady-state effort would have to adjust to a new equilibrium effort E'. In the first condition, adjusting effort leads to a stable equilibrium (trajectory 1.). In contrast, the assumption that the hunting effort does not adjust over time would lead to a lower moose stock and could lead to a collapse of the stock in the long run (trajectory 2.). We will only look at the scenario of trajectory 1, assuming that it is likely that changes in effort are made instantaneously as a response to wolf recolonization and hence a new equilibrium is reached. The second trajectory is less likely to occur, as there is no currently known danger of a collapse of the moose stock. (For an open-access equilibrium both equation (6) and (7) have to be satisfied (Barbier and Strand 1998).)

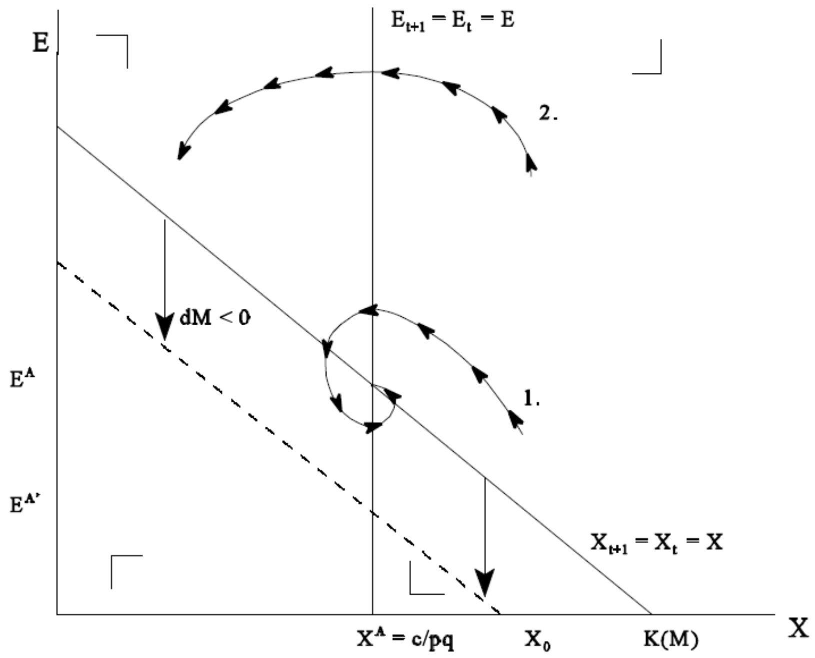

Figure 2: Open access equilibrium with trajectory 1. and 2. (Barbier & Strand, 1998)

The Comparative Static Effects of Changes in the Number of Wolves and the Traffic Load

Equation (7) yields the comparative static effect of a change in the number of wolves and traffic load respectively on the equilibrium level of hunting effort

$$\frac{dE}{dW} = -\frac{rg}{q} \quad \leftrightarrow \quad dE = -\frac{rg}{q}\, dW \tag{8.1}$$

$$\frac{dE}{dT} = -\frac{rk}{q} \quad \leftrightarrow \quad dE = -\frac{rk}{q}\, dT \tag{8.2}$$

This shows that an increase in the number of wolves W would decrease the effort E, which is intuitive assuming that more wolves eat more moose and hence decrease the number of moose that can be harvested. In a scenario with increasing wolf predation, the effort would have to be adjusted to keep a steady state level of moose stock. The same argumentation follows for the traffic load. We assume that when the traffic increases there will be an effect on the number of accidents with moose and hence more moose would die in traffic accidents. Therefore, if the traffic load increases, the effort would have to decrease to keep the stock at steady state.

If effort decreases, harvest also decreases (see equation (3)). The change in harvest can be calculated by taking the steady state level of moose stock from equation (6) and the change in effort of equation (8.1) and (8.2) respectively and substituting it into equation (3)

$$\frac{dh}{dW} = \frac{dh}{dE} * \frac{dE}{dW} = qXdE = -\frac{rcg}{pq} \qquad \leftrightarrow \qquad dh = -\frac{rcg}{pq}\, dW \qquad (9.1)$$

$$\frac{dh}{dT} = \frac{dh}{dE} * \frac{dE}{dT} = qXdE = -\frac{rck}{pq} \qquad \leftrightarrow \qquad dh = -\frac{rck}{pq}\, dT \qquad (9.2)$$

Regression of the Harvest Function

This paper has the purpose to evaluate moose harvest data over a ten-year period. It should quantify the effects of the growth of the wolf population on the moose harvest. For this, a regression was run on the harvest function to determine the impacts. .

By substituting equation (3) in the steady-state effort (7) and assuming that the stock remains constant over time, we obtain an equation that shows the relationship between hunting harvest, wolves and effort.

$$E = \frac{r\,(K0 - gW - kT)}{q} - \frac{rh}{q^2E} \qquad \leftrightarrow \qquad \mathrm{h} = \mathrm{q}K^0\,\mathrm{E} - \mathrm{qg}\,\mathrm{E} * \mathrm{W} - \mathrm{qk}\,\mathrm{E} * \mathrm{T} - \frac{q2}{r}E^2$$

Hence, for the regression we set $a_1 = qK^0$, $a_2 = -qg$, $a_3 = -qk$, and $a_4 = -\frac{q^2}{r}$. The coefficients will be measures of the impact by the different variables on the moose harvest. The harvest function appears as follows:

$$h = a_1E + a_2E * W + a_3E * T + a_4E^2 + u, \qquad (10)$$

where E describes the hunting effort, W the number of wolves, T the traffic load and u some error term. Notice that the model is described such that the habitat factors are only relevant when there is hunting activity (compare Foley et al. 2010).

Another functional form of the regression of the harvest function will be considered, which is achieved by dividing equation (10) by the effort E. It appears as follows:

$$\frac{H}{E} = a_1 + a_2 * W + a_3 * T + a_4\,E\,. \qquad (11)$$

In this equation, however, there will be an intercept which is why the model is only defined for $E \neq 0$.

With equation (10) we can analyze how the harvest changes for an additional unit of effort, i.e. the marginal productivity of hunting effort:

$$\frac{dh}{dE} = a_1 + a_2W + a_3T + 2a_4. \quad (12)$$

We will also look at the marginal product of one wolf, i.e. how the harvest changes when there is one more wolf but the effort is kept constant, such as

$$\frac{dh}{dW} = a_2E. \quad (13)$$

The marginal product for one more unit of traffic is thus

$$\frac{dh}{dT} = a_3E. \quad (14)$$

As a result, we can calculate the marginal revenue lost due to wolves or traffic respectively as in Barbier and Strand (1998), which is

$$TR = p * dh. \quad (15)$$

Chapter 4 - Empirical Data

Our analysis includes balanced cross panel data for the variables harvest, effort, wolves and traffic load over a period of 10 years. The years included reach from 2002 to 2011. The data was used to estimate equation (10). All variables occurring in the regression were adjusted for the size of each county in square kilometers to avoid that large counties have too much impact in the analysis. We divided all data on county-level by the size of the respective county. Data on the area of Sweden's counties was collected from Statistiska centralbyrån.

Figure 3 shows a map of Sweden and its counties. We included twenty of the twenty-one Swedish counties in our analysis. The county of Gotland is not included, since there is no data on wolves available. Therefore, when we refer to the national analysis or the whole of Sweden in the remainder of this paper, it entails that Gotland is not part of it.

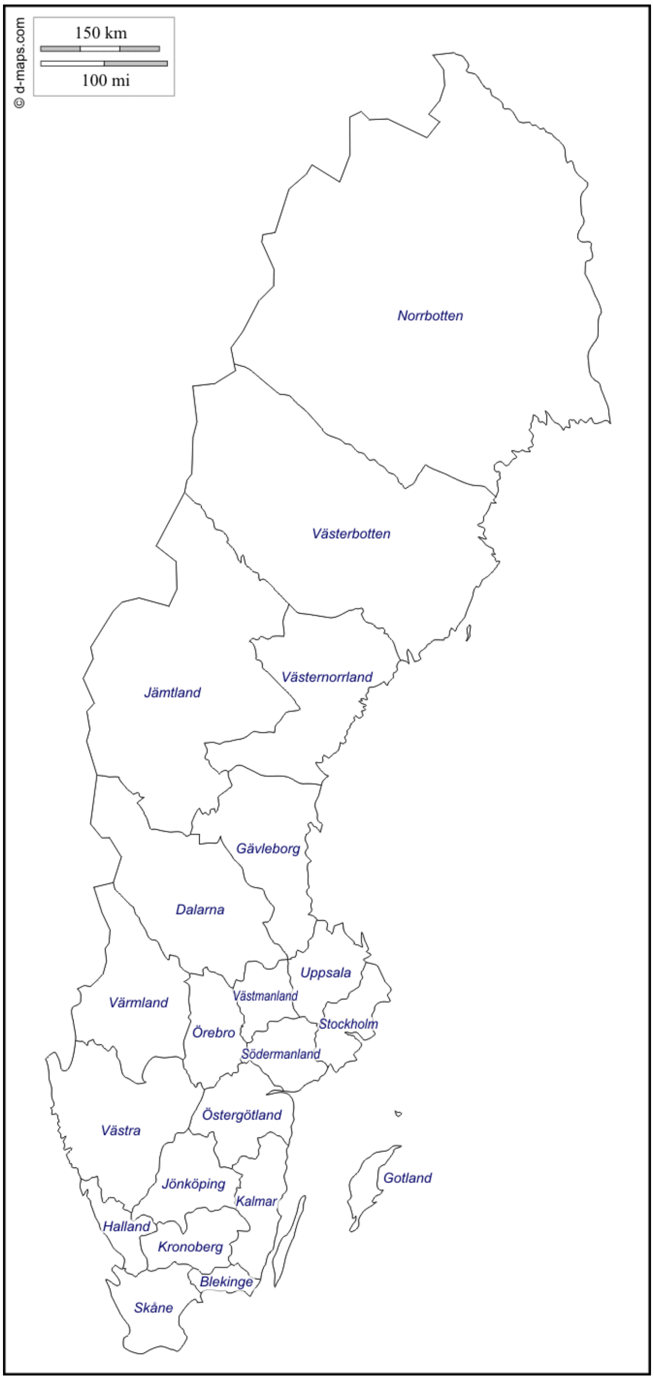

Figure 3: Swedish counties

Source: author's creation

The Harvest

The harvest is measured in moose shot per square kilometer. The development of the moose harvest for each county during our study period is shown in figure 4, where we can observe a general decrease until about 2006/2007 and an increase thereafter. Data was collected from viltdata.se.

Especially the north due to its low forest productivity and the far south due to its agricultural land, have low moose densities. The highest moose densities are found in central Sweden (Lavsund et al. 2003) which also occur to be the counties with the highest wolf densities.

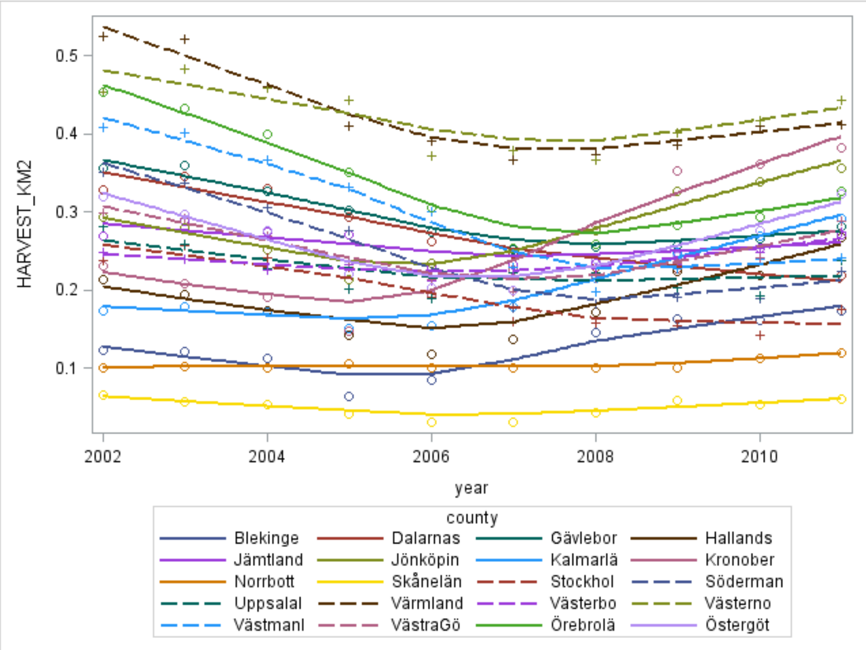

Figure 4: Harvest per square kilometer over the years

Source: author's creation with SAS

The Effort

We borrow the calculation of the effort variable in our regression from Foley et al. (2010). Their effort variable includes the number of vessels used for fishing and a percentage of the species fished among the total harvest of the fishery. It also includes days spent at sea and a ratio of the harvest per unit time fishing of a vessel compared to the harvest of a standard vessel. According to Sylvén (2003), hunting effort is very complex. It normally includes many characteristics of hunting groups, such as experience, traditions and hunting methods among others (Sylvén, 2003). For this reason, we need to keep in mind that the effort variable is often a simplified measure of the effort.

With respect to this, our effort variable only comprises two components. It would be more accurate to include additional parameters such as time spent hunting and the number of people who hunt moose. However, this is not possible due to missing hunting statistics on county-level. We simplify therefore by assuming that hunting days and the number of hunters are constant over time.

Consequently, the hunting effort E in our study is continuous and consists of the following components:

$$E_t = number\ of\ national\ hunting\ licenses \\ * percentage\ of\ moose\ shot\ among\ Swedish\ game\ species$$

Data about hunting licenses was collected from Naturvårdsverket from 2002 till 2011. The number of hunting licenses refers to the licenses issued to people who take the hunter's examination to become a hunter. A study by Boman et al. (2011) discovered that among 280,000 hunters in 2005/06, 245,000 hunted moose. The short time period of our data analysis is due to the fact that there is no earlier data on hunting licenses available. The licenses from 2002 till 2004 for a region called "Mitt norrland" cannot exactly be assigned to one of the twenty counties included in our analysis. These data were proportionally allocated to the counties of Jämtland and Västernorrland. Moreover, we did not include foreigners who obtained a hunting license in Sweden, as data was missing for most of the years.

Effort also comprises a percentage of moose shot amongst important game species in Sweden. For this, we add up all available numbers of game shot and divide the annual moose harvest by it. The result times one-hundred gives us the percentage. This calculation is made on a yearly basis for both the whole of Sweden and for the counties individually. The data on game shot is yearly panel data for killings by hunters in Sweden. It was collected from viltdata.se and jagareforbundet.se. The game shot comprises the number of red deer (Cervus Elaphus), fallow deer (Cervus Dama), roe deer (Capreolus Capreolus), wild boar (Sus Scrofa) and moose (Alces Alces)[6]. The percentage of moose shot is supposed to take care of the fact that there might be license holders who do not participate in the moose hunt. Then, the effort can be interpreted as the number of licenses targeted towards moose hunting.

We have low and high effort counties as can be seen in figure 5. The counties which started with high efforts in 2002 all decreased to an average level; whereas some of the counties with lower levels in the beginning increased or remained at low levels respectively. Some counties, however, maintained a low level of effort. The change in effort in our analysis could be caused by several effects, which are linked with the two variables that account for the effort variable. For instance, the percentage of moose shot is connected with the moose harvest as well as the harvest of other animals. We have to be aware of the fact that the percentage varies highly. In general, the percentage increases from the

[6] Notice that the data for different types of deer and wild boars from Västra Götalands län consists of collective data from four different counties (namely Göteborg and Bohus, Södra Älvsborg, Norra Älvsborg, and Skaraborg), which added up to Västra Götalands län in 2011.

South to the North of Sweden (see table A.1 in appendix). The number of licenses stayed relatively constant during our study period, although it experienced a slight overall decrease. The county of Västra Götaland has the highest number of licenses by far (see figure A.1 in appendix).

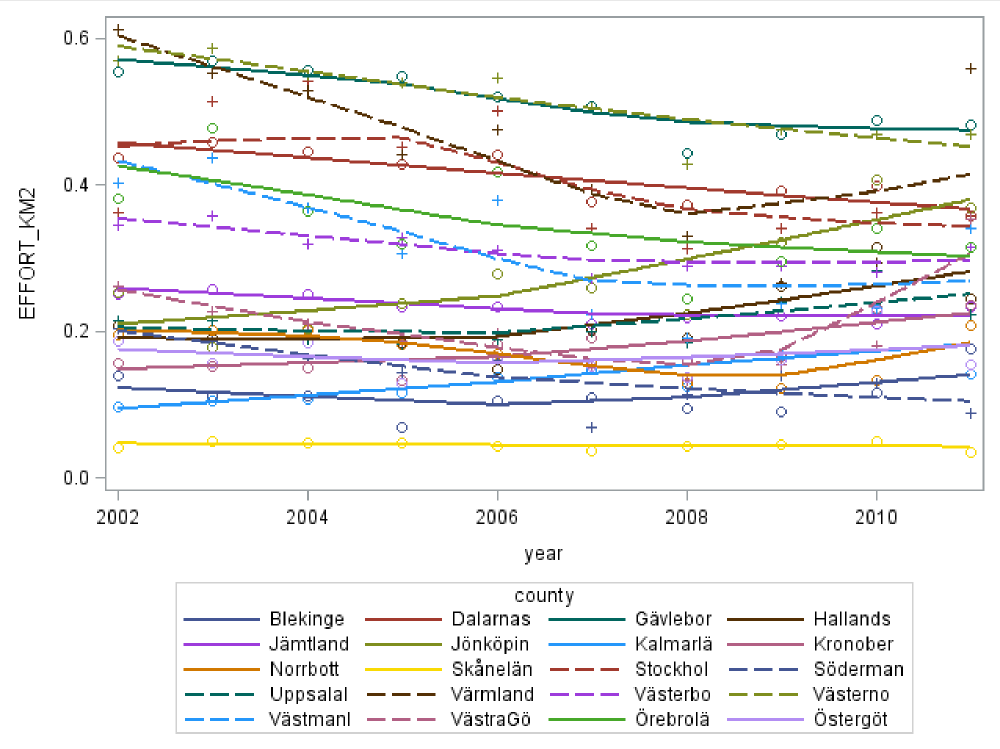

Figure 5: Effort per square kilometer over the years

A relation can be observed, when looking at the average harvest and the average effort for all counties over the years (figure 6). They almost show the same pattern apart from an increase in average effort in 2005, while the harvest is still decreasing. The overall shape of the average harvest is decreasing until 2007 and increasing thereafter. The relation between harvest and effort is intuitive, because, if, for example, the hunting licenses decrease to a number close to zero, we can be sure that the moose harvest will also approximate to zero. However, since licenses are obtained at the beginning of the year, we would expect the harvest to follow the effort.

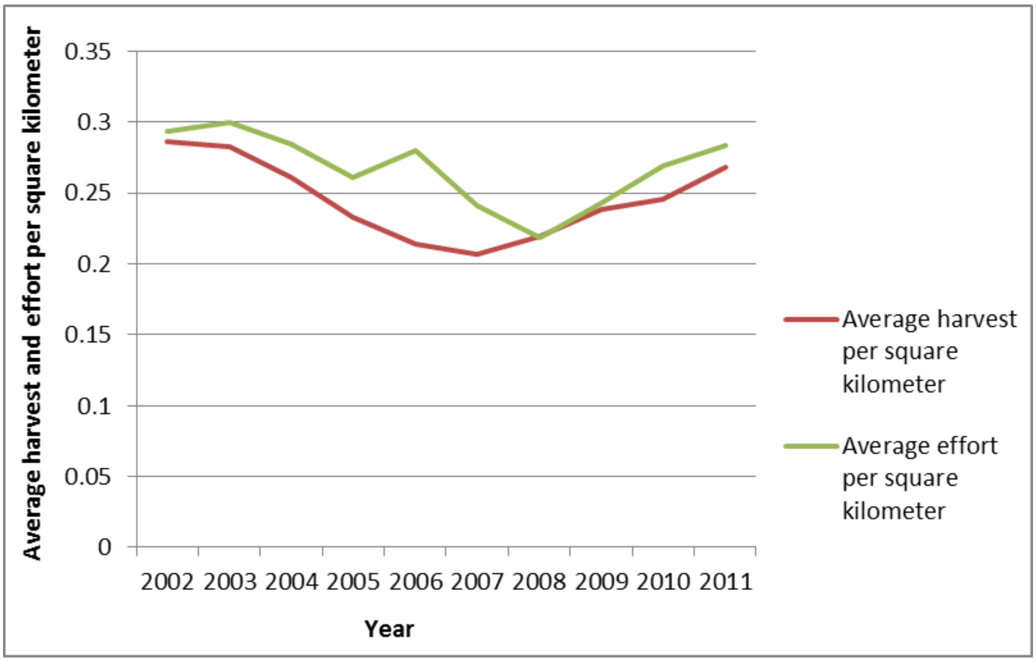

Figure 6: Average Harvest and Effort per square kilometer over the years

source: author's creation with excel

The Wolves

There is data available from viltskadecenter.se on the number of wolves living in Sweden. These numbers are based on county level-observations. Yet, many times wolves cross borders and are therefore counted for several counties. If this was the case, we divided the number of wolves by the number of counties they were counted in. Since we cannot have half of a wolf, we rounded decimals up. Moreover, there are two scenarios to look at based on the observations. We can distinguish minimum values and maximum values. Minimum values are verified counts from experienced reporters and trackers. Maximum values include public sightings which are not verified. We only used minimum values, as they seemed at least to be verified by professionals.

Figure 7 shows the development of the wolf population for the different counties during our study period. The number of individuals at the end was almost four times as high as in 2002. As mentioned above, wolf numbers varied highly in the counties where wolves were present. In general, about half of the wolf counties had an increasing trend in wolf population. On the other hand, some counties maintained a low wolf population, while some counties did not have wolves at all. We were therefore looking at different groupings of counties in our analysis. For a list of the counties included in each grouping look at **figure x** in chapter 4.

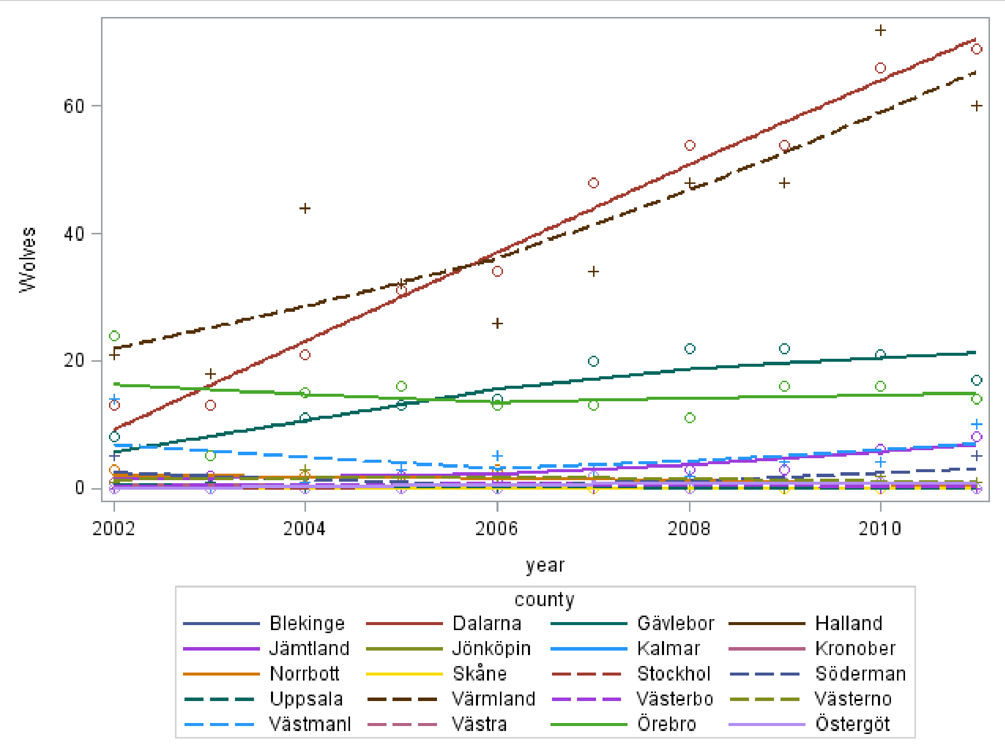

Figure 7: Total number of wolves per year for all the counties included in the national analysis

Source: author's creation with SAS

Because of the high variation of local conditions between counties, we decided to look at three different groupings for the original harvest regression function. Besides, the small number of observations for one county would not make it meaningful to run a regression just on one county. Therefore, we chose to categorize for these different groupings to have counties with probably similar conditions together.

One grouping includes all counties with a high density (HD) of wolves. Our definition of a HD wolf county was that there had been at least one year within the 10-year period with 10 wolves or more. We chose to classify HD wolf counties, because of the assumption that the harvest in counties which just had a few wolves in one or two years would not be influenced as much by wolf predation as counties with a constantly big wolf population. HD wolf counties included 6 counties, namely Dalarna, Gävleborg, Värmland, Västmanland, Västra Götaland and Örebro. The development of the wolf population in these counties is shown in figure 8. The number of wolves in the HD wolf counties varied highly throughout the years.

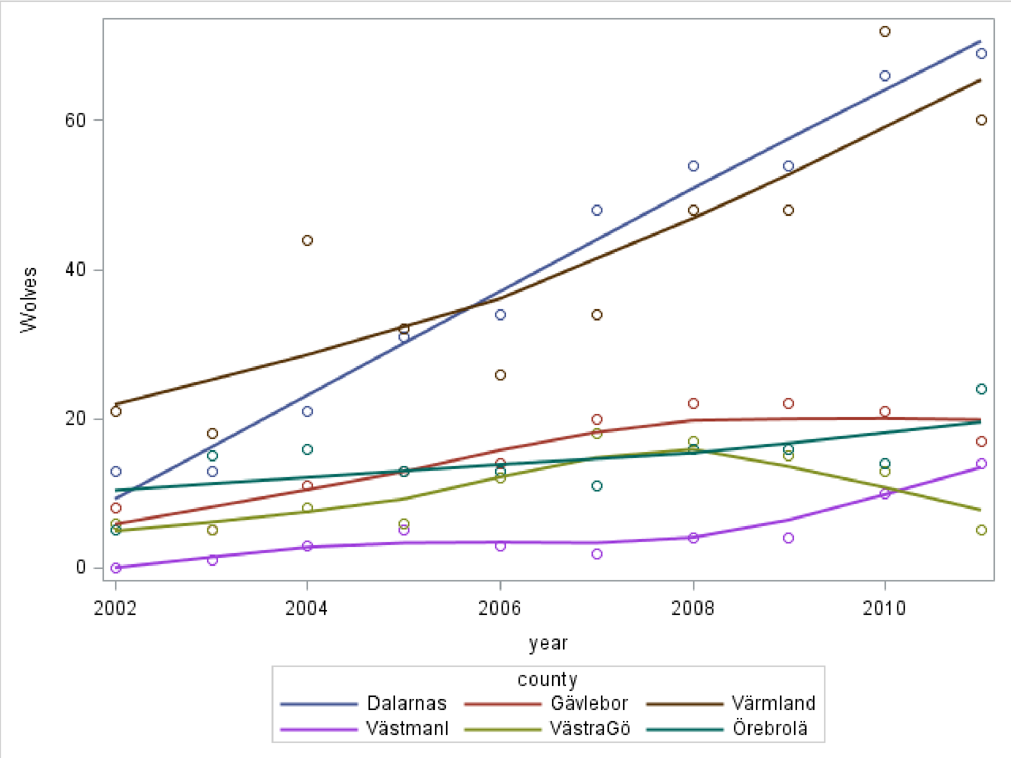

Figure 8: Total number of wolves per year in the counties with high wolf densities

Source: author's creation with SAS

Furthermore, we divided the counties with low wolf densities between counties located north of the HD wolf counties and south of the HD wolf counties. In the North of Sweden, we have the conflict of wolves with reindeer herding which provides a special situation why wolves are not wanted in these counties. Besides, as mentioned before, the percentage of moose shot is higher in the North compared to the South.

In figure 9, which also shows the four counties included in the North, we can observe that Jämtland had an increase in wolf numbers in 2010 from 3 to 8 individuals, whereas the other counties experienced a decrease in the end. Figure 10 shows wolf numbers for the remaining ten southern counties. Jönköping had a small increase in wolf numbers in 2010, but the other counties overall remain at a low number of wolves. We should bear in mind that the counties of Stockholm and Jämtland are located close to the HD wolf counties and therefore to the wolves' main breeding area. This could be a reason for why numbers there are a bit higher compared to the rest.

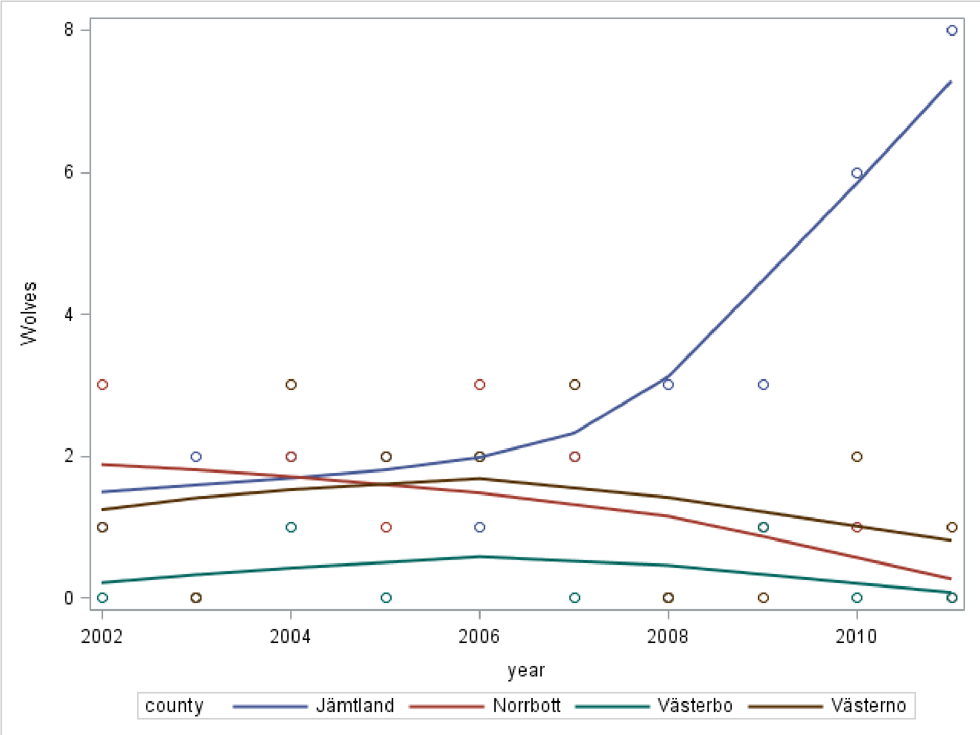

Figure 9: Total number of wolves per year for all the counties included in the analysis of the counties north of the HD wolf counties

Source: author's creation with SAS

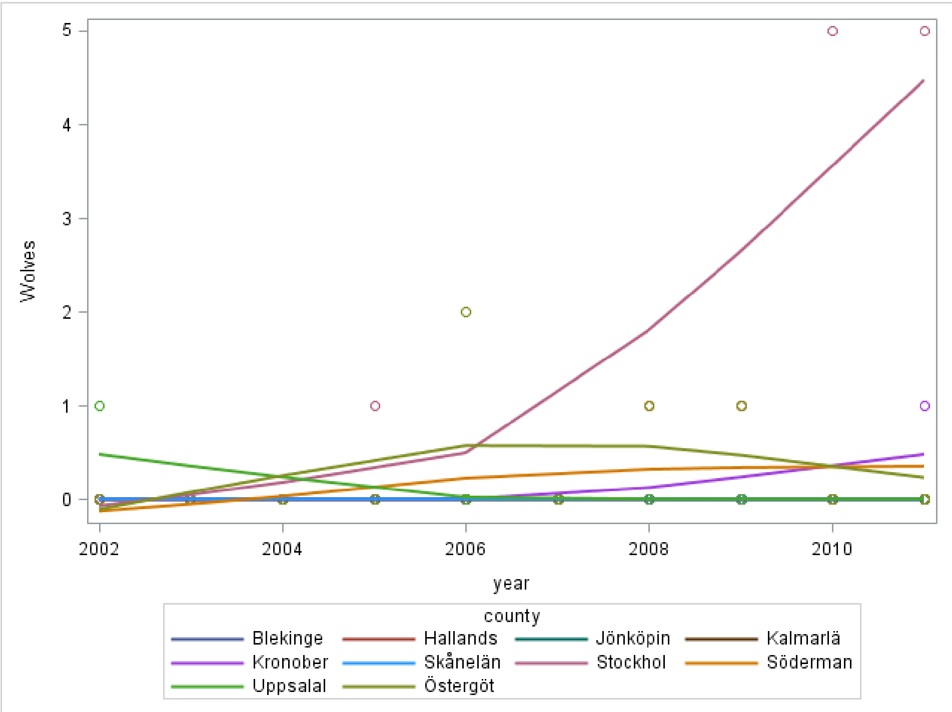

Figure 10: Total number of wolves per year for all the counties included in the analysis of the counties south of the HD wolf counties

Source: author's creation with SAS

The Traffic Load

The traffic load is measured in Swedish miles, one Swedish mile being equivalent to 10 kilometers. Data about the traffic load was obtained from viltskadecenter. It was available for all counties during our study period and included cars, trucks, and busses, both for personal and commercial reasons. However, it did not include foregin traffic.

The county of Stockholm had by far the highest traffic load per square kilometer. However, traffic load did not seem to vary much during our study period (see figure x).

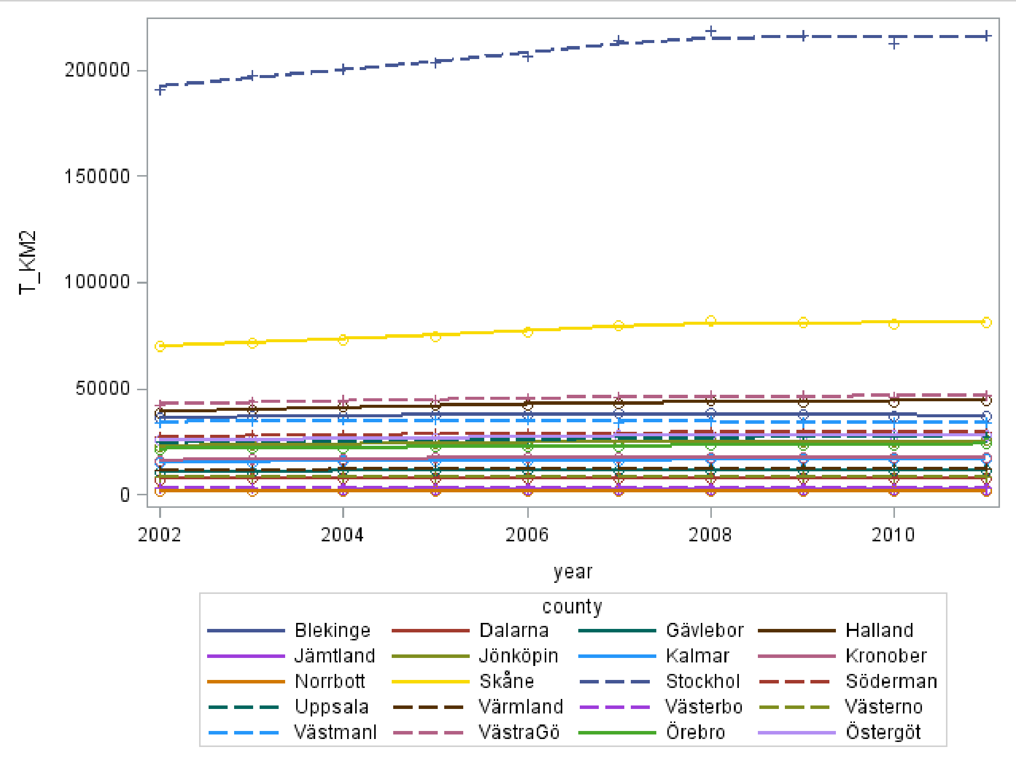

Figure 11: Traffic load in Swedish miles per county per year

Source: author's creation with SAS

The Value of the Moose Hunt

In order to obtain p to calculate equation (15), we took the unit value of the moose hunt as calculated by Boman et al. (2011). It was calculated to 7,000 SEK in 2005/2006. We use it to account for the monetary loss of moose hunting harvest due to wolves. Boman et al.'s (2011) value was based on willingness to pay-questions, such as how hunters value hunting including all costs and what they would be willing to pay to avoid the loss of hunting. We use this value instead of just a per kg meat price, because, as mentioned above, moose hunting has other values than just the simple value of meat. Hence, p includes both profits and the leisure value of hunting. Nevertheless, it is a simplification to assume that the value remains constant over our time period because there can be changes. Besides, the willingness-to-pay for the preservation of hunting can change in conjunction with income.

Chapter 5 – Results and Discussion

To be finalized

Chapter 6 – Conlusions

To be finalized

Refernces

To be finalized

Appendix

To be finalized