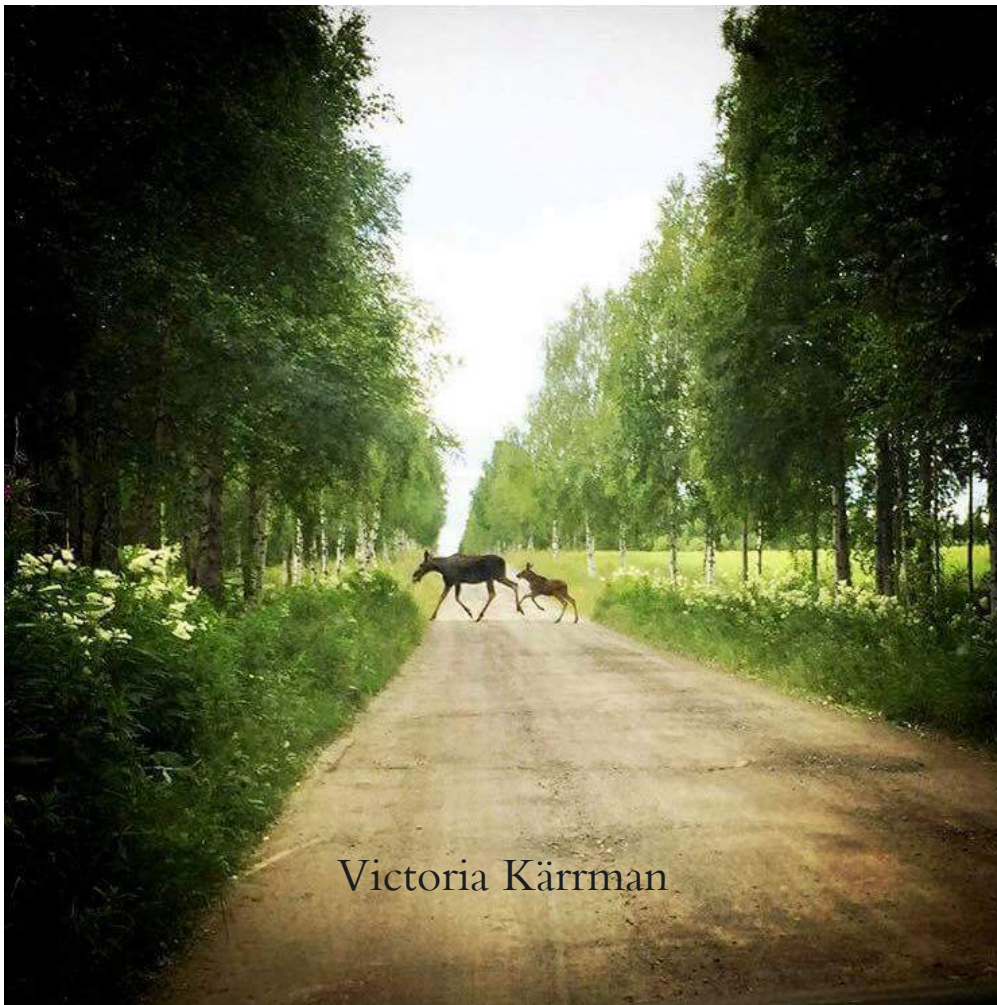


The effects of the Swedish moose management



Victoria Kärrman

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Luleå University of Technology
Department of Business Administration, Technology and Social Sciences

ABSTRACT

The purpose of this study was to examine the effects on the Swedish moose population of a new moose management system introduced in 2012. To this end, the size of the population had to be measured. The methodology used was an empirical version of the Gordon–Schaefer bioeconomic model previously employed to estimate Sweden’s wild boar population. The *Effort* variable for the model was modified in that traffic accidents relative to traffic density served as a proxy for it. The study investigated years for which data was available, namely 2004–2017. Nineteen out of Sweden’s 21 Counties were included in the study. The result produced extremely high population estimates, suggesting that the model could not be directly transferred from wild boar to moose. Nonetheless, although the study’s population estimates in absolute terms are unrealistic, their relative sizes indicate that moose populations were somewhat smaller in 2017 than in 2012 – the latter year being when the new management system was introduced. However, the trend line shows that, over a longer period, the moose population has increased in Sweden, and 2017 may just be a temporary deviation from that trend. It appears, therefore, that Sweden’s latest moose management system does not have the desired effect on its moose population.

Keywords: Wildlife management, moose, population growth, population density, Gordon–Schaefer model, bioeconomics

SAMMANFATTNING

Syftet med denna studie var att undersöka om den nya älgförvaltningen som infördes 2012 gett önskad effekt på den svenska älgstammen. Stammens storlek behövde mätas. Metoden som använts är en empirisk version av den bioekonomiska modellen Gordon–Schaefer som tidigare använts för att uppskatta Sveriges vildsvinpopulation. Med viss modifiering ändrades ansträngningsvariabeln och trafikolyckor mot trafiktäthet användes som ansträngningsvariabel. Denna studie undersökte åren 2004–2017 för vilka data fanns tillgänglig. Nitton av tjugo län ingick i studien. Resultatet gav extremt höga populations siffror, vilket tyder på att modellen inte direkt kan överföras från vildsvin till älg. Även om studiens populationsuppskattningar i absoluta tal knappast är rimliga, pekar de på att älgstammen är något mindre 2017 än 2012 då den nya älgförvaltningen infördes. Trendlinjen visar dock att älgpopulationen under en längre period har ökat i Sverige och att 2017 kanske bara var en tillfällig avvikelse från den trenden. Det verkar därför som att den svenska älgförvaltningen inte ger önskad effekt på älgstammen.

Nyckelord: Viltförvaltning, älg, populationstillväxt, populationstäthet, Gordon–Schaefer modell, naturresursekonomi

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LIST OF ABBREVIATIONS

CAB	County Administrative Board (<i>Länsstyrelsen</i>)
CWD	Chronic Wasting Disease (<i>Avmagringssjuka</i>)
EPA	Environmental Protection Agency (<i>Naturvårdsverket</i>)
LA	Licence Area (<i>licensområde</i>)
MBI	Moose Browsing Inventory (<i>älgbetesinventering</i>)
MMA	Moose Management Area (<i>älgförvaltningsområde</i>)
MMG	Moose Management Group (<i>älgförvaltningsgrupp</i>)
MMU	Moose Management Unit (<i>älgskötselområde</i>)
MO	Moose Observation (<i>älgobservationer</i>)
NWAC	National Wildlife Accident Council (<i>Nationella Viltolycksrådet</i>)
RFMO	Regional Fisheries Management Organisation
SFA	Swedish Forest Agency (<i>Skogsstyrelsen</i>)
SMHI	Swedish Meteorological and Hydrological Institute (<i>Sveriges Meteorologiska och Hydrologiska Institut</i>)
WD	Wildlife Delegation (<i>Viltförvaltningsdeligationen</i>)

CHAPTER 1

INTRODUCTION

1.1 Background

In the beginning of the 20th Century, the moose (*Alces alces*) had almost disappeared in Sweden; today, its moose population is the world's largest, with Wallgren (2016), for example, estimating it as being about 350,000 individuals. From a yearly harvest of approximately 5,000 moose in the 1930s, this peaked in 1982 with over 170,000 moose being shot. Despite this massive increase in hunting, the population grew rapidly. This growth was due partly to the high availability of food that modern forestry created and partly to the near absence of predators such as wolves and brown bears – species which have been close to extinction during most of this period (Törnström, 2018). The Swedish moose population now provides excellent hunting opportunities as well as a great chance of seeing this magnificent animal in the wilds. However, so many moose browsing has an immense impact on young pines, and as the animals' numbers increase, so do the traffic accidents involving moose. Hunting is currently the only tool for managing moose population numbers and for creating a balance between their food supply and maintaining biodiversity, while reducing traffic accidents involving these animals. These are the most important factors addressed by the changes in moose management introduced by the Swedish Government in 2012 (GKS, 2009).

Forest damage linked to moose (see Appendix A; SFA, 2018) has also been increasing by 50% since 2002, with moose–vehicle collisions increasing as well, according to the National Wildlife Accident Council (NWAC, 2018). These factors have caused conflict between the forest sector and hunters for a long time because of their competing interests. Furthermore, moose browsing on young pine plantations holds economic consequences for the respective landowners, such as loss of growth, replanting costs and poorer quality of timber. A survey conducted by Future Forest (2014) shows that non-landowning hunters and non-hunting landowners differ in their attitude towards browsing damage.

Not surprisingly, the non-hunting landowners regard such damage as more detrimental to their economic well-being than the non-landowning hunters do, while the attitudes of landowners who also hunt lie somewhere between those of the two other groups (Ezebilo et al., 2012).

Moose usually browse pines during winter, when deep snow restricts other food sources. Moose herds that browse in one local area for a long time during winter can cause severe damage to trees in this way. An adult moose needs to eat about 6-8 kg of coniferous and deciduous branches a day during the winter (Törnström, 2018). In 30 to 50 years' time, when the wood is harvested, the cost of impaired timber quality relating to current browsing damage will be in the order of SEK500 million to SEK1.3 billion annually (Glöde et al., 2004). A recent study by SFA (2019) shows that the estimated loss of growth on young pine forests with today's browsing damages, represent a socio-economic cost of SEK 7.2 billion annually through a reduction in GDP for the Forestry and forest industries.

Moose–vehicle collisions are another big issue that needs to be addressed. Such accidents have increased rapidly and cause significant welfare costs. For example, since 2010, moose–vehicle collisions have increased by 20% (NWAC, 2018).

To deal with browsing and moose–vehicle collisions, the Swedish Government decided to introduce a moose management system that was as local and adaptive as possible. To this end, in 2012, it introduced a system that aimed to create an adaptive, locally-oriented and ecosystem-based type of management that would at once maintain a high-quality moose population and not jeopardise food resources or the biodiversity (GKS 2009).

The purpose of this study was to investigate the effects of the new moose management system, which entered its seventh year in 2019. However, an important problem for any evaluation of the new system is the lack of reliable data on the size of the moose population. Moose management decisions are currently based on relatively limited biological and economic data. The most common indicators used to determine a plan for

managing moose (hereafter *management plan*), for example, are moose observations (MOs), a moose browsing inventory (MBI) and shooting statistics. Other indicators are moose–vehicle collisions, the occurrence of predators like brown bears and wolves, and inventories of moose droppings (SLU, 2011). However, it is unknown how reliable these indicators are, and they are currently not used systematically for estimating moose populations either for the country as a whole or for different parts of it. Therefore, based on currently available data, it is impossible to say whether moose populations have grown or declined since the introduction of the new management regime.

One option for estimating moose numbers is to connect the damage associated with moose–vehicle accidents and browsing to moose population density. For example, Skonhøft and Olaussen (2011) argue that a higher moose population density would create more damage. Other indirect evidence of moose numbers is presented by reduced vegetation diversity and habitat quality (Witmer and DeCalesta, 1991). Today, landowners in Sweden are planting spruce on land meant for pine trees precisely because moose are less likely to browse on and cause damage to spruce (SFA, 2018). By using the data on such damage, methods from bioeconomic studies can be applied to attempt to estimate the size of the moose population and assess how it has changed since the new management regime was introduced.

To the author’s knowledge, this is the first attempt to present such a bioeconomic study for the Swedish moose population.

The research question for the study, therefore, is this: *Has the new moose management system had the desired effect on the moose population?* To answer this question, it is necessary to first answer two secondary research questions, namely, *What comprised Sweden’s moose population to 2012, and How did that population develop before and after the new management system was introduced?*

1.2 Purpose of the study

This study investigated whether the moose management system introduced in Sweden in 2012 has had the desired effect on its moose population. The size of the population will be estimated, and the results will be used to discuss whether the new system has achieved its aim of reducing browsing damage and moose–vehicle accidents.

1.3 Methodology

To analyse whether the new moose management system has affected the moose population, the study will use a classic standard in the field of natural resource economics, namely the Gordon–Schaefer model. This is a widely used tool in fisheries, for example.

With some modification, Gren et al. (2015) used this model to estimate Sweden’s wild boar population. Their modification entailed the *Effort* variable typically used in the model, which in their context would have been the number of hunting hours spent harvesting wild boar. Gren et al. (ibid.) argued that, since traffic leading to traffic accidents involving wildlife was a more closely monitored cause of death among boar than hunting was, and since there was no data on the exact number of hunting hours in different years, they adapted the model so that traffic accidents involving boar became the main *Effort* variable.

In the moose study, the aim was to estimate – using panel data analysed by an ordinary least squares (OLS) regression model – the carrying capacity of Sweden’s 21 Counties in respect of sustaining moose in their ecosystem, the moose population’s size and its rate of growth. This would enable one to conclude, firstly, whether it was possible to estimate the moose population using the modified Gordon–Schaefer model and, secondly, whether the new management system’s aims to reduce browsing damage and moose–vehicle collisions had been achieved.

The data that was needed comprised shooting statistics, moose–vehicle accidents, snow depth, road length, fence length, County size, number of daylight hours, and management

plans from Moose Management Groups (MMGs). From this data, the carrying capacity of the ecosystem was calculated, along with the moose population's size and growth rate.

1.4 Scope

The scope of this study was to examine the 20 Swedish Counties that have MMGs with a moose management plan. One County – Gotland – is excluded since there are no moose there.

The study will investigate the size and growth rate of the moose population, as well as the carrying capacity of the ecosystem that sustains them, using the Gordon–Schaefer bioeconomic model. Some of the Gren et al. (2015) modifications of the said model will be employed to calculate the size of the moose population in the 20 Counties, and the results will then be compared with data from current moose management efforts to evaluate the effects of the new moose management system.

The years that will be investigated in this study are 2004 until 2017. Although the law in Sweden already obliged one to report moose–vehicle collisions to the police from 1987, there is only data from 2004 onwards. Nonetheless, this data will show how the moose population developed during the period of study. Since the new management system was introduced in 2012, including data from earlier years will help show whether – and, if so, the extent to which – the new system affected moose population numbers.

1.5 Outline

Chapter 2 of this study will explain the new moose management system, while Chapter 3 presents and discusses previous studies in wildlife management together with selected studies that have used the Gordon–Schaefer model. Chapter 4 contains the theoretical framework for this research. Chapter 5 will define and describe the data employed and discuss its potential limitations, whereas Chapter 6 will explain the methodology adopted for the study. In Chapter 7 the empirical results are presented. Chapter 8 discusses these results and offers some conclusions.

CHAPTER 2

MOOSE MANAGEMENT IN SWEDEN

This Chapter offers a background to how Sweden managed its moose populations in the past and what the status quo is today.

2.1 Moose management in Sweden's history

In the 16th Century, Gustav Vasa introduced the first legislation on moose in Sweden. The development of rifles accelerated during that Century across the world, and an increased population of livestock competed with moose for food resources. Because moose were a significant food supplement for rural families, by the early 1900s, unregulated hunting and decreased land availability due to an increase in population and agricultural land, had driven the moose to near extinction. The 1930s saw the introduction of new legislation that coordinated and regulated moose hunting. The new law subsequently led to a sharp increase in the moose population (Törnström, 2018).

Since the 1930s, moose management in Sweden has been carried out by County Administrative Boards (CABs). In the early 2000s, an increasing number of traffic accidents and an increasing level of browsing damage on young pines led the Government to launch a review of the existing moose management system. In December 2010, Parliament decided to change the moose management system when it became clear that the current system lacked adequate oversight and control, which limited its capacity to manage the moose population effectively. The concept of management as being locally anchored and ecosystem-based was promoted instead, in the belief that it would create a high-quality moose population in balance with food and other natural resources. Among the aims of the proposed new system were to take better account of predators like brown bears and wolves, to decrease the number of moose–vehicle accidents, to decrease the amount of browsing damage to forests, and to focus more sharply on biodiversity. The

new system encompassing these revised aims was introduced in 2012 (Swedish EPA, 2018).

To be able to go hunting in Sweden, every hunter needs to buy an official hunting licence. According to the Swedish Environmental Protection Agency (Swedish EPA, 2018), the number of hunters paying licence fees has been decreasing in Sweden since 1995 (Eriksson et al 2018). For example, in the 2016/7 hunting season, a total of 256,236 hunters paid for a hunting licence, compared with over 300,000 hunters that did so five years earlier. If hunter numbers continue to fall, moose population management will be impacted.

Moreover, changes in the development and structure of society have led existing hunters to change their hunting patterns. Whereas hunters used to spend their entire holiday hunting moose, this trend has been declining as other interests and family needs compete for their time. Thus, today's hunters may spend a week on holiday hunting moose; for the rest of the hunting season, they may only hunt over weekends. This tendency and the decline in the number of hunters since 1995 are likely to place higher demands on moose management in the future.

2.2 Moose management in Sweden today

Moose management today is hierarchical (see Figure 1 for an example of the hierarchy for Norrbotten County). Each County has a CAB. Most of the work regarding wildlife management takes place at the CAB which, among other things, is responsible for issues concerning protective hunting, harvest fees for moose, administration of moose management, operational issues within predator management, and information issues.

At each CAB there is a Wildlife Delegation (WD) made up of representatives of various social interests and several politically elected members. The Chairperson of the WD is the County Governor.

Each County's WD decides on the overall guidelines for –

- its wildlife management
- its moose management
- all licensed and protective hunting, and
- any allowance or financial compensation granted in accordance with the Wildlife Damage Ordinance (2001:724).

According to the Swedish EPA (2019), the WD is also responsible for examining and approving –

- wildlife management plans for the County, and
- proposals for minimum levels for the County's predator populations.

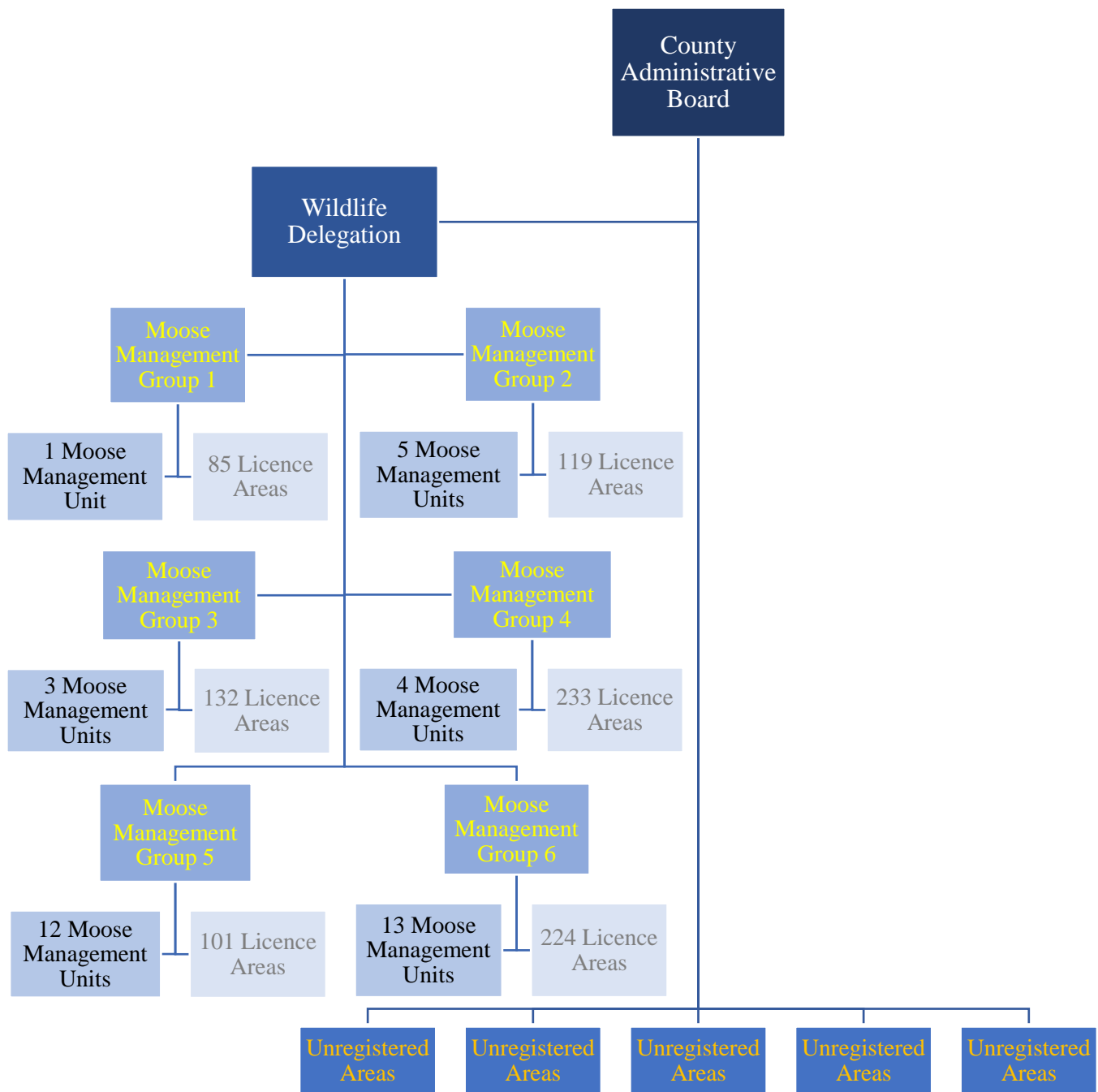


Figure 1: Moose management decision-making process, Norrbotten County

Source: Adapted from Swedish EPA (2019); CAB (2019).

For management purposes, Counties are subdivided into Moose Management Areas (MMAs) (see Figure 2 for the example of Norrbotten County). The MMAs, in turn, are subdivided into Moose Management Units (MMUs) which are responsible for individual Licence Areas (LAs) in the MMA concerned. There are also unregistered areas which are not part of MMAs (see Figure 1). For the 20 Counties studied in 2018, moose management was executed by 144 MMAs with a combined total of 864 members, of whom 5% were women; 2 982 MMUs; and 937 LAs (CAB, 2018). There are large differences among the country’s MMAs. For example, they range in size from 50,000 ha in Södermanland to millions of hectares in northern Sweden.



Figure 2: The six MMAs in Norrbotten County (7,845,594 ha of registered land).

Source: CAB (2018).

In Norrbotten County there are 7,845,594 ha of registered land, or 25% of Sweden’s land surface area. This area is divided in six MMAs; - an equivalent land area in the middle of Sweden consists of 48 MMA (CAB, 2018). This gives the MMAs very different conditions both in terms of administrative costs and opportunities to be able to make local and adaptive decisions.

For each MMA there is an MMG that proposes a management plan to the WD for the whole area it represents. These MMA management plans include in their scope the MMUs and the respective LAs for which they are responsible.

Thus, moose hunting takes place in three types of hunting areas:

- **LAs:** These are large enough to permit at least one calf a year to be harvested. LAs are issued an annual licence directly by the CAB.
- **MMUs:** An MMU consists of several LAs that voluntarily manage their moose jointly. MMUs are large enough to permit, in the long term, a harvest of at least ten (or, in exceptional cases, five) adult moose a year. The hunters who manage an MMU are responsible for consultations between hunters and landowners, they are obliged to compile and administer inventories, and will draft and implement three-year management plans that are subject to CAB approval after consultation with the MMG.
- **Unregistered areas:** The CAB may, for a period not exceeding five days a year, grant hunters the right to harvest an unlimited number of calves on land that is not registered as a moose hunting area. Although hunters are not required to register themselves in respect of these brief annual concessions, they are obliged to report to the CAB the number of calves they harvest and to pay a fee for each such calf (Swedish EPA, 2018).

Hunters are, therefore, divided into three different categories according to where they hunt, i.e. in MMUs, LAs or unregistered areas. The three categories of hunters are all obliged to report to the authorities on how many moose they have shot during a hunting season. Such reports also detail the animals' gender and, if possible, their weight and age.

In addition, all hunters pay a fee to the CAB for each moose harvested. The fee varies between different Counties, ranging from SEK200 to SEK1,200 for an adult moose and SEK50–300 for a calf (CAB, 2018). Harvesting statistics are available at Moose Data, the Government's national moose databank.

Each MMG consists of six members, three representing landowners and three representing hunters. In the Counties that have reindeer husbandry, the group consists of three landowner representatives, two hunter representatives and one person representing the interests of the reindeer husbandry industry. The various MMG members have no deputies; hence, if one member cannot participate, the group will be one member short (CAB, 2018).

The 144 existing MMGs deliver a management plan to the CAB every three years for their respective MMAs. Thus, to determine the 20 CABs' objectives for the moose population in 2017, the author collected their various management plans. With some local variation, the broad national goal in respect of Sweden's carrying capacity for moose in 2017 was 7.0 individuals per 1,000 ha (CAB, 2018). However, although there was a numerical target, without population estimates it was impossible to establish whether the target had been missed, reached or exceeded.

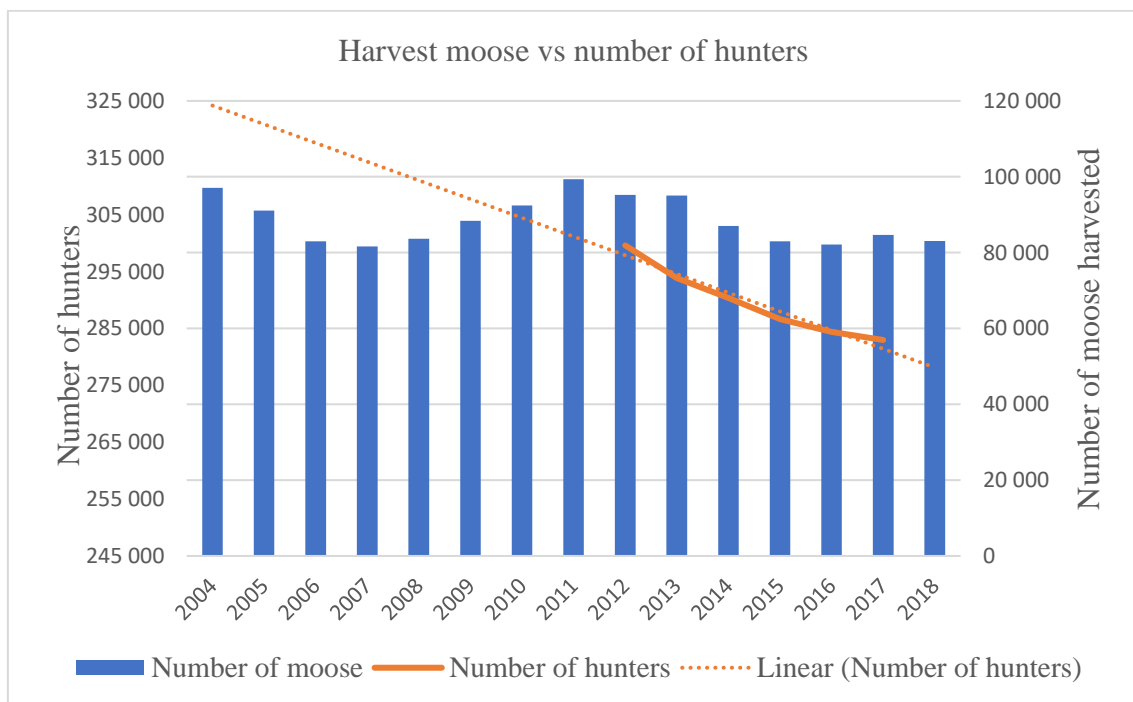


Figure 3: Linear trend in number of hunters.

Source: Moose Data (2018); Swedish EPA (2018).

As seen in Figure 3, the number of hunters decreased in the period 2004–2017 (Swedish EPA, 2018), while the number of harvested moose for that period remained at approximately the same level. A major challenge for future moose management, therefore, is to take into account any changes in hunting trends. At the same time, it is believed that the moose population has never been this large in Sweden (Wallgren, 2016). This means that fewer hunters will manage an ever-increasing moose population. It is against this background that the new moose management system was based on local adaptive management, giving hunters at the local level greater influence over management and, in so doing, incentivising them to become more active in local moose management (Swedish EPA, 2012).

2.3 Changes in moose management

Over the years, Sweden's moose management structure has remained the same, with only minor changes in the number of hunting days, the gender and age distribution of harvested moose, and the sizing of LAs (CAB, 2018). The problems addressed by the Government in 2012 in the launching of the new management system were the high levels of browsing damage and the increasing numbers of traffic accidents.

However, there are many other problems to tackle in respect of the management of moose. For example, the previous management system was entirely area-based, regardless of the quality of the land or food availability. This meant that those areas with quality land and good food availability for moose – and, hence, large moose populations – often filled their hunting quotas quite quickly and then had a very difficult time controlling continued browsing damage. The former system also resulted in areas with no hunting value being registered – with the sole purpose of increasing the area-based licence. The new system is supposed to build on local knowledge, inventories, feed availability, predatory wildlife, game accidents, etc., but the increase in total costs owing to implementing the new system will have a detrimental effect on it reaching its aims.

The urbanisation of hunters has added more obstacles. For example, changed conditions in family life affect hunting as well: hunters from the younger generation have completely

different demands on their time. This may lead to fewer hunting days and the management plan's aims gets harder to achieve. Another problematic factor is that, in southern and parts of central Sweden, other populations of game are growing. These include red deer, fallow deer and wild boar. This not only offers new hunting opportunities; it also increases competition for hunters' time. This has in turn led to a reduced interest in moose hunting, which means fewer hunters keep specialised moose-hunting dogs, making moose hunting more difficult now. A further major issue is that a large proportion of the hunters who go to northern Sweden – which is home to the greatest part of Sweden's moose population – have travelled long distances from elsewhere in the country, resulting in them having fewer hunting days in total (Ulf Kallin, National Wildlife Manager, personal communication).

Other issues that require address are revealed by data from the NWAC and the Swedish Forest Agency (SFA), which, for the 2018 inventory, shows an increase in moose–vehicle accidents and browsing damage all over Sweden. What is called for, thus, is an evaluation of whether the new moose management system is fulfilling its mission. For instance, it is important to know whether the 20 Counties are working towards the same identified goals, and whether they have all interpreted the Swedish EPA guidelines in the same way.

A major disadvantage of the new system is that it perpetuates the former area-based licensing. Thus, in practice, the new system still does not account for how moose move around in response to weather, the availability of food, etc. Moreover, counting a large number of moose in a specific area in the winter months does not always mean they will still be there during the hunting season in September and October (Ulf Kallin, National Wildlife Manager, personal communication).

In 2015, research on the country's new moose management system, entitled *A new ecosystem-based moose management envisaged*, was conducted by the Swedish EPA (2015). Since the study used the lenses of political science and sociology to focus on organisational aspects of the new system, governance and cooperation became its key parameters. This author's study will add another dimension to the EPA's research by

introducing a bioeconomic perspective that focuses on the extent to which the new system's goals have been achieved in terms of reducing browsing damage and moose–vehicle accidents.

As stated earlier, browsing damage and moose–vehicle accidents are on the rise all over Sweden (NWAC, 2018; SFA, 2018). Nonetheless, the conditions under which moose live – and are harvested – differ vastly across the country. While the north is home to the greater part of the moose population, that section of the country has large areas where few people live. It is also home to the Sami, who need to be consulted. There are migratory moose to a large extent and the length of the hunting season differs. The size of the moose management areas also differs significantly. Conditions in southern Sweden are very different: the days are longer, the winter is shorter, and the snow is not as deep. In addition to differences in natural conditions such as climate and snow, there are also differences in regional conditions such as the composition of the forest, landowner structure with a greater part of government owned forest in the north, the behaviour of the moose, and the presence of predators and other wildlife. Despite these differences, the same moose management system is used throughout the country.

The remaining question to answer is still whether – and, if so, to what extent – the moose population's development is consistent with the new management system's goals and how the moose population has developed after the introduction of the new management regime.

CHAPTER 3

PREVIOUS STUDIES

In this Chapter, previous studies in wildlife management and studies (both of wildlife management and management of other renewable resources) that have used the Gordon–Schaefer model will be presented and discussed. Other studies that are relevant to moose management will also be addressed.

3.1 Different forms of wildlife and fisheries management

Most of the previous studies in wildlife management involve organisational and biological aspects. As far as economic consequences are concerned, the studies have mostly been about the harvesting of game. Schuhmann and Schwabe (2000), for example, presented a framework for wildlife managers in the US to help become aware of the economic perspectives of their tasks. The authors investigated how the value of natural resources such as the natural environment, hunting and wildlife management could be estimated. To this end they used a cost–benefit analysis to show how different management decisions affected gains and losses. The authors also conducted research on certain problems the wildlife managers had sought to address, such as human–wildlife conflicts. They concluded that such conflicts comprised a small part of a much bigger problem within management. Although managers could easily estimate the benefits, costs and net benefit of a country’s wildlife populations, two other factors were crucial because they deepened the complexity of wildlife management. The first of these factors involved wildlife populations being a renewable resource; this meant that today’s management decisions would impact future wildlife populations. The second factor was that wildlife management consisted of different persons involved in different decisions, with the benefits and costs of wildlife management occurring at different times.

Another important study whose insights could be applied to moose management is that by Pintassligo et al. (2010) at Campus de Gambelas, Portugal, who examined how fish stocks are best managed together in a group through regional fisheries management organisations (RFMOs). The study's purpose was to examine how successful these organisations are. One of the highlights that emerged from the study was that, because RFMO members could not prevent non-members from harvesting the fish stock, their incentive to be a part of an RFMO was low. For an RFMO to function effectively, all the fishers needed to understand the benefit of cooperative management so that the free-rider problem could be minimised.

Major parallels exist between these RFMOs and the MMUs in Sweden's moose management system. Firstly, members of an MMU also cannot preclude non-member LAs from harvesting moose stock under its jurisdiction. Secondly, as with their RFMO counterparts, MMU members' incentive to be a part of such a volunteer management group can be low. Thirdly, like the fishers in an RFMO, a well-functioning MMU requires all the hunters to understand the benefit of cooperative management so that the free-rider problem is minimised.

The management of game in general also offers experience that can be applied specifically to moose management in Sweden. Hunting was the only management tool capable of bringing wildlife under control; to this end, the regulations for hunters must be facilitated, and governments needed to put effective hunting laws in place. This was the conclusion by Witmer and DeCalesta (1991) in their study of the need to bring the Pennsylvania white-tailed deer population under control – and the difficulty that such control entailed. They investigated the historical growth rate of these deer, what challenges there had been in their management, and how farmers' harvests had been affected. The results showed that corn, alfalfa hay, vegetables, soybeans, fruit and small grains had been damaged significantly by the deer population. Since Pennsylvania's leading economic activities are agriculture and forestry, browsing by these deer had serious financial consequences. Relative to its population size, Pennsylvania also had the largest number of game-vehicle accidents in the country. The study highlighted not only the deer population's financial impact on landowners, but also that government

regulations with regard to hunting licences made it difficult to hunt deer, to keep them off the farmers' property, although that would keep deer numbers under control. The authors concluded that browsing damage, game–vehicle accidents and Lyme disease – a human health issue – were all related to high deer-population density and they made various recommendations regarding regulatory action that could be taken to address these impacts.

The findings in the Witmer and DeCalesta (ibid.) study are similar to those of the Swedish Government (GKS 2009) investigation before it implemented the new moose management system: Sweden's moose population density was too high because their numbers were having negative impacts by way of increases in moose–vehicle accidents and browsing damage. The conclusion to take regulatory action was similar to Pennsylvania's.

3.2 The dual role played by game

A recurring concern in moose management is the browsing damage that these animals cause. This was one of the crucial factors the Swedish Government took into account when it introduced the new moose management system in 2012. Nonetheless, at the same time, moose are one of the most important game species for hunters in Sweden. Thus, the moose are not only an asset for recreational value, they also add to Sweden's biodiversity. However, as Schuhmann and Schwabe (2000) found in their study, these animals will continue to be responsible for high social welfare costs by way of vehicle accidents involving moose and by way of farmer livelihoods being impacted because of browsing damage by moose on their tree plantations. Thus, human–wildlife conflict is part and parcel of moose management.

The specific question of whether moose could be a resource rather than a pest was investigated in a study by Chen and Skonhøft (2013). They used Scandinavian moose as a case in point to examine the economic interdependency between the hunter's harvesting of moose and the landowner's harvesting of timber. Their paper reveals how the interaction of density-independent migration of moose and market prices led a variety of

landowners to adopt different moose management strategies. The study found that damage linked to moose migrations and market interaction tended to create an economic interdependency among different landowners. On the other hand, when landowners themselves decided on the best strategy for harvesting moose on their property, the price of the hunting licence became an important factor.

The Chen and Skonhoft (*ibid.*) study also addresses the fact that the moose population was causing various costs in respect of vehicle accidents and browsing damage to young pines in particular. Browsing damage occurred in winter, when the snow was deep, and the moose migrated from their summer habitat to their winter habitat. The moose would accumulate in small areas where food was plentiful, but their intensive browsing would damage the trees. During the hunting season, the moose were still at their summer habitats. This meant that the farmers whose plantations had been damaged by browsing in winter had no benefits of moose hunting in autumn. Put in economic terms, the areas where damage occurred were not the same as the areas where moose generated utility during the hunting season.

This is a big issue for moose management in northern Sweden, for example, where certain areas suffer severe browsing damage during winter. Moreover, moose populations are hard to estimate because of their migration patterns. This author's study therefore takes migration into consideration by working with large areas such as Counties instead, where the moose can be assumed to remain in the estimated area.

According to Wam and Hofstad (2007), the commercialisation of hunting Scandinavian moose is on the increase. Thus, a new type of financial income is being associated with the moose. The Wam and Hofstad (*ibid.*) study investigated whether it was possible to have moose and timber on the same land and obtain an economic value from both at the same time. The study found that, although a combination of moose and timber would produce the best net value, the moose was not the major source of income (its share of overall income was 30% or less). This study may, therefore, assist in creating a management tool to serve as an indicator for determining the optimal level of the moose

population. However, many other factors, such as the price of timber and game, also need to be considered. Also, the quality of the land determined the forest growth rate – a factor that is important because it will take a longer time for the pine to grow on less nutritious fields.

Similar to Wam and Hofstad (*ibid.*), Zivin et al. (2000) investigated the dual role played by game. Their study looked at feral pig management in California to see whether a pest could be transformed into a resource. The study developed a model in which agricultural damage was a function of the feral pig population and its dynamics. The authors then investigated different management strategies and found that, by controlling the size of the feral pig population with different hunting strategies, farmers and landowners could indeed transform this pest into a resource.

3.3 Game–vehicle collisions

Increasing game–vehicle collisions are a problem in several other countries as well. In the US, for example, Schwabe et al. (2002) analyse how to address this problem via deer management, because the social costs relating to deer–vehicle accidents exceed US\$1 billion a year. Schwabe et al. (*ibid.*) focus on Ohio, where they examined different management strategies to identify how they could achieve a decrease in the deer population – and, hence, a decrease in traffic accidents involving deer. Their study focused mainly on two factors, namely the stated social costs, and the benefits for the hunter. They found that “factors such as deer population size, traffic volume, and type of hunting regulation significantly influence the incidences of deer[–]vehicle collisions”.

The importance of the size of a population of game and the problems that such game can cause to society were also what Skonhøft and Olausson (2011) investigated when they made a cost–benefit analysis of moose management in Norway. They used a harvest model, dividing the moose population into different age segments in an age-structured framework. In this case, the landowner obtained the benefit of the value of the harvested moose and paid the cost of the browsing damage – but not the cost of other possible damage such as moose–vehicle accidents. One of the said study’s aims was also to look

at different management strategies and how economic values could change. Besides the landowner management strategy described above, the study also looked at overall moose management, i.e. a strategy that covered the social costs of moose–vehicle accidents as well. The authors found that, in comparison with their hunting income value, Norway’s moose population in general appeared to be too large because it was causing excessive costs in traffic accidents and excessive browsing damage. Thus, higher population density meant more damage, both browsing damages and moose-vehicle damages.

3.4 Impact of wildlife population density

As shown in section 3.3, Skonhøft and Olaussen (*ibid.*) investigated the importance of game species’ population size and the problems that that could cause for society. Their findings are supported by Zivin et al (2000), Wam and Hofstad (2007) and Chen and Skonhøft (2013), who illustrate that the impact of wildlife density is indeed a pivotal factor in managing wildlife.

Other authors, such as Seiler (2004), have also found a meaningful connection between ungulate–vehicle accidents and wildlife density. Seiler (*ibid.*) examined trends and used regional variation in vehicle accidents involving ungulates – here, moose and roe deer – to test the hypothesis that such accidents were proportional to wildlife density and traffic volume. The study investigated spatial patterns at the LA, MMA and County level. Trends in ungulate–vehicle accidents were examined at national, County and MMA level over periods of 30, 16 and 12 years each. The researcher found that the number of vehicle accidents involving these ungulates reported at national level during the period 1970–1999 was correlated not only with increasing national traffic volumes, but also with changes in the number of hunting licences issued for moose. At County level, the clear association was borne out further: changes in the number of moose–vehicle accidents at County level showed a close correlation with shooting statistics and traffic volumes. This supports the view that moose management systems should take moose–vehicle accidents into consideration.

Seiler's study (ibid.) also highlights that there are other important factors affecting vehicle accidents besides the density of wildlife populations and traffic volumes. Such factors include road density, road underpasses that offer animals such as moose a thoroughfare, and preferred habitat. However, the study's results show no linear relationships between wildlife population density, traffic, remedial actions and the number of ungulate–vehicle accidents.

Witmer and DeCalest (1991) also concluded that a high wildlife population density – in their study, the white-tailed deer – was closely related to browsing damage on both crops and forest as well as to game–vehicle accidents and disease.

3.5 Estimating populations with the Gordon–Schaefer model

Several studies have used the Gordon–Schaefer bioeconomic model (see Chapter 4 for more detail) to estimate different animal populations. Pintassligo et al. (2010), for example, used the model to show that fish stocks were best managed in groups through RFMOs. Kataria (2007) used the model to estimate the growth rate of signal crayfish and the carrying capacity of their ecosystem in Sweden. With the estimated result, the study made a cost–benefit analysis to see if it would be economically efficient to introduce a non-native species, compared to the existing noble crayfish. As with effective moose management, effective crayfish management demands that one calculates its population growth rate.

According to Gren et al. (2015), the difficulty of assessing the size of wildlife populations in general hampers their effective management. In their study on Sweden's wild boar, therefore, they used a method similar to Kataria's (2007) to establish whether the Gordon–Schaefer model could be used to estimate Sweden's wild boar population more accurately. Besides employing that model, the authors also developed an econometric model to enhance their estimations. Gren et al (2015) model is based on data from traffic load and traffic collisions with wild boar from different Counties in Sweden. The Gordon–Schaefer model is widely used with in the fishing industries, and an important variable in the Gordon–Schaefer model is the *Effort* variable. When it comes to hunting, however, it

is hard to estimate how many hours of effort hunters use to catch game. As a proxy, therefore, traffic load and traffic accidents involving game were used as an *Effort* variable.

3.6 Conclusions based on previous literature

Many of the previous studies of wildlife management discussed in this Chapter have investigated the introduction of a new management system with a focus on the interaction in the social structure, focusing on the interaction between wildlife populations and social elements. When it comes to bioeconomic analyses, these have mostly been used in the fishing industry to calculate the growth rate of the fish stock being harvested. However, Schaefer (1954) writes that his economic theory regarding common property can be applied to any wildlife stock. Nonetheless, in order to apply these findings to the effective management of game, one needs to be able to calculate the growth rate of the wildlife population in question; doing so will also provide an indicator for estimating the size of that population. To this end, several of the articles cited in this Chapter have estimated different game populations by using the Gordon–Schaefer model.

Research that relates to the same problem that occurs in Sweden’s moose management is that by Schuhmann and Schwabe (2000). They state that raised costs such as wildlife–vehicle collisions and browsing damage must be weighed up against the benefits of the natural resource to optimise game management strategies. They also found that, due to time lags and the organisational set-up, different people participate in different decisions within the same management. There is no unified body of decision-makers making consistent decisions together for the entire system. This is also the case in Sweden, where MMGs are elected for a period of three years, while the WD is elected for four years. Consequently, institutional knowledge is compromised as individuals in the structure exit and newcomers take their place, and the two entities do not communicate their decisions to each other.

The contribution made by Schwabe et al. (2002) to the current research was their study of, among other things, the relationship between the size of a deer population, the deer management strategies and deer-related traffic accidents. Another valuable contribution was that by Skonhøft and Olaussen (2011), who wrote that, from an economic

perspective, it seemed strange to maximise meat production (which animals one chose to shoot) without considering the cost of the browsing damage and accidents they caused. From these studies and from national data, it was obvious to the author that a moose population that was too large would cause excessive costs in traffic accidents and browsing damage in comparison with their hunting income value. That was the case in Sweden as well, and it prompted the launch of the new moose management system.

As the previous literature evidences, one of the main problems in wildlife management is being able to estimate the size of a specific population. Some of these studies have shown the successful employment of the Gordon–Schaefer model in this regard. To estimate Sweden’s moose population, therefore, this model has been applied as well, together with the econometric enhancements for such estimations suggested by Gren et al. (2015). The carrying capacity for moose in each County will also be estimated. This will provide an indicator for interpreting the goals in moose management plans, and for measuring whether those goals are achievable. The moose population’s growth rate will also be assessed to measure how many individuals need to be harvested to achieve a good balance between the moose population and the natural and social elements in the ecosystem they inhabit.

CHAPTER 4

THEORETICAL FRAMEWORK

This Chapter contains an introduction to an economic model of renewable stock resources such as wildlife; the Gordon–Schaefer model, a logistic growth model often used in economics to analyse the management of biological stock resources.

4.1 The Gordon–Schaefer model

Gordon (1954) pointed out that one of the crucial factors for managing a biological resource (in our case, wildlife) was being able to calculate the population. He is known for having introduced a method to calculate populations in fishery resources, an approach which has since become known as the *Gordon–Schaefer model*. The Gordon–Schaefer model was designed to use catch and effort data for estimating wildlife population parameters. Gren et al. (2015), for example, adapted the Gordon–Schaefer model to analyse wild boar populations in Sweden. Their method was considered most appropriate for, and was adopted in, this author’s study because when it comes to hunting, it is hard to estimate how many hours of effort hunters use to catch game. As a proxy, therefore, traffic load and traffic accidents involving game were used as an Effort variable.

The central concept in a population model is the growth function. Assume that population growth is proportional to the population x and the net growth rate r , defined as $r = b - m$ where b is the birth rate and m the natural mortality rate. The population growth rate can then be described as follows:

$$\frac{dx}{dt} = rx \tag{1}$$

However, if the population is not managed in any way, with this growth function the population will grow exponentially towards infinity if $r > 0$. But such a process cannot last for any length of time. As the population increases, competition for food and living room will limit growth rates. Hence, the net growth rate will decrease as the population increases. The growth function will then be modified to –

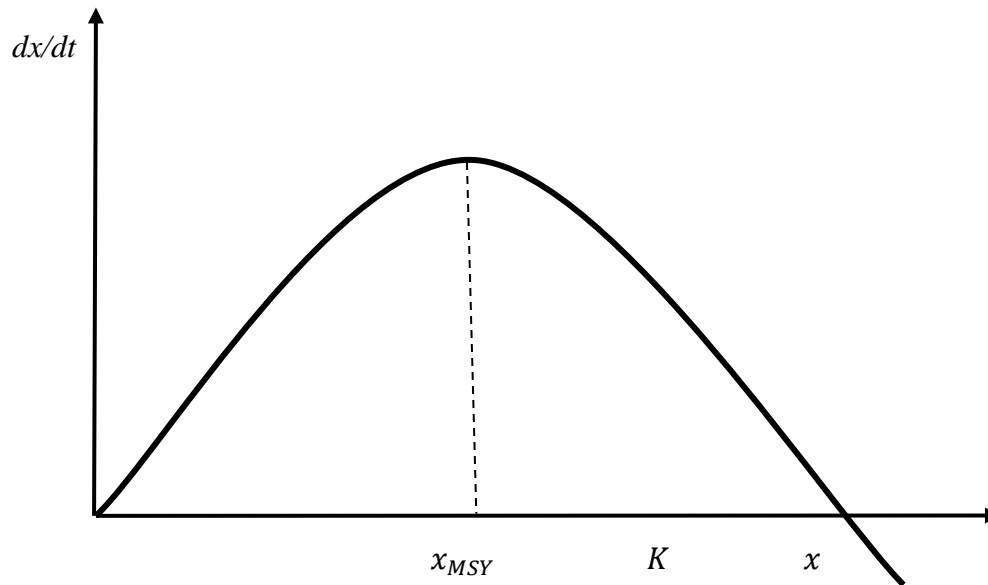
$$\frac{dx}{dt} = r(x)x \quad (2)$$

where the growth rate $r(x)$ is a function that is decreasing in x . Defining $r(x)$ as $r(x) = r \left(1 - \frac{x}{K}\right)$ gives us the logistic growth function as stated in Equation (3) below (Bostedt 2013):

$$\frac{dx}{dt} = rx \left(1 - \frac{x}{K}\right) \quad (3)$$

In Equation (3), the net growth rate r – also called the *intrinsic growth rate* – is a positive parameter between 0 and 1, and K is the maximum population at the ecosystem’s carrying capacity. With no human interference, over time the population in this model will reach K . The maximum size of the population at the ecosystem’s carrying capacity is often related to the availability of food.

Figure 4 below illustrates the logistic growth function. The figure shows that the maximum sustainable yield (x_{MSY}) of wildlife population x is the level that offers $\frac{dx}{dt} = MSY$, where the highest net growth is achieved, that is, the largest sustainable harvest we can obtain without the population slowly moving towards eradication.



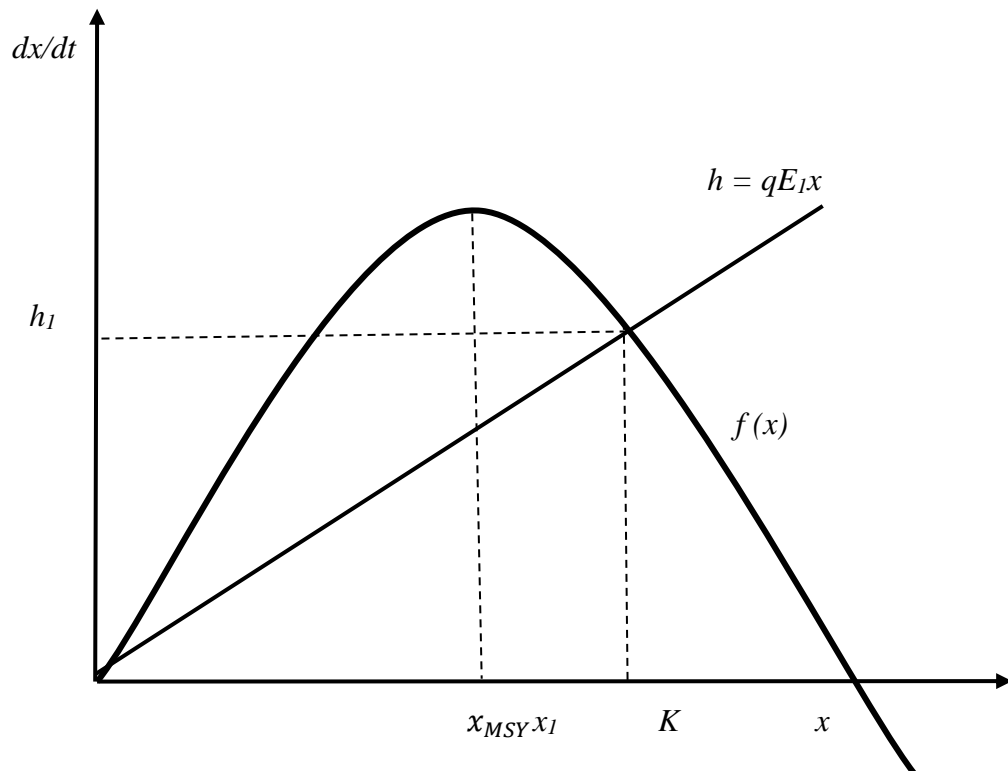
x_{MSY} = maximum sustainable yield of x ; K = ecosystem carrying capacity;
 x = population

Figure 4: Logistic growth function, with highest net growth at x_{MSY} .

Source: Bostedt (2013).

The latter Figure shows us that, if the growth function is given by $f(x)$ and the harvest by $h = qE_1$, where effort is represented by E_1 and catchability by q , then the population will be x_1 and the harvest will be h_1 when we have a bioeconomic equilibrium where the population size does not change. The harvest $f(x) = h$, obtained at a bioeconomic equilibrium, can be said to be a *sustainable* harvest. If the population is less than x_1 , the harvest is less than the population growth rate and the population will increase – and vice versa if the population is greater than x_1 (Bostedt, 2013). The harvesting of moose in Sweden can be assumed to be less than the species' population growth rate, as the population's growth in size is evidenced by the annual increase in browsing damage and moose–traffic accidents (NWAC, 2018; SFA, 2018). Thus, the population is moving towards K . The carrying capacity for the moose population depends on the amount of food in the landscape. The available food in turn depends primarily on how much productive young forest there is, which in turn is an effect of forest management. If food availability decreases while the moose population grows, the damage their browsing

causes increases. Heavy damage linked to moose indicates that the moose population in Sweden is approaching their ecosystem's maximum sustainable carrying capacity (K). Discussions with staff at the CAB also indicate that, at some places, the moose population in Sweden has passed K , since dead moose have been found in some areas each year and they have most likely died of starvation; thus, scarcity of food has occurred.



x_{MSY} = maximum sustainable yield of x ; x = population; h = harvest; K = ecosystem carrying capacity; q = catchability; E = effort; f = function

Figure 5: Biological growth function with a harvest equation.

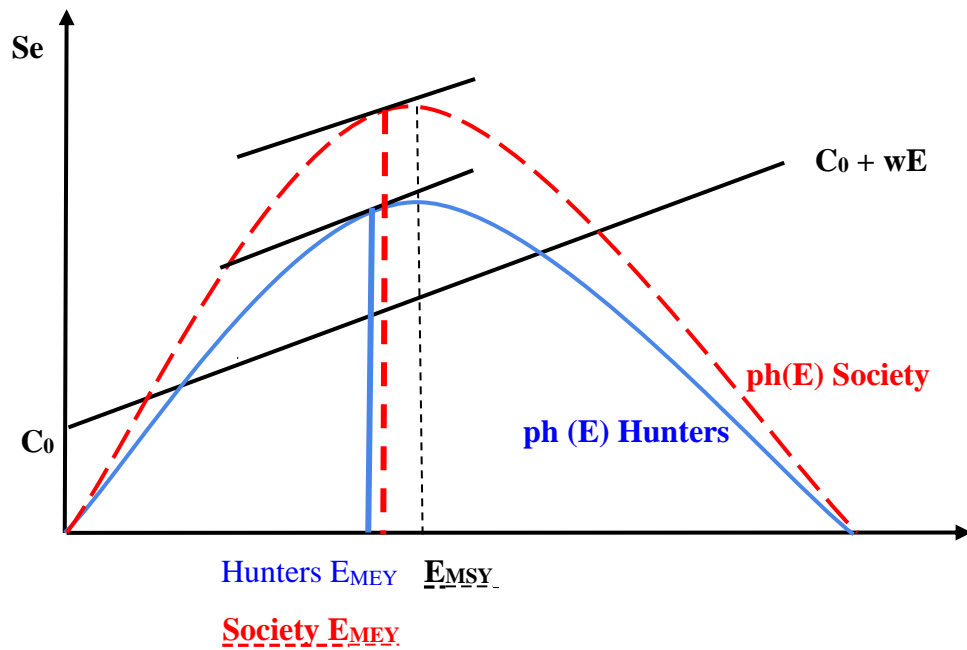
Source: Bostedt (2013).

Figure 6 below describes the costs and benefits from hunting efforts. The costs and benefits associated with moose hunting differ for the hunter and for society. To assume full competition in this case, two conditions are added to the current scenario. The first condition entails that, by way of a hunting licence, the hunter has sole rights to a part of

the moose population; the second condition entails that the hunter does not discount future revenues and costs.

The biggest possible profit is maximum economic yield, *MEY*. Again, this differs for the hunter and for society: the private benefits considered by the hunter include only the meat and the recreation value of the hunting, i.e. they exclude the social benefits of reduced browsing damage and reduced traffic accidents – even though these matter to the rest of society.

What is also evident in Figure 6 is that the effort associated with the *MEY*, is less than the effort associated with the *MSY*, i.e. $E_{MEY} < E_{MSY}$. Hence, the effort level with the highest profit is less than the effort level which provides the *MSY*. This is intuitive, as costs are associated with harvesting. To achieve the highest sustainable harvest, therefore, it would only be optimal to set the level of effort at E_{MSY} if $w = 0$. If $w > 0$, the optimal effort is less than this and $x_{MSY} < x_{MSY} < K$. Thus, the size of the population will be between the population x_{MSY} , that gives the highest sustainable harvest and the carrying capacity K (see also Figure 5). In other words, the population will not risk extinction (Bostedt, 2013).



MEY= Maximum Economic Yield E = Effort ph(E) = Price harvest
 MSY= Maximum Sustainable Yield C₀= Fixed costs wE = Variable costs

Figure 6: Relative marginal revenue product for the hunter and society.

Source: Adapted from Bostedt (2013).

From the hunter's point of view, the smaller the moose population, the greater the harvesting effort (E) required. The main problem in Sweden is that E will become more expensive when wages (and, hence, the opportunity cost for the hunter's time) increase at the same time as the externalities from browsing damage and moose-vehicle accidents increase in cost with increased traffic. Additionally, the harvest fee for the moose makes the financial cost per unit higher for the hunter; this is another reason why there is a gap between privately and socially optimal harvests. Therefore, the socio-economic problem of negative impacts by moose persists, and it is not profitable for the individual hunter to hunt more, meaning that increased hunting will also not help to bring moose numbers under control.

In the early 1900s, before hunting was regulated, Sweden was in an open-access equilibrium where profits were zero, and costs and revenue were equal. Because the opportunity cost of people's effort was then also significantly lower, this equilibrium was close to the level where the stock would be decimated. During the 1900s, hunting was regulated, which meant that Sweden moved from the open-access equilibrium to something akin to profit maximisation. At the same time, the opportunity cost of people's effort rose dramatically. All in all, this meant that the cost line turned counterclockwise, so that both open-access and profit maximisation entailed lower effort and larger moose populations, compared with the early 1900.

Moose in Sweden are what one could call a *common property resource*, in that all moose hunters with a valid licence are entitled to harvest from the same moose population. Thus, Sweden's moose population is subject to so-called common-pool resource management. Based on the moose management plan compiled by an MMG, the CAB will decide how many moose can be harvested. Then, if a local hunting team does not follow the plan but decides to harvest less than the number to which their licence entitles them so that they can later harvest from a bigger moose population, that population will move towards K . Unless the population is in balance with the food resource, heavy browsing damage ensues, and some animals starve. To this end, a dialogue between forest owners and hunters is necessary to create a balance between the size of the population, food availability and damage in both traffic and forests and the negative impacts of moose-vehicle accidents and browsing damage to public forests and privately owned tree plantations (Solveig Larsson, National Association of Huntsmen, personal communication).

The fact that the optimal level – or, indeed, even the size – of the moose population is unknown remains one of the greatest obstacles in moose management. To be able to estimate how big the moose population is today, their growth rate must be calculated. Once this rate has been estimated together with the carrying capacity of the moose's ecosystem, the Gordon–Schaefer model can be employed to estimate the size of the moose population.

4.2 Gren et al. (2015)'s adaptation of the Gordon–Schaefer model

Gren et al. (2015) adapted the Gordon–Schaefer model to analyse Swedish boar populations, and in this study a further adapted version of Gren et al.'s method will be used. A key component of Gren et al.'s model is that some wildlife deaths are linked to traffic accidents rather than hunting. This is described in the logistic function presented as Equation (4), where changes in a wildlife population (boar in Gren et al.'s case, and moose in this one) are contingent on population growth, traffic accidents and hunting.

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

The region (county) is represented by i where $i = 1, \dots, n$. P_t^i is the moose population in region i in period t . The intrinsic growth rate is r^i and the maximum moose population that the region could support if there were no accidents or hunting is the region's carrying capacity, K^i . V_t^i represents moose–vehicle accidents and the last variable, H_t^i , signifies moose killed by hunting.

Statistics on the number of moose shot are available for each region in Sweden, but there is no data on the hours spent on each harvest. Hence, it is not possible to employ the usual way to estimate the population and its growth. Instead, we use moose–vehicle collisions V_t^i , which are assumed to be related to the traffic load T_t^i , as given below:

$$V_t^i = a^i T_t^i P_t^i \quad (5)$$

Following Gren et al. (2015), from this equation the estimation of the number of accidents per unit of traffic effort, S_t^i , is done, as follows:

$$S_t^i \equiv \frac{V_t^i}{T_t^i} = a^i P_t^i \quad (6)$$

Equation (6) lacks one set of variables that will affect a region's overall carrying capacity, however, namely the habitat characteristics L_t^i . Gren et al. (2015) use two different models to introduce habitat characteristics in two different ways. In one (their “direct model”), these characteristics are introduced as additional explanatory variables on the right-hand side in Equation (7), while in the other (their “indirect model”), they are introduced as variables that affect the intrinsic growth rate, r^i . According to Gren et al. (2015), in this context, one cannot predict beforehand which one of the two models will work best, but by modelling, one can test their relative efficacy. The influence that the ecosystem characteristics have on population growth can be modelled in the direct model as follows where L_t^i is a vector of habitat characteristics:

$$\frac{\partial P_t^i}{\partial t} = r^i P_t^i \left(1 - \frac{P_t^i}{K^i}\right) - a^i T_t^i P_t^i - H_t^i + f^i L_t^i \quad (7)$$

In Equation (7), every coefficient f^{ij} in the vector f^i of habitat variables shows the influence that the different habitat variables have on population growth. According to Gren et al. (2015), there is an important assumption that this model needs to have, namely that a proportional change in the moose population can entail a proportional change in accidents per unit of traffic effort S_t^i . Thus, in Equation (7), P_t^i needs to be replaced by $\frac{S_t^i}{a^i}$, and then both sides of Equation (7) need to be multiplied by a^i/S_t^i , as follows:

$$\frac{\partial S_t^i}{\partial t} = r^i - \frac{r^i}{a^i K^i} S_t^i - a^i T_t^i (1 + X_t^i) + a^i f^i \frac{L_t^i}{S_t^i}, \quad (8)$$

where $X_t^i = \frac{H_t^i}{V_t^i}$, i.e. moose killed by hunting (H_t^i) divided by moose–vehicle accidents (V_t^i) in one effort variable (X_t^i).

According to Gren et al. (2015), a final approximation is also made to obtain the derivative of the dependent variable with respect to t :

$$\frac{\partial S_t}{\partial t} = \frac{S_{t+1} - S_{t-1}}{2} \quad (9)$$

The regression equation for moose population growth with respect to their direct impact on the habitat can therefore be specified as –

$$Y_t^i = \alpha^{i1} + \alpha^{i2} S_t^i + \alpha^{i3} T_t^i (1 + X_t^i) + \alpha^{i14} \frac{L_t^{i1}}{S_t^i} + \dots + \alpha^{in4} \frac{L_t^{in}}{S_t^i} + \varepsilon_t^i \quad (10)$$

where; ε_t^i is the error term. Gren et al. (2015) explain that the habitat effect model in Equation (8) shows a relationship between the variables and the coefficients in Equation (10), as shown below:

$$Y_t^i = \frac{S_{t+1}^i - S_{t-1}^i}{2}, \quad r^i = \alpha^{i1}, \quad \alpha^{i2} = \frac{r^i}{\alpha^{iK^i}}, \quad \alpha^{i3} = \alpha^i, \quad (11)$$

$$\alpha^{ij4} = \alpha^i f^{ij} \quad \text{for } j = 1, \dots, n$$

According to Gren et al. (2015), once the coefficients in (11) have been estimated, the carrying capacity K^i , the marginal impact of habitat characteristics f^{ij} , and the population level P^i can be calculated – as illustrated in Equation (12):

$$K^i = \frac{r^i}{\alpha^{i2} \alpha^{i3}} \quad f^{ij} = \frac{\alpha^{ij4}}{\alpha^{i3}} \quad \text{and} \quad P^i = -\frac{S^i}{\alpha^{i3}} \quad (12)$$

In their indirect model, on the other hand, Gren et al. (2015) assume that the intrinsic growth rate is given by $r_t^i = b^i + c^i L_t^i$, where c^i is a vector of coefficients and L_t^i is the vector of habitat variables $j = 1, \dots, n$. Thus, if there is a change in any of the habitat

variables, then the intrinsic growth rate can vary over time. The moose population growth equation can then be defined as –

$$\frac{\partial P_t^i}{\partial t} = (b^i + c^i L_t^i) P_t^i \left(1 - \frac{P_t^i}{K^i}\right) - a^i T_t^i P_t^i - H_t^i \quad (13)$$

Gren et al. (2015) explain further that, as in the derivation of the direct landscape effect model, P_t^i is replaced by $\frac{S_t^i}{a^i}$ in Equation (13) and both sides of the equation multiplied by $\frac{a^i}{S_t^i}$, giving the logistic function for the indirect landscape effect model as –

$$\frac{\partial S_t^i}{S_t^i} = b^i + c^i L_t^i - \frac{(b^i + c^i L_t^i)}{a^i K^i} S_t^i - a^i T_t^i (1 + x_t^i) \quad (14)$$

The regression equation is then specified as follows:

$$Y_t^i = \beta^{i1} + \beta^{i2} S_t^i + \beta^{i3} T_t^i (1 + x_t^i) + \beta^{i14} L_t^{i1} + \dots + \beta^{in4} L_t^{in4} + v_t^i, \quad (15)$$

where v_t^i is the error term. The coefficients in Equation (15) are related to the logistic regression in Equation (10) and are defined as –

$$\beta^{i1} = b^i, \quad \beta^{i2} = -\frac{r_t^i}{a^i K^i}, \quad \beta^{i3} = -a^i, \quad \beta^{ij} = c^{ij} \quad \text{for } j = 1, \dots, n \quad (16)$$

where $r^i = \beta^{i1} + \sum_{j=1}^n \beta^{ij4} L_t^{in}$.

When the coefficients in (15) have been estimated, the ecosystem's carrying capacity is calculated from Equation (16) as –

$$K^i = \frac{\beta^{i1} + \sum_j \beta^{ij4} L_t^{ij}}{\beta^{i2} \beta^{i3}} \quad (17)$$

The population level P is then estimated by $P^i = -\frac{S^i}{\beta^{i3}}$

The indirect model worked better than the direct model in the Gren et al. estimations. It is reasonable, therefore, to assume the same outcome in the current study. Nonetheless, both models will be calculated in the current study.

CHAPTER 5

DEFINITION AND DESCRIPTION OF THE DATA

In this Chapter, the core and supplementary data will be defined and described. Potential problems regarding the data will also be discussed. The core data is presented first in this Chapter, namely that used in current management, while supplementary data used to obtain more robust picture of the management situation is presented thereafter.

5.1 Description of the core data

To be able to conduct this study, a variety of data was needed. The core data comprised that currently being used in moose management, which includes shooting statistics, a moose browsing inventory (MBI) and moose observations (MOs).

A supplementary set of data (see 5.2 below) related to the preferred habitat of the moose, the number of moose–vehicle accidents, traffic loads relative to County size, depth of snow, and the number of hours of daylight between October and April. This additional information was selected based on data from the NWAC, which showed that most moose–vehicle accidents occurred in woodlands during hours without daylight in the months specified.

5.1.1 Shooting statistics

You need a licence to hunt moose in Sweden. Such licences specify where hunting is permitted. A licence from the CAB, for example, specifies the number of moose that may be shot in a defined LA, and may also specify their gender and age distribution. Unlike in LAs, in unregistered areas hunters are permitted to shoot calves, but only during the first five days of the moose hunting season. The shooting statistics used for the current

study were derived from the reports that hunters submit after a hunt, and which are stored in the Moose Data archive.

5.1.2 Moose browsing inventory

An MBI is one of the most important indicators an MMG can employ when it sets up a management plan. Based on a quality-assured method developed collaboratively by the SFA and the Swedish University of Agricultural Sciences, the MBI is a statistically secured means of estimating the proportion of young trees damaged by browsing from moose or other deer in an inventory area. In such areas, selected at random, young trees are measured and evaluated based on their species and height as well as on the extent and recency of damage to them. Information about the moose's favoured tree species – rowan, aspen, sell and oak (RASE) – is also collected (SFA, 2018). Thus, an MMG's MBI report contains information about an inventory area's tree species, the proportion of damaged trees and the distribution of new and old damage. All MBI data is available at the SFA.

The SFA has also set up a feed forecast which takes into account tree growth and planned harvests. For example, when timber is cut down, space is given to RASE species, which produces considerable food for the moose in a few years' time (ibid.).

5.1.3 Moose observations

Hunters in Sweden and Norway have been reporting on MOs since 1985 and 1967, respectively. This method of moose management requires hunters to report not only on the number of moose they see, but also on what effort has gone into enabling that sighting. The MO method was evaluated by a Norwegian–Swedish cooperation group between 1996 and 1997, after which certain revisions were made to it in 1997. Since then, MO has become the primary method recommended for counting moose each year because it is simple to perform and interpret, besides being cost-effective.

A key variable in the MO method is the number of hours spent in observing moose. To make MOs a reliable index, a minimum of 5,000 person-hours of observation within a

certain area is needed during the first seven days of the new hunting season in which actual hunting takes place. This seven-day period must be within the first 30 days of the new hunting season, because an MO value from a September hunt cannot be compared with a value from an October hunt, for example. MOs are related to how long the hunting day was, and how many hunting participants were involved as observers. The more person-hours spent on MOs, the better the estimate of numbers observed. Thus, MOs should not be used for comparisons at hunting team level, but rather at MMU level. In that way, larger areas can be covered for observation.

After a specific area has conducted MOs for a minimum of four years, a trend becomes evident in respect of the moose population's development in the area. Thus, the *reliability* of estimates depends on how well the recommended methodology for collection is followed.

An MO value is calculated as –

$$\frac{M}{H} = MH$$

where M is the number of moose observed, H is the number of person-hours used, and MH is average number of moose observed per person-hour – which is also the measure of population density. From this, trends can be identified: if it takes fewer hours to see a moose, the population density is probably increasing – and vice versa. All MO data is available at Moose Data (Ericsson et al. 2011).

MOs are currently a key part of moose management. Nonetheless, some crucial requirements still need to be met for the data to be reliable. The method is relatively vulnerable to conscious or unconscious errors in data collection and reporting. If the hunting day or number of observers is misreported, or if shot moose are not included in the number of moose reported as having been observed, such errors and omissions are

critical and can lead to biased data, analyses, and results. Another important limitation in MO data is that, as mentioned earlier, the MO values from different hunting periods cannot be compared. Different Counties also cannot be compared with each other, since each County in Sweden has a different relationship between moose density and observed moose per person-hour.

Björn Sundgren of the Swedish Association for Hunting and Wildlife Management works with the reporting forms used for MOs. In his opinion, bias in the data could be suspected if, for example, reports showed that all hunting days had been exactly eight hours long, or when the number of moose reported as having been shot have not been included in the number observed. Since many hunters compile their reports directly on the Internet, the digital reporting system can detect some of the bias.

Another important question in respect of obtaining reliable data from MOs is whether all the hunters know how to count an observation correctly. Providing hunters with training on what an MO is and how it works is a crucial factor, therefore (Ericsson and Kindberg, 2011).

Another possible data bias that may occur is at areas where a moose hunting season has been cancelled. Since MOs are only carried out in combination with hunting, areas with no hunting will go under- or unreported, and the data will generate incorrect conclusions.

All these minor biases together can cause MOs to show a false trend. This should be borne in mind – particularly since moose browsing damage and moose–vehicle accidents continue to increase despite the new management system, and MOs form a major part of moose management plans. It is important, therefore, to investigate whether there are not more reliable calculation models.

5.2 Description of the supplementary data

Apart from the core data traditionally used in moose management, this study also used supplementary data to estimate the size of Sweden's moose population. First among these additional sources was the number of moose–vehicle accidents – which, in line with Gren et al. (2015), is used as an *Effort* variable.

Since 1987, paragraph 40 of Sweden's hunting regulations (*Jaktförordningen*) obliges drivers to report moose–vehicle accidents to the police, even if the animal was not visibly hurt. The police report data is available at the NWAC.

The study also used data on traffic load related to the County size. This data was obtained from Traffic Analysis, which is the Traffic Department's official database, and Sweden's Central Statistics Bureau (Statistiska Centralbyrån/SCB).

Other factors that affect the number of accidents with moose are landscape characteristics, wildlife fences along the roads, weather conditions such as the depth of snow reported, and the number of hours of daylight. This type of data was collected from the Swedish Transport Administration and the Swedish Meteorological and Hydrological Institute (SMHI).

5.2.1 *Depth of snow*

Snow depth has the greatest impact on traffic accidents in the northern Counties, where the snow is deep during for longer periods than in the more southerly parts of Sweden and where the numbers of hours of daylight is limited during winter. Data on the maximum depth of snow for each County and year is stored by the SMHI. For the purposes of the current study, the winter's maximum depth of snow between the years 2004 and 2017 was summarised for all SMHI stations. However, if only a few stations exist for a large area, since there may be significant differences in local snowfall, the data on snowfall in that area may be skewed. Therefore, an average was taken for each County's deepest snow recorded for the stated years.

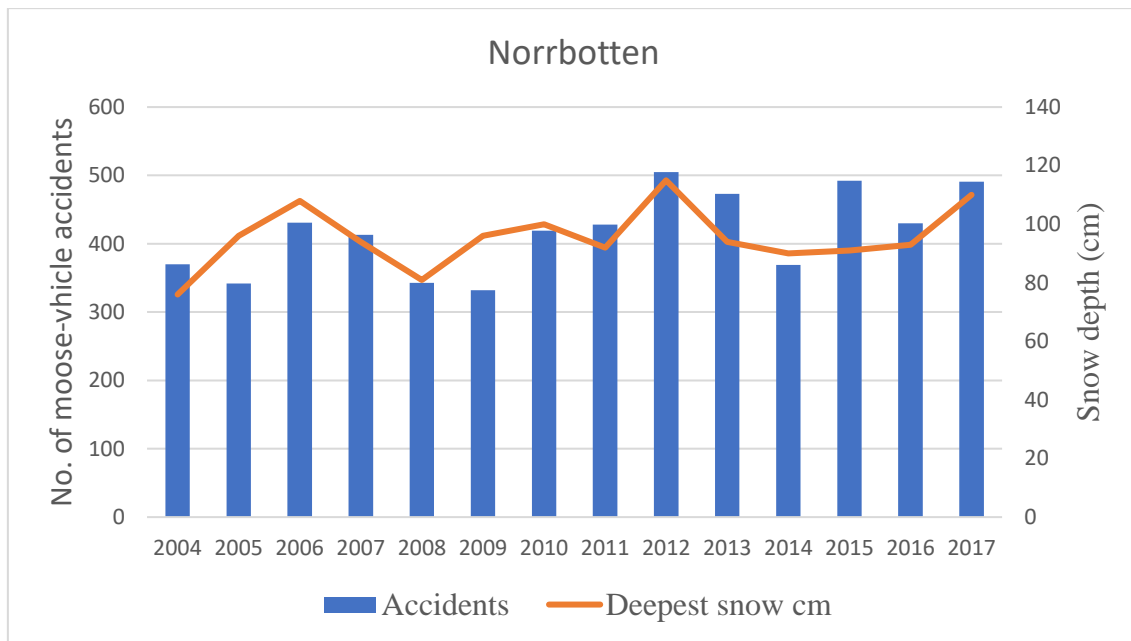


Figure 7: Moose–vehicle accidents in winter, Norrbotten County, 2004–2017.

Source: NWAC and SMHI (2018).

Figure 7 shows that, in Norrbotten, deeper snow is correlated with an increased number of moose–vehicle accidents. The Figure also shows that the number of accidents has been increasing on average, which could be a sign of an increasing moose population.

The relative variation in snow depth between different winters is greater in southern than in northern Sweden. Moreover, with climate change, the duration of snow cover is expected to decrease, while southern Sweden will probably not have any lasting snow cover at all (Wern, 2015). The impact of snow depth on moose movement patterns is not as clear in southern Sweden as it is in the north, as both road networks and traffic are denser, meaning that the moose cross roads more often – regardless of snow depth. Also, in the north, deep snow frequently means that moose concentrate their food search near the roads, where it is easier for them to move around (Ulf Kallin, National Wildlife Manager, personal communication).

5.2.2 *Traffic load relative to the County size*

The definition of *traffic load* is all vehicles that travel on a road. Traffic load is determined using measuring instruments located on the roads. Sweden's Transport Administration has a model for calculating traffic load on the country's roads, but not at a regional level. Furthermore, this Administration only reports traffic load on government-owned roads, which entails that significant parts of Sweden's countryside – where there are many roads – are not included in their data. The study therefore used data from the Traffic Database instead, following the approach taken by Gren et al. (2015) as well.

The traffic load data used in this study derives from Traffic Analysis. The data, which Traffic Analysis collects from the Swedish Motor Vehicle Inspection Company, is based on the number of kilometres each vehicle has been driven each year. These numbers refer to the total mileage driven by vehicles registered in a County, regardless of whether or not the vehicles were driven in that County. For the purpose of this study, however, the reported kilometres will be assumed to have been driven in their vehicles' respective home Counties.

Data on the land surface area of the Counties in Sweden was sourced from the SCB.

5.2.3 *Roads and fencing*

Data on the country's roads and fencing along them was obtained from Seiler (2018) and from Sweden's National Road Database (*Nationella Vägdatabasen*).

Data from the NWAC (2018) shows that most moose–vehicle accidents occur in woodlands. This study would have benefited from data on moose habitat parameters such as deciduous and coniferous forest. However, to establish how many kilometres of each forest type there were along the roads would have demanded a geographic information system (GIS) analysis comparing road data according to forest type. Such an analysis was unfortunately not possible, owing to the limited scope of the study as well as time and funding constraints.

5.2.4 Number of hours of daylight

For the period from October to April the following year, the number of hours of daylight will vary considerably with latitude (but not with longitude) (SMHI, 2018). Since NWAC (2018) data shows that most moose–vehicle accidents occur in the dark, the number of hours of daylight was an important factor to consider in the calculations. Thus, data from the SMHI was used to determine, per County, the average number of hours with sun above the horizon during the period from October to April.

The number of hours of daylight can be a crucial factor when it comes to moose–vehicle accidents, since it is easier to detect game in daylight. This is borne out by NWAC data, which shows that most moose–vehicle collisions occur during winter months, when the hours of daylight are limited. Moose move most at dawn and dusk, which coincides with rush-hour traffic and increases the risk of moose–vehicle collisions. Although there is no research to confirm this yet, the statistics (Figure 8) indicate that most accidents happen in the early morning and early evening (NWAC, 2018).

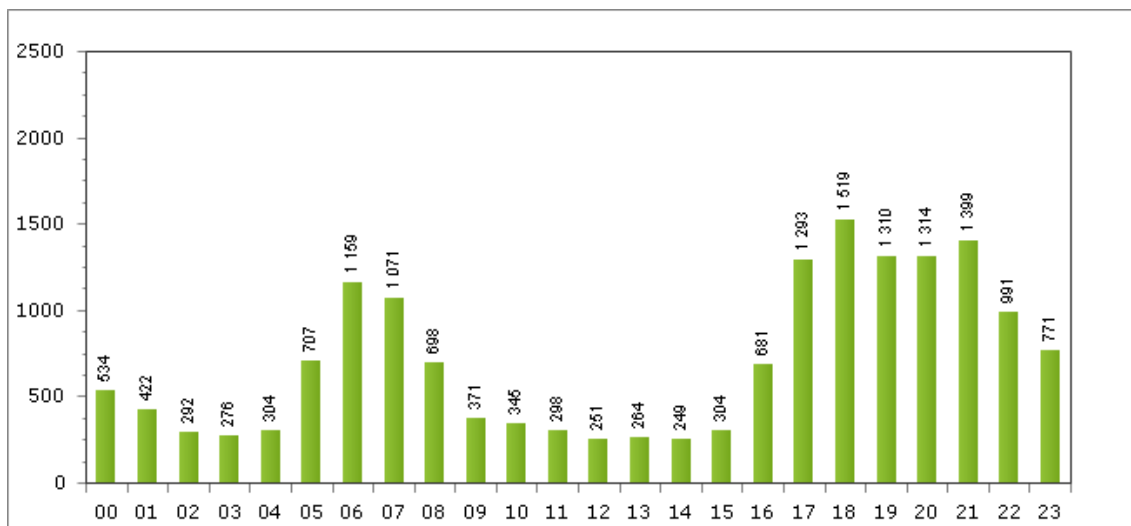


Figure 8: Moose–vehicle accidents per time of day, 2017. The Y axis shows the number of accidents, while the X axis shows the time of the day when the accident occurred.

Source: NWAC (2018).

CHAPTER 6 METHODOLOGY

This Chapter discusses and explains the model specifications, along with exogenous factors in today's moose management.

6.1 Model specifications

This study represents an attempt to establish whether the new moose management system in Sweden has affected the moose population. The first step, therefore, is to estimate the population by using traffic and other data described in Chapter 5 in combination with the adapted Gordon–Schaefer model described in Chapter 4. The study will then compare these with the moose population estimates in the various County management plans. The resulting more robust estimates of the moose population in Sweden will then assist in determining whether the new management system has been effective.

To calculate the moose population via existing traffic data, as explained in Chapter 4, two different models can be used, according to Gren et al. (2015): the direct model and the indirect model. The benefit of the indirect model is that it considers how changes in habitat characteristics over time in a region will affect the intrinsic growth rate. Gren et al.'s (ibid.) indirect model is defined as –

$$Y_t^i = \beta^1 + \beta^2 S_t^i + \beta^3 T_{it}^i (1 + x_t^i) + \beta^4 Ara_t^i + \beta^5 Dec_t^i + \beta^6 Fec_t^i + v_t^i$$

where Y_t^i represents population growth with the indirect impacts of habitat characteristics; S_t^i is accident intensity per traffic load; T_t^i is traffic load in relation to region size; x_t^i is moose killed by hunting (H_t^i) divided by moose–vehicle accidents (V_t^i); Ara_t^i is arable

land/total area; Dec_t^i is deciduous forest/total area; Fec_t^i is fence length/road length; and v_t^i is the error term.

In the direct model, habitat characteristics affect the intrinsic growth rate of the moose population, causing their numbers to either increase or decrease. Gren et al. (ibid.) define this model as follows:

$$Y_t^i = \alpha^1 + \alpha^2 S_t^i + \alpha^3 T_t^i (1 + x_t^i) + \frac{\alpha^4 Ara_t^i}{S_t^i} + \frac{\alpha^5 Dec_t^i}{S_t^i} + \frac{\alpha^6 Fec_t^i}{S_t^i} + \varepsilon_t^i$$

In their study on Sweden's wild boar population, Gren et al. (2015) conducted a Shapiro–Wilk test of normal residual distribution on the indirect and direct models in order to establish if a hypothesis of a normal distribution could be rejected at a 10% level. The test showed that, for the indirect model, a hypothesis of a normal distribution could not be rejected at a 10% level, but for the direct model it could. Taking this result into consideration, as well as the fact that the habitat characteristics of a region change over time, the current study preferred to use the indirect model. Nonetheless, for comparison, the direct model is also estimated.

In order to adapt the indirect model to moose, two additional variables (discussed in Chapter 5) are included, namely *Snow depth* and *Number of hours of daylight*. The revised indirect model can then be defined as –

$$Y_t^i = \beta^1 + \beta^2 S_t^i + \beta^3 T_{it}^i (1 + X_t^i) + \beta^4 Ara_t^i + \beta^5 Dec_t^i + \beta^6 Fec_t^i + \beta^7 Wet_t^i + \beta^8 Lit_t^i + V_t^i$$

where *Wet* is the winter's deepest snow per County and *Lit* is the average number of hours the sun is above the horizon during October until April in each County.

This study uses data from 20 different Counties in Sweden. Only Gotland is left out since there are no moose in that County. The period investigated constitutes the years 2004–2017. Since this study comprises panel data, a suitable method of data estimation was needed for its analysis. Ordinary least square (OLS) is one of various methods of linear regression; another is the random effects method. According to Gren et al. (2015), a Hausmann test showed that the null hypothesis could not be rejected for the random effect model. However, when a small area as Sweden is investigated, cross-sectional dependence is likely to occur, making a random effects model problematic. For simplicity, OLS is therefore used instead.

6.2 Model discussion

Discussions with staff at the National Association of Huntsmen indicate that the main causes of death for moose are hunting, car accidents and natural mortality. Therefore, these factors are important aspects to incorporate into the growth rate model. As regards traffic accidents, these are affected by traffic density, road density and fencing. Another factor that matters is the kind of biotope (defined by Merriam-Webster as “a region uniform in environmental conditions and in its populations of animals and plants for which it is the habitat”) that surrounds the road. If it is a biotope with food the moose prefer, then it is likely that the moose will remain in such an area. The view of the driver can be a decisive factor as well: compared with sparse coniferous forests, thick deciduous forests make it more difficult to see what is on or beyond the side of the road.

One possible bias in the data could be that some moose–vehicle accidents go unreported. However, as mentioned in section 5.2 of Chapter 5, since 1987 drivers have been legally obliged to report moose–vehicle accidents to the police – even if the animal is not visibly

hurt. Not reporting an accident involving moose is punishable by a fine. Because of the legal obligation to notify police of such accidents, the data from the NWAC is considered reliable.

Exogenous factors such as extremely snowy winters will affect the population as the feed supply gets worse and the moose begin to migrate from their home habitat. According to Gordon (1954), the Gordon–Schaefer model is best applied to non-migrant species. However, the study covers large areas such as Norrbotten County, which comprises 25% of Sweden’s land surface area; for this reason, most moose can be regarded as non-migrant because they will remain within a single region.

Diseases such as chronic wasting disease (CWD) is one uncertain factor for the population. CWD is a prion disease that is characterised by degenerative changes in the brain, leading to neurological symptoms, deprivation and death. The disease was detected in Norway in 2016 and, by 2017, further cases were found in both reindeer and moose (SVA, 2018). Consequently, the Norwegian Government culled the reindeer in the Nordfjella area, where all the CWD cases to date had been detected (Sönnergren, 2018).

Another uncertainty in the indirect model is that the moose population is part of an ecosystem. Therefore, changes in populations of other species who compete for food, such as deer, or in those who predate on moose are likely to affect the moose population. A case in point is a recent study by Rivrud et al. (2018), who found that the normal behaviour of reindeer (*Rangifer tarandus tarandus*) who ranged in territory densely inhabited by brown bear (*Ursus arctos*) differed from those in sparsely populated bear territory. The study found that dense populations of bear prevented the reindeer from following the vegetation’s development, which usually ensured they had long-term access to grazing during spring and summer. Not having access to good grazing in summer meant the reindeer’s body reserves would deteriorate during winter. This in turn entailed that the calf – and, hence, the population – growth rate deteriorated. Rivrud et al. (ibid.) stressed the importance of understanding what direct and indirect impacts that increased numbers of large predators in Scandinavia in recent decades have had on large vegetarians

such as reindeer and moose. Knowing this would facilitate assessing the predators' impact not only on the population dynamics of their prey, but also its potential consequences for the ecosystem. However, since no data is available on whether bear populations prevent moose in Sweden from following the vegetation's development, this study is obliged to leave out that variable.

It is very difficult to predict outcomes when important parameters are frequently changing, as one can expect to find in cases like the present study. Therefore, as Gordon (1954) pointed out, a crucial factor in wildlife management is being able to calculate the population concerned: without the right data to begin with, a bias is unavoidable and management plans based on that data will be questionable.

CHAPTER 7

EMPIRICAL RESULTS

This Chapter will discuss the determining parameters and main results of the study. The limitations of the data will be pointed out as well.

7.1 Determining the parameters

As already stated, this study investigated the years 2004–2017 for which data was available. Twenty of Sweden's 21 Counties were initially included in the investigation. However, the County of Stockholm was eliminated from the data set owing to a very low R^2 value in the exploratory analysis that could be explained by that County having significant higher traffic density compared with the rest of the country. These extreme values for County Stockholm probably caused a bias in the regression because R^2 showed a better result after the County's elimination for the data set. Hence, the final study covered the remaining 19 Counties. The panel data was then estimated with OLS to obtain the intercept and coefficients to integrate with the indirect and direct models.

When the regressions were conducted, the relative change in the number of moose–vehicle accidents was used as the dependent variable, namely *Annual rate of change in traffic accident intensity* (Y).

As independent variables, the following data was used: *Accident intensity per traffic load by County size* (S), *Traffic load divided by County size* (T) multiplied by moose harvests/accidents plus one ($x+1$), *Fencing* (Fec), *Snow depth* (Wet) and *Hours of daylight* (Lit). Since the variables are quite stable across time, the variation is assumed to be explained by differences across Counties. However, the number of moose–vehicle accidents was quite low in comparison with the number of moose harvested per County.

This comparatively low figure may deliver questionable results because a considerable part of the model depends on the *Accident intensity per traffic load* variable working well as a proxy for the *Effort* variable. Table 1 presents the descriptive statistics.

Table 1: Descriptive statistics (n = 265 observations).

	Average	Standard deviation	Minimum	Maximum
Dependent variable				
<i>Y</i> , annual rate of change in traffic accident intensity	0.04574	0.209811334	-0.4409722	0.76
Independent variables				
<i>T</i> , traffic load divided by County size	278.394	213201.9808	23145.0488	985561.7
<i>V</i> , traffic accidents	298.812	199.4032884	33	1263
<i>S</i> , accident intensity per traffic load	0.00322	0.005137406	7.8842E-05	0.022115
<i>H</i> , moose harvests	4617.13	4048.115005	189	15600
<i>Fec</i> , fence/road length	0.08274	0.045909102	0.00115664	0.17423
<i>Wet</i> , winter's deepest snow per County	37.4393	26.17025082	0	115
<i>Lit</i> , hours per County with sun above the horizon during October through April.	5122.9	404.8582344	3588	5506

The intercept was significant in both the indirect model (Table 2) and the direct model (Table 3). As expected, *Accident intensity per traffic load* (*S*) and the traffic *Effort* parameter ($T(x+I)$) in both models had negative signs, meaning that if either variable increased the population growth rate would decrease. *Fence/road length* and *Hours of sun* each had a positive sign in the indirect model, implying that if either variable increased, so would the population growth rate. The value for *Hours of sun* was negative in the direct model, i.e. if the variable for Hours of sun increased the population growth rate would decrease.

Unexpectedly, the depth of the snow showed a positive sign in both models, meaning that if the snow depth increased, so would the population growth rate – which is the opposite of what biological expertise suggests. This could be a bias due to an insufficient number of observations measured for each County. Large variation among the Counties is evident

in respect of snow depth, especially among those in the north, which have substantial land surface areas.

Both models showed a low R^2 – as was the case for Gren et al. (2015). This correspondence indicates that some variation is not explained by the variables in either model. The aggregated regression findings for the indirect and direct models, respectively, are presented in Tables 2 and 3 below.

Table 2: Regression results from the indirect model.

	β	Standard error	P-value
Intercept	-0.77404	0.3581	0.0316**
<i>S</i> , accident intensity per traffic load	-0.23321	5.4952	0.96618
<i>T(x+I)</i> , (traffic load)(moose harvests/accidents + 1)	-3.55E-08	0.0000	0.00115***
<i>Fec</i> , fence/road length	0.5854	0.3546	0.10005
<i>Wet</i> , winter's deepest snow per County	0.0024	0.0007	0.00075***
<i>Lit</i> , hours per County with sun above the horizon during October through April	0.00015	0.0001	0.01586**
R²	0.1107		
Prob > F	0,000		

Significance level ***p < 0.01, **p < 0.05, *p < 0.10.

Table 3: Regression results from the direct model.

	α	Standard error	P-value
Intercept	0.16985	0.0412	0.00***
<i>S</i> , accident intensity per traffic load	-4.72987	3.2267	-1.4659
<i>T(x+I)</i> , (traffic load)(moose harvests/accidents + 1)	-4.36E-08	0.0000	0.00018***
<i>Fec</i> , fence/road length	5.21E-08	0.0000	0.66358
<i>Wet</i> , winter's deepest snow per County	3.81E-07	0.0000	0.28031
<i>Lit</i> , hours per County with sun above the horizon	-9.29E-10	0.0000	0.68314
R²	6,35E-02		
Prob > F	0,007		

Significance level ***p < 0.01, **p < 0.05, *p < 0.10.

The results from the indirect model regression (Table 2) indicate that four of the coefficients are statistically significant, namely *Intercept*, *T(x+I)*, *Wet* and *Lit*. Results

from the direct model regression (Table 3) show that only two out of six coefficients are statistically significant, i.e. *Intercept* and $T(x+1)$. This was expected since the choice of the indirect model was based on the Gren et al. (2015) study, which found the indirect model performed better in statistical terms.

7.2 Main results

For the indirect model in this study, the growth rate r^i was estimated according to Equation (13), namely $r^i = \beta^1 + (\beta^{14} * Wet) + (\beta^{24} * Fec) + (\beta^{34} * Lit)$. In this study, the indirect model estimates were done at County level and then aggregated to national level. Thus, the intrinsic moose population growth rate for Sweden as a whole was registered at 0.15 for 2012 and at 0.12 for 2017, but because of the differences in the variables determining the growth rate, there are local variations between the Counties.

The carrying capacity of the ecosystem is calculated from Equation (14), which in this case will be $K^i = \frac{r^i}{\beta^2 \beta^3}$. Thus, according to the estimation, in 2012, Sweden's carrying capacity for moose amounted to 347,594,112 individuals in 2012, and 276,314,449 individuals in 2017, representing a 20.5% decrease in carrying capacity between 2012 and 2017.

The last parameter calculated was also the most important, namely the size of the moose population. Estimated by Equation (1), in this case it would be $P = \frac{S_t^i}{\beta^2}$. The result shows a population of 2,017,158 for 2012 and one of 1,926,827 for 2017, a decrease of approximately 4.5% for the 2012–2017 timespan. However, the population estimates for both years in question are unrealistically high: other estimates such as those from harvesting statistics show an approximate total of 350,000 individuals (Wallgren, 2016). Part of the problem could be that β^2 is not significant in the regression.

7.3 County comparison

From Figure 9, 10 and 11 one sees that the estimated moose populations obviously differ between Counties, and – as with the national estimate – that County-level populations are unrealistically high. For all the Counties in the study, there is a minor decrease in the moose population after 2012, i.e. the year in which the new moose management system was implemented. The only exception in this trend is Västerbotten County, where an increase of 6.7% is seen in the estimation. However, the trend line in Figure 9 shows that, over a longer period, the moose population has increased in Sweden.

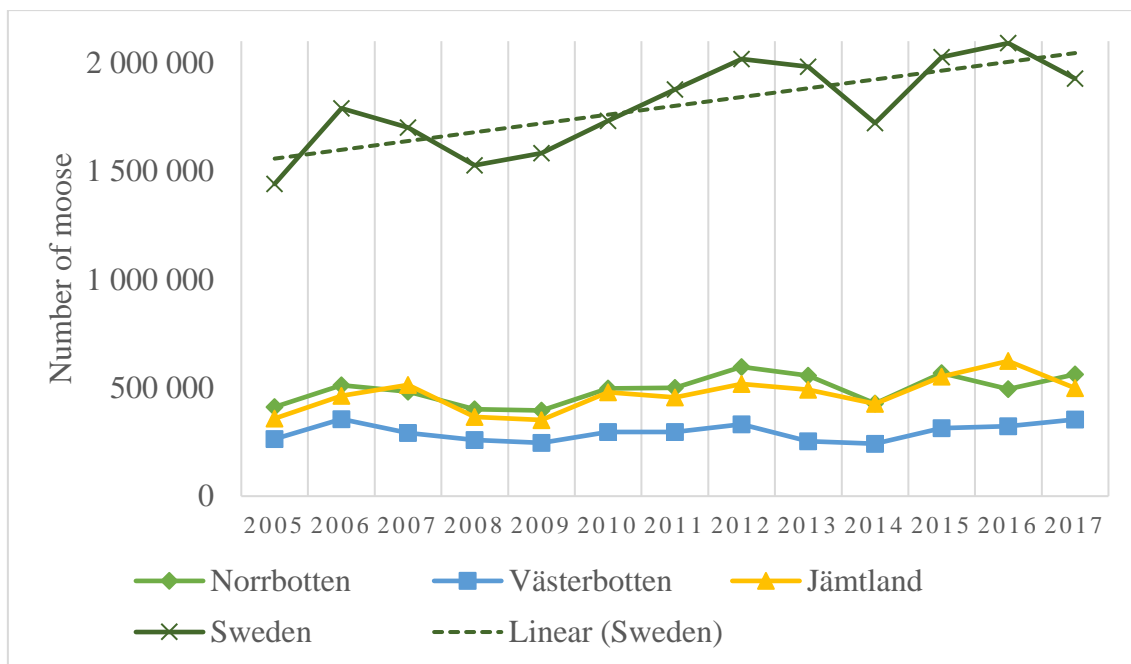


Figure 9: Estimated moose population in Sweden, 2005–2017. Linear trend Sweden.

There is some local variation between the 19 Counties;- a minor decrease of approximately 4,5% is seen from 2012 – when the new moose management system was introduced – to 2017. In all, the trend line shows that, over a longer period of time, the moose population has increased in Sweden, and 2017 may just be a temporary deviation from that trend. However, there are many circumstances that play a role here. Growing populations of fallow deer and red deer, for example, compete with moose for food resources; scarcity of these resources will lead to game browsing – and perhaps causing

damage – to alternative tree species as well, tree species that are not their normal food (SFA, 2018).

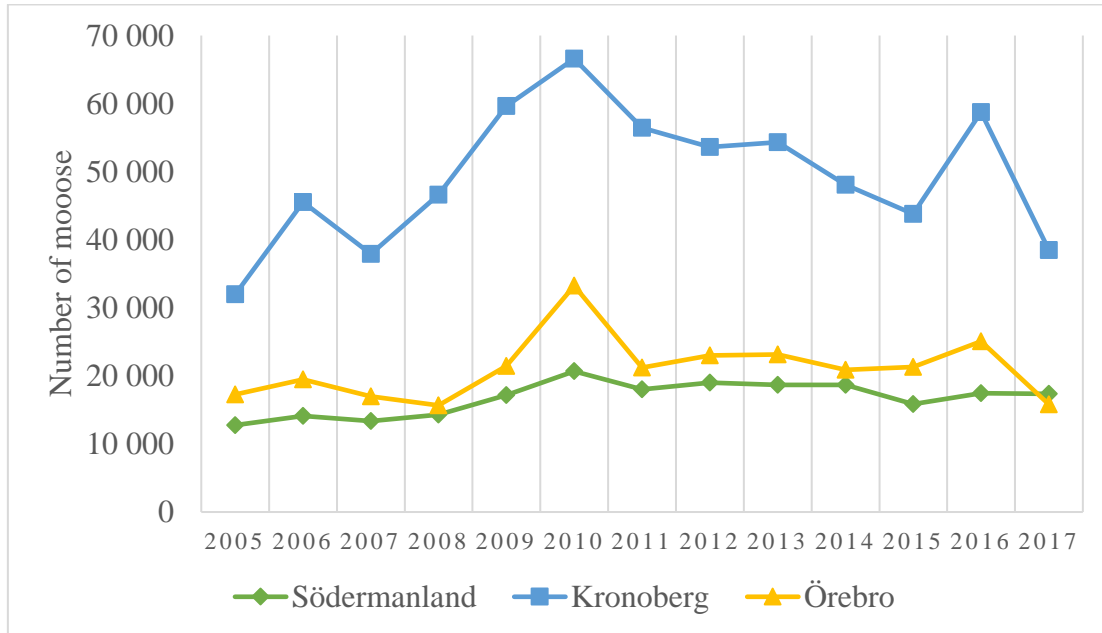


Figure 10: Estimated moose populations in Södermanland, Kronoberg and Örebro Counties, 2005–2017.

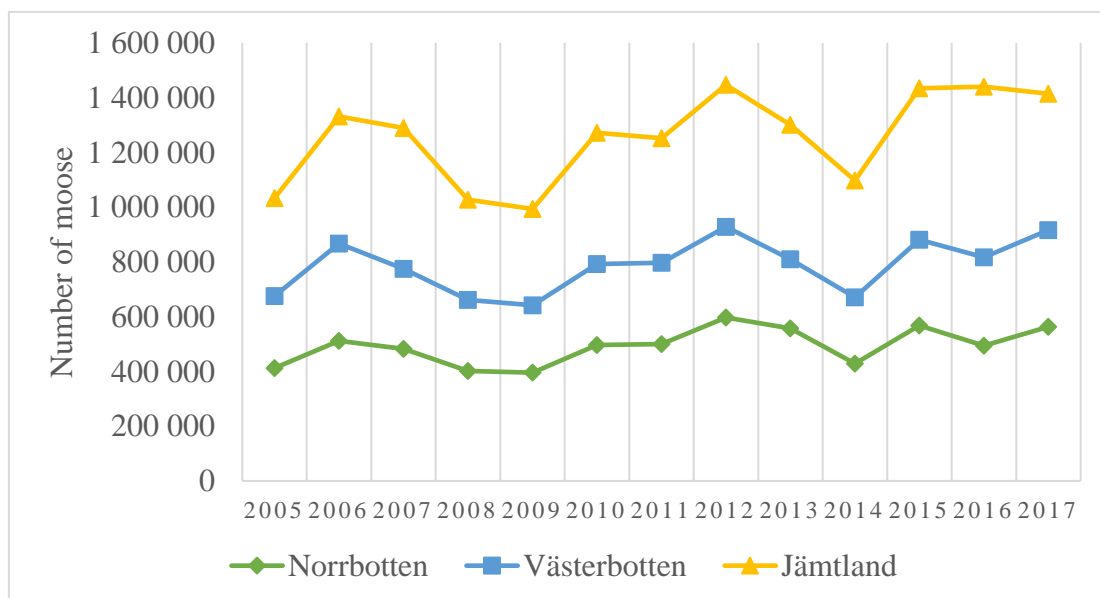


Figure 11: Estimated moose populations in Norrbotten, Västerbotten and Jämtland Counties, 2005–2017.

CHAPTER 8

DISCUSSION AND CONCLUSIONS

This Chapter offers a discussion of the empirical results of the study, showing how they tie in with natural resource economic theory. The results will also be compared with previous literature on moose management.

The purpose of this study was to investigate if the new Swedish moose management system has had any effect on the country's moose population. To this end, the study needed estimates of the moose population. Since there are no existing reliable estimates of these numbers, the study applied a model developed by Gren et al. (2015) for other game stock in Sweden, namely its wild boar population. However, this model did not work satisfactorily in the current study because the population figures estimated were unrealistically high. A possible way forward would be to develop the model further so that it works with game in Sweden in general, and not just for wild boar. Furthermore, since a crucial reason for using this model was that actual hunting effort is difficult to measure, those who are concerned about moose management – e.g. the SCB or CABs – should perhaps think about how to collect better data over time for different kinds of hunting in all parts of the country.

Other results from this study reveal that the negative impacts of browsing damage and moose–vehicle accidents continue to increase despite the implementation of the new moose management system. For example, according to each of the 19 Counties' numerous MMG management plans, the aim for the moose population was 231,985 individuals in the 2017 winter stock. Whether these numbers coincide with the reality on the ground today is difficult to tell. However, in terms of achieving these plans' goals for harvested moose, the Counties' overall performance was less positive, with Norrbotten County being the best performer. Discussions with members in one of the MMGs in Norrbotten indicated that, despite their County's good goal achievement as well as an

increasing harvest over the period 2012–2017, negative phenomena such as moose–vehicle accidents and browsing damage continued to increase as well. The Norrbotten MMG members therefore suggested (personal communication) that the input values in their management plan might have been underestimated.

As stated, the estimated models in the study produced unrealistically high population figures.

There are some obvious factors that have generated the strange results in the model. For example, when it comes to the *Effort* parameter, the study used moose–vehicle accidents as a variable. Therefore, according to Seilor (2006), one bias in the data that may have affected the results reported here could be the existence of unreported moose–vehicle accidents. However, the data from the NWAC should not be underestimated too much, as there is a legal obligation to notify the police of any vehicle accidents involving moose – even if they appeared unharmed by the collision.

Another bias that might have arisen could have derived from the fact that 35% of the moose involved in moose–vehicle collisions were assessed as being unhurt (NWAC, 2018); hence, the total moose mortality from such accidents was lower than the total number of accidents reported. However, 35% is assumed to be a very small number in proportion of the vast moose population, so it should not have created any significant bias in respect of the population estimation. On the other hand, some moose are presumably also killed in railway accidents, but there is no available data on those mortalities.

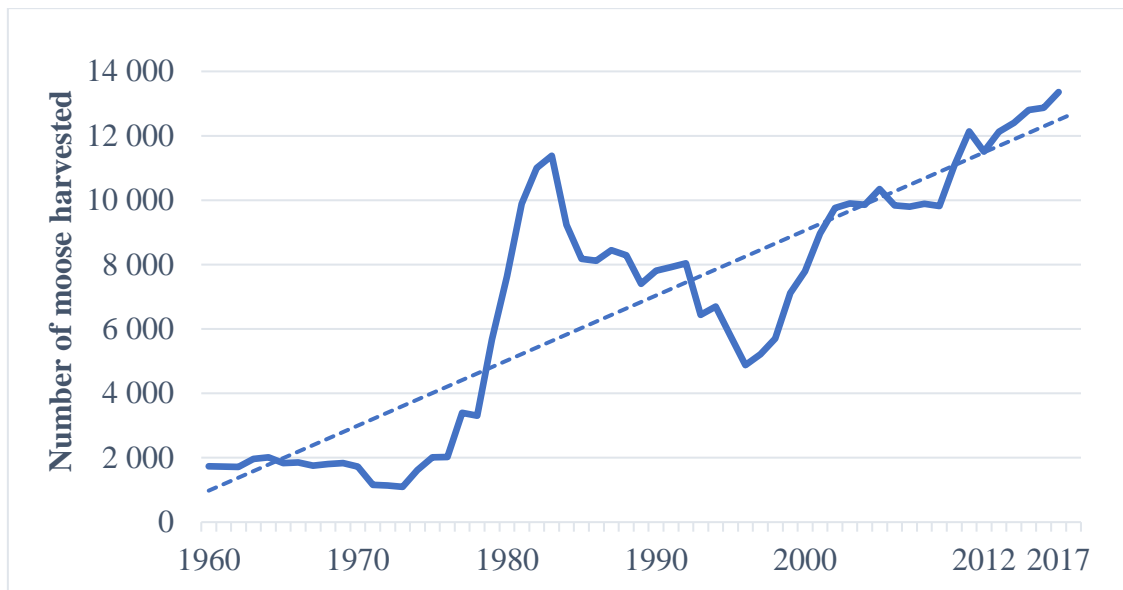


Figure 12: Moose harvested in Norrbotten County, 1960–2017.

Source: CAB (2018).

According to Gordon (1954), one of the crucial factors for wildlife management is being able to calculate the population. Norrbotten County has the best goal achievement against the management plans in the country, 99% harvest moose according to the CAB for the hunting season 2017/18. Despite this great result, an increase of traffic accidents and browsing damage is seen (NWAC, 2018; SFA 2018). Norrbotten has had all time high in harvesting moose for the past five years with the new management. This could indicate, in line with the suggestions from MMG members referred to above, that the entry values of the moose population in the management plans are incorrect. There will more or less always prevail a bias if we do not have the right data to begin with.

As regards other results, the regression analysis shows that the traffic *Effort* parameter $T(1+x)$ was statistically significant; however, further investigations of the data regarding T (*Traffic load divided by County size*) are needed to obtain reliable values. There were also some complications regarding the data on vehicle mileages. The data employed refers to mileage for vehicles registered in a County – regardless of where the vehicle has been driven; thus, the data does not correspond to how much a vehicle has been driven in a particular County. Some bias may have arisen, therefore, and would need further

investigation. Moreover, the vehicle mileage data does not include vehicles registered in countries other than Sweden, which means vehicle mileage totals – and, hence, accident intensities – are underestimated. On the other hand, some vehicles may be driven in a County other than the one in which they are registered; this, too, could cause an over- or underestimation of accident intensities in specific Counties.

Data on the landscape characteristics relating to moose habitats would have been useful in the current study. These characteristics would comprise a set of variables that takes deciduous or coniferous forest as well as arable land and pasture into account. Such data is obtained by measuring the length of the biotope along the roads by GIS. However, due to the considerable effort needed to produce this data, it was not included in the study and may, therefore, have created a bias in the calculations.

Data was, however, available on snow depth for each County. The study compiled a summary of the average for the deepest snow measured for each County during the period 2004–2017 for all 41 SMHI stations (see Appendix B). It turned out, however, that it was only possible to produce complete series from 37 stations. To complete the series, the study had to use a number of nearby stations. If only a few stations exist for a large area, since there may be significant differences in local snowfall, the data on snowfall in that area may be skewed. Therefore, an average was taken for each County's deepest snow recorded for the stated years.

Furthermore, the R^2 estimation showed a low value. However, the regression analysis shows that all independent variables except S and Fec were statistically significant in the indirect model. Nonetheless, S is a key variable in the estimation, so it probably causes a bias. The overall regression accuracy was low.

Discussions with staff at The National Association of Huntsmen indicate that, as society has changed over time, so has hunters' behaviour. Generally, hunters have become more comfort-oriented, i.e. they need machinery and additional human resources during a moose hunt. Therefore, it is easier to handle smaller game, such as deer. In southern and

most of central Sweden, forest companies do not charge any fees for harvesting moose. Moreover, the need to hunt moose has generally been overtaken by the fact that enough game meat is available from wild boar and deer. Additionally, hunters will not usually use specialised dogs to the same extent in southern Sweden as they do in the north. Another change in hunters' behaviours entails the fact that the moose harvest is more random, as many species of game are harvested at the same time. Hunters from the south are also less likely to go to their homesteads in the north for extended hunting periods, they are often content with only a few days of hunting in September. It means a decreasing number of hunters have the same number of moose to manage. Another factor to consider, according to The National Association of Huntsmen, is that using hunting dogs during a moose hunt has been restricted by the increased presence of wolf, who kill the dogs. All of these different factors need to be considered not only for optimal moose management, but also in terms of their influence on the Gordon–Schaefer model's *Effort* variable used in calculating the moose population.

Indeed, if hunting effort were correlated linearly with the number of hunting hours, the number of hunting days or the number of hunters, the study could have used one of these measures as a reliable proxy for *Effort*. However, the correlation changes over time, so the connection cannot be assumed to be constant. Therefore, another measure needed to be found for the *Effort* variable – and, in this case, the number of moose–vehicle accidents was selected as a proxy for it. However, the ratio between the number of moose harvested and the number killed through moose–vehicle accidents was so different for moose in comparison with the same ratio for wild boar that the modified model by Gren et al. (2015) for wild boar failed to work well enough in calculating the size of Sweden's moose population.

The available data to see if the new moose management system has had any effect is then the management plans, MBIs, MOs and the number of traffic accidents. Data from the NWAC (2018) and SFA (2018) indicates that moose population levels are still too high. According to the management plans the aim for the winter population (after harvest) for 2017 was 231,985 individuals in Sweden. Unfortunately, given the uncertain quality of the existing data and the lack of reliable population estimates, it is impossible to say

whether that target was achieved or not. It is also impossible to say whether this is the best target size for the moose population or if it is in line with the various Counties' carrying capacities.

It is difficult to evaluate the new moose management system without knowing how large the moose population is. Because of externalities on forests, traffic and incentives to harvest adult moose rather than their calves, the socio-economically desirable harvest might be higher than the harvest the hunters themselves would choose if they were allowed to decide freely. The new moose management system is supposed to solve this, but from an economic point of view, it is unclear what exactly has changed since the previous system. One part of the management is the landowners that suffer financially from browsing damages, and the governments regulations with licences that make the hunting difficult to go through with.

According to Witmer and DeCalesta (1991), who studied the Pennsylvania deer herd, hunting is the only effective tool for bringing wildlife numbers under control and the regulations for the hunters must be facilitated. Their research has parallels with the current study on moose management in Sweden, in that the management problems are similar to those challenging Sweden with its moose population. The landowners do not have full control over of how many moose there are to be harvested, even if they are in possession of the hunting right.

Since the trend line over time for the moose population in Sweden shows an increased stock (see Figure 9), another form of management should be implemented. Ulf Kallin, National Wildlife Manager, proposes trying a general hunt for moose, as is currently done for managing roe deer and some other species, where the local hunter makes local decisions based on the local stock. In this way, Kallin believes, unnecessary bureaucracy will be removed from the management system.

As observed in the main results, the estimated parameters, namely the moose population's intrinsic growth rate and its ecosystem's carrying capacity, showed a decreasing trend.

The data from the SFA and NWAC are in line with the estimated pattern evident from applying the Gordon–Schaefer model. There are fewer young pines to browse during winter, so the moose may change their pattern of movement as they search elsewhere for food – increasing the risk of moose–vehicle accidents. These results all point to the conclusion that the new Swedish moose management system has not had the desired effect on the moose population, i.e. the Government’s aim to decrease browsing damage and moose–vehicle accidents by way of the new management system is not being achieved.

The study’s intention was to present results on the moose population’s size and intrinsic growth rate as well as on the carrying capacity of its ecosystem in respect of each of Sweden’s Counties. This data would later have been compared with the target moose population sizes stated in the various management plans. If the estimated outcomes from the current study had been reliable, they would have answered the question as to each County’s carrying capacity, and the size of the growth rate. However, further investigations of the data are required to obtain reliable values.

The author’s scientific contribution by way of this study was to try to answer the question of whether – and, if so, to what extent – the moose population’s development was consistent with the new management system’s goals; how the moose population had developed after the introduction of the new management regime; and whether it was possible to use Gren et al.’s (2015) model to say something about that matter. The study applied Gren et al.’s (ibid.) model to moose and finds that it led to unrealistic results; hence, the model would need to be modified or better data would need to be used if the model were to be applied to Swedish game management in general rather than just to wild boar. In addition, although the study’s population estimates in absolute terms are hardly reasonable, they nonetheless indicate that moose populations have continued to grow after 2012, when the new management system was instituted. Thus, the study’s policy contribution is that it shows, albeit with shaky estimates, that the moose population is not going in the right direction.

In all, one could conclude that the moose population cannot be estimated by using the modified Gordon–Schaefer model at this stage, and that the aims of the new management system – to reduce browsing damage and moose–vehicle collisions – have not been achieved, according to data on both moose–vehicle accidents (NWAC, 2018) and browsing damage (SFA, 2018).

The concluding proposal is that further research with better data is required to offer a more reliable evaluation of the efficacy of Sweden’s moose management. Moreover, further economic research is needed in respect of the achievement of the economic costs to society. Other aspects such as loss of forest growth, reduced timber quality and the social cost of moose–vehicle accidents need to be brought into the research scope as well to make a proper assessment of whether Sweden has a moose management regime worthy of the title.

A final suggestion is to investigate whether moose management can be left to hunters, and where unnecessary bureaucracy in the system can be removed. The right to hunt is a property right and, like a business owner, the hunter is assumed to take rational decisions about the harvesting of the moose (Perman et al., 2011).

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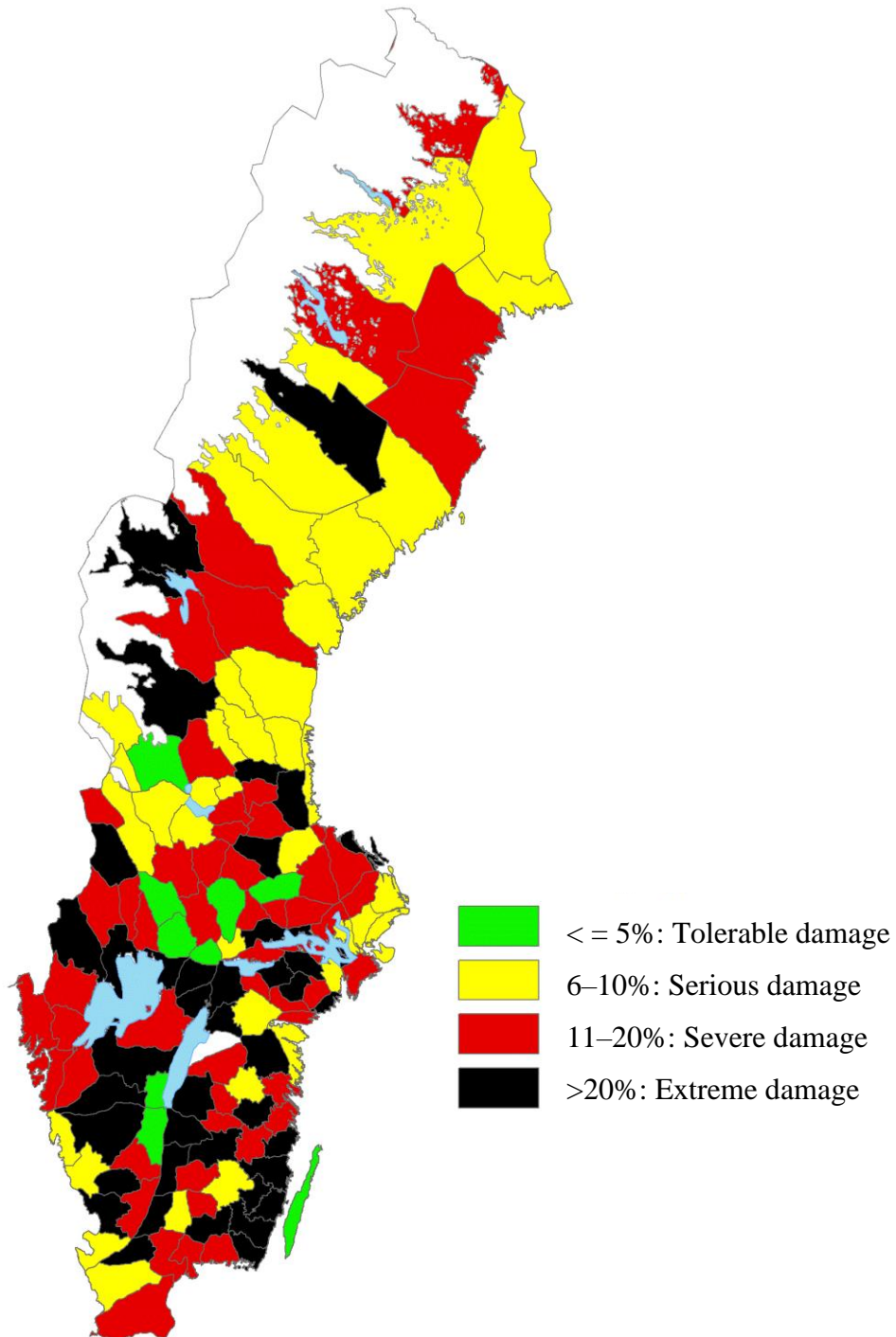
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**APPENDIX A:
MOOSE BROWSING INVENTORY, 2016–2017:
ANNUAL DAMAGE TO PINES**



Source: SFA (2018).

APPENDIX B: STATIONS WITH CONTINUOUS DATA ON SNOW DEPTH

The map below shows the 41 stations in Sweden that have continuous data on snow depth, dating from the winter of 1904/5 to that of 2016/7. The blue lines show SMHI geographical borders between Götaland, Svealand, southern Norrland and northern Norrland.



Source: SMHI (2018)