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Costs of Reducing Phosphorus Runoff from Horse Pastures in Sweden

Annie Möller

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Annie Möller

Supervisor:	Katarina Elofsson, Swedish University of Agricultural Sciences, Department of Economics
Examiner:	Jens Rommel, Swedish University of Agricultural Sciences, Department of Economics
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Abstract

Eutrophication is an environmental issue that causes deterioration of inland waters and oceans. It is induced by leaching of nutrients from different sources. One such source that has been getting attention lately is the leaching of nutrients from horse pastures. This thesis investigates if reducing the number of horses and mucking pastures is a cost-efficient measure to reduce the leaching of phosphorus. A minimization model was developed where the costs of reducing horses and removing dung were minimized for different levels of reduction of phosphorus runoff. The costs of reducing horses were estimated as the loss in consumer surplus, and the cost of removing manure was calculated based on the cost of labor. The results indicate that the measure is not cost-effective, with a marginal cost at 281 559 710 SEK and a total cost at 259 034 933 SEK for a reduction level at 10% of the leaching caused by the horses. Compared with other studies the marginal cost was significantly larger, hence the conclusion is that the measure cannot be considered cost-efficient.

Contents

1 Introduction

Eutrophication is a great environmental issue and is one of 12 environmental objectives that the Swedish government tries to regulate (Swedish Environmental Protection Agency, 2017). It is caused by leaching of excessive nutrients from different sources such as human sewage, fertilizer and livestock waste. Sewage treatment occurs in many areas, but nutrient loads from non-point sources, for instance agriculture, still poses a problem (United Nations Environmental Program, 2012). Eutrophication causes deterioration of the water quality in both oceans and inland waters and can in severe cases lead to oxygen depletion of the water body (Swedish Agency for Marine and Water Management, 2017). Furthermore, commonly eutrophication can affect the provision of ecosystem services (Mäler, 2000). In Sweden the agricultural sector conduces about 40 % of the phosphorus runoff to the Baltic Sea (Swedish Board of Agriculture, 2017b). Over the last twelve years the number of horses in Sweden has increased by more than 25 percent. In 2004 there were 283 100 horses in Sweden and in 2016 the number had increased to 355 500 horses (Swedish Board of Agriculture 2005; Swedish Board of Agriculture 2017a). Of all the farm properties in Sweden about 28 % accommodates horses and of those sites, approximately 71 % are situated near large cities (Swedish Board of Agriculture 2017a). Horse manure contains both phosphorus and nitrogen and is not always removed on a regular basis from pastures. Potential losses of phosphorus and nitrogen are higher from soil of paddocks than other soils and can be a significant source of nutrient loss which can cause eutrophication (Parvage *et al.*, 2014).

1.1 Research question and objectives

The objective of this thesis is to determine the minimum cost of reducing phosphorus leaching from horses in Sweden. Measures considered include a reduction of the number of horses in different parts of Sweden, and manual mucking. Costs for reducing horse numbers are estimated as the forgone consumer surplus of horse purchases in different parts of Sweden, and costs for mucking are calculated based on the labor cost. The impact of horses on phosphorus leaching is calculated using a nutrient runoff model accounting for the relationship between horse density on pastureland and the eventual runoff to surface water.

The first delimitation of the scope of this thesis is that it only considers the leaching of phosphorus. There is a problem with leaching of both phosphorus and nitrogen from horse pastures, however the nitrogen comes from urine. Therefore, it has been excluded since it cannot be removed from the pastures. One of the limits to the scope of this study is that it does only consider manually mucking the dung. There are other possible ways of removing dung, for example with a tractor, which would induce other kinds of costs.

Another delimitation is that the study does not consider the possibility of residents in one county receiving benefits from horse in another county. It is however likely that this occurs, since residents can travel across county borders to buy horses. To capture this effect, the model would need more complex spatial features.

1.2 Background to the problem

Eutrophication is one of the great environmental problems of our time. Nutrient runoff creates all sorts of damages to both oceans and ground water. For example, the Baltic Sea suffers from eutrophication and in some areas, there are no living animals or plants at the bottom of the sea left. Agriculture is causing a lot of nutrient runoff, both from fertilizing of arable land and from animal production. Furthermore, one of the common nutrients, phosphorus largely contributes to the eutrophication in lakes and waterways.

Today, the number of horses has exceeded the number of dairy cows in Sweden (Swedish Board of Agriculture, 2018). The number of horses has risen by approximately 25 % over the past decade. In 2016 there were 355 500 horses in Sweden and of all farm properties in Sweden about 28 % accommodates horses. Of those accommodating horses 71 % of the sites are situated near large cities (Swedish Board of Agriculture, 2017a). When the survey on the number of horses in Sweden was done in 2004 there were 283 100 horses (Swedish Board of Agriculture, 2005).

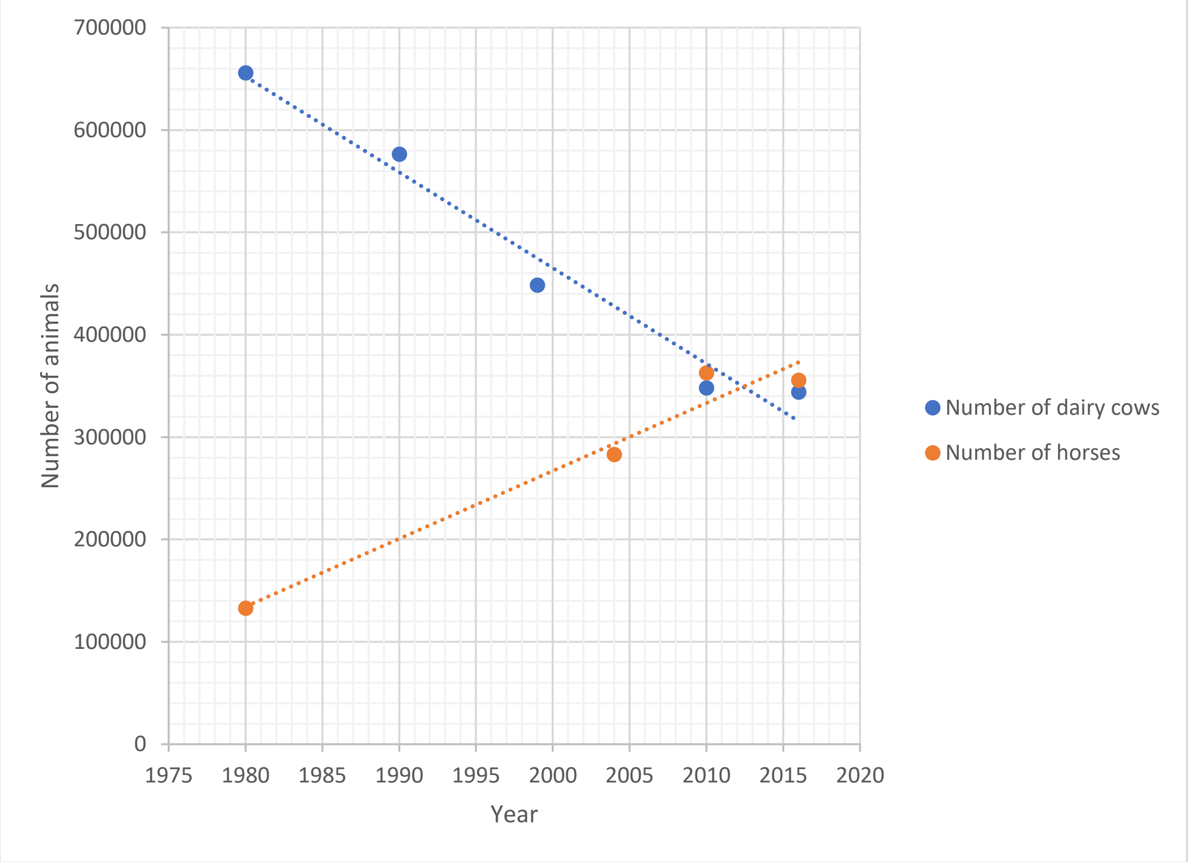

Figure 1. The development of the number of dairy cows and horses since 1980. Source: Swedish Board of Agriculture, 2018.

As of today, there are no definite value of the Swedish horse industry. About 20 % of the horses in Sweden are engaged in horse related businesses and almost 1 million Swedes are regularly preforming some activity involving horses (Lunner *et al.*, 2013). The demand for horses and activities has been increasing for the last years (Lunner *et al.*, 2013). There are several types of values connected to the horse sector, for example it can pose as an additional source of income for farmers and it attracts people to settle in rural areas (Flygare & Isacson, 2003). In a survey, 30 % of the asked persons who have a business involving horses said that there is low profitability for their business (Enhäll *et al.*, 2012). Four out of five horses in Sweden are privately owned and not used in any business activity at all, such as racing (Lunner *et al.*, 2013). These horses still bring business in other ways, giving opportunities to farmers to sell hay etc. The horse industry is highly valued both from an economic, social and cultural perspective. With a decreasing number of cattle, keeping horses also pose a chance of keeping the agricultural landscape clear (Dahlin & Johansson, 2008).

There are great differences of horse density between different regions in Sweden which affects the potential nutrient losses. For example, riding schools are mainly located in peri-urban areas where commuting with public transport is key for the availability to the consumers (Hess *et al.*, 2014). The density of horses in a pasture are also thought to enhance the loss of nutrients (Dahlin & Johansson, 2008). The leakage of phosphorus can be significantly decreased with frequent removal of manure, while the leakage of nitrogen is also decreased but not to the same extent as the phosphorus (Dahlin & Johansson, 2008).
Since horse keeping is popular in Sweden, and the number of horses is extensive contributing with various benefits to people and at the same time damaging the environment, there is a need for regulation of the environmental damages that the horse sector generates. This should also be a concern for other European countries, where the horse density is higher than in Sweden (Liljenstolpe, 2009).

Eutrophication from horse manure.

Recently, the potential environmental damages from horses has started to attract attention. For instance, scientist at the Swedish University of Agricultural Science has conducted research about the nutrient runoffs from horse pastures (Parvage *et al.*, 2011, 2013, 2014; Parvage, 2015). Compared to many other animals, the horse manure has a high content of phosphorus (Moreno-Caselles *et al.*, 2002).
Parvage et al (2013) researched the runoffs from pastures Uppsala county. It was shown that horse pastures pose a risk of damaging the environment. Especially, there were hotspots in the feeding and drinking areas, as well as near the gate of the pasture. Small pastures were to a greater extent associated with leaching of a damaging magnitude than larger pastures. The potential of leaching is small in big, grazing pastures. However, in the larger pastures there are still potential hotspots in the areas where there is food and water.
Furthermore, Parvage et. al (2011) suggest some measures to reduce P losses from horse pastures, such as a maximum livestock density per hectare and regular removal of manure from the pasture. Furthermore, they propose that P-absorbing materials could be added in the feeding areas and that the fodder imports to grazed fields should be limited (Parvage *et al.*, 2011)

2 Literature review

This section sum some of the literature that consider livestock policy, deriving recreational benefits from consumer surplus and damage functions concerning the leaching of phosphorus. The relevance for this thesis of the mentioned literature is also discussed.

There are several different studies that exist on the topic of horses and the leakage of nutrients, but there are few that are of economic nature. Eriksson (2017) studied how horse farmers in Sweden handle the management of the horse manure. One of her findings was that there were a higher frequency of removing the manure for small pastures (Eriksson, 2017). Furthermore, the contamination of the run-off water and the magnitude of the nutrient leakage has been researched in different areas of Scandinavia (Airaksinen *et al.*, 2007; Parvage, 2015). Relevant for this thesis is also studies about the prices of riding lessons and preferences of Swedish consumers (Hess *et al.*, 2014; Tienhaara *et al.*, 2017). Although, these studies do not include any externalities.

I have not found any papers dealing with the optimization of social welfare with respect to nutrient leakage or any construction of policy. Instead I have reviewed economic studies that examine policies of livestock regarding water quality management. There are some papers that deal with regulation of stock size and the impacts of such policies.

Westphal et al. (1989) examined the relationship between nutrient management, dairy herd size and the net return of the farm. The problem posed in the paper was the effect of excessive plant nutrients on the waters suitability for usage and disruption of the natural systems. High animal density in farmland areas relative to the land available for application of the manure contributes to potential pollution (Westphal *et al.*, 1989). Some management strategies concerning non-point nutrient source pollution control can have negative effects on the economic performance of the farm. The objective of the paper was to examine the effects of various plant nutrient management strategies for two crop sequences on the optimal herd size and farm net returns of a dairy farm by linear program simulation.

They set up 8 different scenarios and used linear programing to maximize the farms net return where they calculated for gross receipts from production minus the costs directly associated with the production and the cost of hiring labor. The costs that were directly associated with the animal activities were based on the herd size. They included constraints for nutrient accounting purposes, but it had no importance for the optimization of the economic performance objective function. To optimize the herd size and maximize the farm net return the number of cows at the farm was variable, as opposed to the farm size which was set to 50 ha in the simulation. The nitrogen from the manure was assumed to be utilized with either high or low efficiency.

From the results they could conclude that high efficiency of manure utilization and available nitrogen restricted to crop requirements limited the number of cows the most. Because of the link between the number of cows and the net returns other nutrient strategies that allowed for a greater number of cows resulted in considerably higher net returns. Furthermore, manure management with high efficiency would be more likely to pollute the ground water than other management strategies. They concluded that a feasible policy approach should emphasize particular nutrient strategies for individual farmers instead of uniformly limit the animal numbers.

Goetz and Zilberman (2000) analyzed the optimal management of the negative externalities from agricultural production while considering both spatial and intertemporal aspects. Both phosphorus and nitrogen have spatial and intertemporal aspects as a negative externality (Goetz & Zilberman, 2000). The analysis has a full-information approach which accounts for the differences in environmental vulnerability of locations and improved monitoring technology. The spatial aspect does not only account for distance from the pollution source, the location also have other characteristics that affect the vulnerability of a water body. The authors used a P-index to assess the environmental vulnerability, which allows for assigning catchment of the water body to each location. In the United States it has been shown that lakes are often eutrophic where the number of animal units per hectare is large. The authors maximize the present discounted net benefits from the agricultural production within the watershed of the lake while taking the economic losses resulting from the accumulation of bioavailable P in the lake into account. They use a two-stage approach, where they solve the spatial problem in the first stage and the intertemporal problem in the second stage. The authors propose to introduce taxes on mineral fertilizer, on manure applied on the fields and on the stock of animals. The taxes should reflect the spatial and intertemporal dynamic, but since this is difficult to administrate in practice because of the many combinations that can occur, they recommend that the land is divided into smaller zones. When the regulator does not have full information about the damage and the private production and costs, the social optimum can be obtained with a zonal system of tradable permits, here defined per kilogram of discharge of bioavailable phosphorus into the lake.

Innes (2000) examined the waste from livestock and how it was regulated in the U.S., after some events had brought focus to environmental costs of livestock waste. The increased concern of the environmental effects of livestock waste are to some extent related to the increasing scale and concentration of livestock (Innes, 2000). The main objective of the paper was to model the spatial and waste management decisions of private livestock producers, how they affect the environment and how they are affected by market forces. Furthermore, the author wants to examine the implications this has on the efficient design of government regulatory policies. They consider three types of environmental effects from the livestock production; nutrient leaching and runoff that can be linked to the application of manure to cropland; spills from animal waste stores; and direct ambient pollution from livestock operations, such as odors and ammonia gases. The policies that are examined are direct taxes on livestock operations, scale regulation that limits the number of animals allowed in a given number of acres, fertilizer taxes and the waste storage and handling regulations. The main findings that are relevant to my research is that producers have incentives to produce too much animals with facilities that are either larger than is efficient or too numerous than what is efficient, or in some cases both. The reason is that the increased animal production increases the size of potential waste storage spills, it increases the excess manure application and increases the ambient pollution in general. The farmer does not incur these costs and thus, they tend to overproduce. Regulation of the waste management alone does not attain efficiency, but regulation of livestock facility size and entry can enhance the efficiency. For example, the environmental costs might fall with increased production dispersion and then an efficient spatial arrangement of producing facilities can be achieved by combining regulation of animal number per acre and a limit to the facility size.

Doole and Romera (2014) has done a fairly recent study on the cost-effective regulation of emissions from pastoral agriculture in New Zealand. With the nutrient enrichment of ground and surface water worldwide, concerns arise of the nonpoint pollution from pastoral agriculture. The dairy industry in New Zealand is of great importance while it affects the water quality through nitrogen leaching (Doole & Romera, 2014). The objective of the paper is to evaluate different policies for reducing nitrogen leaching. They use a nonlinear optimization model which incorporates climate variability and soil heterogeneity to assess the implications of these different policies. The main finding was that the most cost-effective policies is constructed to restrict the mean nitrogen leaching rates directly. The use of input-based policies does not motivate the use of mitigation practices that achieves reduction of nitrogen. Further, they also showed that to reduce nitrogen leaching by 10 and 20 percent the stock rates need to be reduced by 17 respectively 30 percent. They conclude that stocking rate is one of the key determinants for reducing the nitrogen leaching.

The paper by Westphal et al. (1989) relates to this research since they have maximized the economic benefits subject to animal herd sizes on a farm. However, the big difference is that the manure is then used as fertilizer and the herd size depends on the uptake from the soils. It also points to the fact that policy should concentrate on the individual case, which is not always reasonable when constructing policy because of difficult and expensive administration. The study by Goetz and Zilberman (2000) suggests taxes as an instrument to regulate the leaching of nutrients, or even a system of tradable permits which might be suitable for the research done in this paper since it will be done on different regions of Sweden. Although this far, it is unclear if it will be suitable in this study, but it still is a really interesting approach. The paper by Innes (2000) relates to this research in a number of ways. One of the suggested policy regulations to decrease the environmental impacts of animal production is to have limits for facility size and animals per acre. The research that is done in this paper will result in how many horses per acre that is optimal in different regions. The author also maximizes a welfare function that consist of the consumer benefits less the producer cost of production and the external cost, which is fairly consistent with what I have in mind. The consumer benefits are measured with the integral of the marginal consumer valuation (price) i.e. the demand. This paper will also find some demand for horses that can be used to measure the consumer benefits from horses.

The gap that this study is going to fill is the lack of studies concerning the leaching from horse pastures and how this might be controlled with policy concerning horse density and removal of manure. There are studies that suggest a horse density as a way of decreasing the leaching, however the study is of natural scientific nature and does not include the benefits of horses.

3 Method

Firstly, this chapter lays out the conceptual framework. Secondly, the objective function is presented and the separate parts of it are described.

3.1 Conceptual framework

The cost-efficient reduction of the leaching of phosphorus in different regions of Sweden was analyzed with a model that minimizes the cost of the reduction. The model examined the optimal number of horses and time spent on removal of manure by minimizing the cost of loss in consumer surplus and the cost of spending time on removing manure at different levels of reduction of the leaching of phosphorus. The model gives a partial equilibrium which implies that it does not consider the whole economy but rather isolates a few aspects to optimize ceteris paribus. The model only considers the effect on the environmental damage cost from the change in quantity of horses per hectare and not how the damage cost is affected by other markets.

A cost-efficient reduction of the p runoff is characterized by reaching the targeted reduction at the least cost possible. The condition for minimizing costs is that the marginal costs of the different parts of the function are equal (Gren *et al.*, 1997). Minimization models are used to allocate resources so that the targeted decrease in runoff are realized with as low costs as possible, i.e. it gives the optimal allocation of the resource. The model in this thesis will minimize the social cost that is the sum of the loss of benefits of keeping horses and the cost of spending time on removing the manure manually. In this case the costs are expressed as the limitation of the experienced utility from horses through decreasing the number of horses causing the runoff and the cost of time spent on removing the manure. There are several possible ways of removing manure, either manually or using a tractor. The cost of manual removal is the time spent on the activity but if it instead was done using a tractor the cost would be the expense of diesel. Removing manure with a tractor would be more time efficient. However, it could also damage the ground which could also be seen as a cost to the environment. In this thesis I will only consider the case where the manure is removed manually.

The loss in benefits of the horses and the cost of time to remove the dung is to be kept at a minimum while the objective is to decrease the leaching of phosphorus. When obtaining this both sensitivity and distribution will matter, the sensitivity will most likely vary with how much pollution the receptor are exposed to already. It is most likely that there will be spatial effects since the damages caused of runoffs will differ between regions in Sweden with the density of horses varies. However, the model in this thesis will not consider the spatial effects of the damages. It will only account for the difference in demand in different regions of Sweden and also the differences in cost of removing the manure.

3.2 Objective function

I will create a model that minimizes the total cost of decreasing the number of horses and the cost of mucking while the reduction of the runoff of phosphorus are set at different levels. The equation below is the objective function that shows the net costs of decreasing the number of horses and removing dung.

$$\boldsymbol{NC^i}(\boldsymbol{H^i},\boldsymbol{R^i}) = \boldsymbol{C^i}(\boldsymbol{H^i}) + \boldsymbol{C^R} \times \boldsymbol{R^i} \tag{1}$$

The index *i* represents the different regions. The variables included in the objective function and the restriction are:
NC^i=net cost of reducing the number of horses and removing manure (SEK)
H^i= number of horses/hectares
R^i= removal of manure in (kg)
$C^i(H^i)$= cost of the decrease of horses in consumer surplus (SEK)
C^R= the cost of removing the manure (hours)

I calculate the minimum total national costs by summing up the costs for all the regions, subject to a given percentage reduction in the total leaching of phosphorus from horse management on national scale.

The costs of reducing the number of horses, $C^i(H)^i$, will be estimated based on the demand of horses. The cost is given by the loss of consumer surplus, CS^i.

$$\boldsymbol{C^i}(\boldsymbol{H^i}) = \Delta \boldsymbol{CS^i}(\boldsymbol{H^i}) \tag{2}$$

The demand function is linear, but the function describing the consumer surplus is quadratic. This implies that the second order derivative is going to be a function of the number of horses.

The cost function for removal of the manure, C^R, is based on the time, *t*, spent on removing manure from one horse annually.

$$\boldsymbol{C^{Ri}} = \boldsymbol{t} \times \boldsymbol{R^i} \tag{3}$$

This cost function is linear which indicates that the first order derivative is constant.

Furthermore, the relationship between the leaching of phosphorus and the number of horse as well as the removal rate needs to be defined. The runoff from horse keeping in each region, Y^i, is a function of the amount of manure, M^i, which depends on the number of horses and the leakage it causes but it also depends on how much of the manure is removed, R^i.

$$\boldsymbol{Y^i} = \boldsymbol{f}(\boldsymbol{H^i},\boldsymbol{R^i}) \tag{4}$$

In the initial state where the is no mucking and the original number of horses the runoff only depends on the number of horses per hectare. The runoff should depend on the number of horses per hectare, how many horses there are in the municipality times the average amount of manure from a horse, the already existing pressure from other sources of nutrient loads and the soil degradation from a high density of horses on one unit of the area. The function is linear which implies the same interpretations of the derivatives as with the cost function for mucking.

The results of the model will show the allocation between the number of horses in each region and how much time that needs to be spent on mucking. The allocated number of horses and time spent on removal will then be transferred into the social cost of the reduction of the leaching of phosphorus.

The allocation problem is that tries to minimize the costs for given quantities of reduction of the environmental damage is given below

$$\boldsymbol{min_{H,R} \sum_{i=1}^{i} NC^{i} = \ C(H^{i}) + C^{R}(R^{i})} \tag{5}$$
$$s.t.\ Y^{*} = d \times Y^{i}$$

Where Y^{*} is the set level of reduction of the damage cost to the environment. An optimization problem with constraints are solved with a Lagrangian function and is given below

$$\boldsymbol{\mathcal{L}\, C(H^{i}, R^{i}) = \sum_{i=1}^{I} C(H^{i}) + C^{R} \times R^{i} - \lambda(d \times Y^{i} - Y^{*})} \tag{6}$$

The minimizing allocation of the horse density and removal of manure is given by the first order conditions

$$\frac{d\mathcal{L}}{dH^{i}} = \frac{dC(H^{i})}{dH^{i}} - \lambda \frac{dY^{*}}{dH^{i}} \tag{7}$$

$$\frac{d\mathcal{L}}{dt} = \frac{dC(R^{i})}{dt} - \lambda \frac{dY^{*}}{dt} \tag{8}$$

$$\frac{d\mathcal{L}}{d\lambda} = \frac{dY^{*}}{d\lambda} \tag{9}$$

To get the cost-efficient solution the first order conditions need to be set equal to zero.

$$\frac{dC(H^{i})}{dH^{i}} - \lambda \frac{dY^{*}}{dH^{i}} = 0 \tag{10}$$

$$\frac{dC(R^{i})}{dt} - \lambda \frac{dY^{*}}{dt} = 0 \tag{11}$$

$$\frac{dY^{*}}{d\lambda} = 0 \tag{12}$$

The above conditions show the marginal cost of reducing the leaching of phosphorus either by reducing the number of horses or by mucking. To get the cost-efficient solution, equation 10 and 11 are set to be equal which gives the following condition

$$\frac{dY^{*}}{dH^{i}} = \frac{dY^{*}}{dt} \tag{13}$$

In equilibrium, the marginal cost of reducing the number of horses must be equal to the marginal cost of mucking. That means that the cost of one more unit of abatement must be the same for abatement by reducing horses or mucking.

4 Empirical functions and data

In this chapter the empirical functions are presented and discussed, as well as the collection of data.

4.1 Consumer surplus

A demand curve describes the quantities that consumers are willing to buy at certain prices. The demand curve is assumed to be downward sloping because of diminishing marginal utility, which indicates that each additional unit consumed is valued less by the consumer than the previous unit (Boardman *et al.*, 2014). Each unit is valued at an amount given by the height of the demand curve which indicates the willingness to pay (WTP) for that additional unit. Benefits can be measured by WTP based on the demand curve since every point on the demand curve shows the marginal benefit of that quantity of the good. The total benefits are measured by both the consumer expenditure and the consumer surplus.

The cost of decreasing the number of horses is calculated as the loss of consumer surplus. The initial quantity of horses in each region, $\widehat{H}^i$, is given. The optimal quantity of horses, H^i, is going to be lower than the observed quantity, which gives the loss of consumer surplus. The lower the optimal quantity of horses, the bigger the loss of consumer surplus and hence the cost. The loss in consumer surplus will vary between different regions depending on the slope of the demand curve.

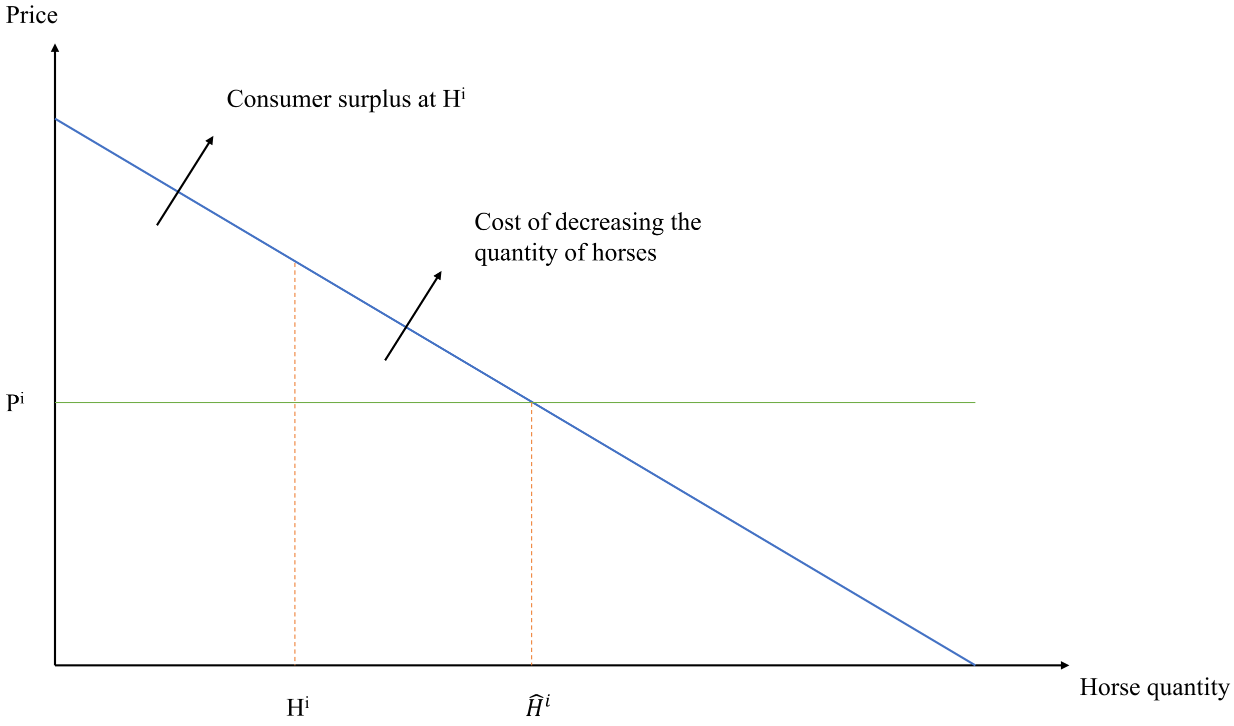

Figure 2. Illustration of the cost to the consumer in the form of forgone consumer surplus.

In this thesis, the loss in consumer surplus will measure the cost to society from the decrease of horses. Benefits received from recreation activities are commonly calculated with consumer surplus derived from the demand function of the recreational activity or site. Tobias and Mendelsohn (1991) used such an approach to value the ecotourism in rainforests in Costa Rica. They used the travel cost method to determine a demand function which was used to calculate the consumer surplus. The consumer surplus estimates the value of changing the quantity of bought trips. The results showed a consumer surplus for rain-forests sites that ranged between 97 500 USD and 116 200 USD (Tobias & Mendelsohn, 1991). Similarly, Bergstrom and Cordell (1991) estimated demand functions for 37 different recreational activities in the U.S., among them trail riding. The demand functions were then used to measure the consumer surplus per day from the recreational activities. Then the total U.S. consumer surplus was calculated by multiplying the surplus per day with the total amount of days spent on activities in the U.S. Their results showed that the U.S. consumer's surplus from horseback riding was at total 376,73 million dollars (Bergstrom & Cordell, 1991). Vass and Elofsson (2016) used consumer and producer surplus to find an optimal combination of carbon abatement measures to meet the EU emissions target by 2050. To estimate a demand function that could be used to calculate the consumer surplus, the authors used the observed prices and quantities of bioenergy and the elasticity of demand for bioenergy and forest products (Vass & Elofsson, 2016).

Another approach to estimate consumer benefits is using the willingness to pay to calculate the average willingness to pay. Willingness to pay can be categorized as stated preferences, which implies that the consumer states the price she would pay, instead of using real prices that can be observed on a market. Two studies have been done on the willingness to pay for riding lessons in Sweden, where the price premiums and preferences of Swedish consumers was examined (Hess *et al.,* 2014; Tienhaara *et al.*, 2017).

The method of deriving benefits of recreational activities has been widely used and is fairly simple, which makes it reliable to use in this context as well. Furthermore, the demand for horses and the prices of horses are characterized as revealed preferences, which implies that they describe the observed behavior of the consumer. As opposed to stated preferences, revealed preferences means that consumers expose their preferences without being asked (Boardman *et al.*, 2014). This thesis is going to use the same approach as the papers mentioned above, and the yearly value will also be inspired by the approach of Bergstrom and Cordell (1991) to calculate the total U.S. consumer surplus. The method of deriving a demand function is approached the same way as in the paper by Vass and Elofsson (2016).
The first step to calculate the net benefits of holding horses is estimating the benefits from holding horses. This can be done by deriving the consumer surplus from the demand function of horses. Since demand curves are derived from utility functions, the demand for horses is the experienced utility of horses and hence can be seen as the benefits.

The demand for horses in different regions can be determined with the quantity of horses in the region, the average price and the price elasticity of the demand for horses. The price and the quantity compose a location on the demand curve and with the elasticity it is possible to estimate the demand curve since the elasticity gives the change in quantity with the change in price.

The demand function is assumed to be linear and can be written as

$$H^i = a^i - b^i P^i \tag{14}$$

Where H^i is the quantity of horses in region i, a^i is the intercept, P^i the price of horses and b^i the slope of the demand curve. The coefficient b^i can be estimated with the elasticity of demand for buying of horses

$$b^i = \frac{\hat{H}^i \varepsilon^i}{\hat{P}^i} \tag{15}$$

Where $\hat{H}^i$ and $\hat{P}^i$ are the observed quantity and prices for horses in different regions. To get the intercept function 15 is inserted in function 14 and then solved for a^i, which gives

$$a^i = (1 - H^i)\varepsilon^i \tag{16}$$

The demand function is then used to calculate the consumer surplus. The consumer surplus is calculated with the inverse demand function and hence, the current demand function needs to be inversed so that the own price is a function of the quantity. The inverse demand function is specified as

$$P^i = \frac{a^i - H^i}{b^i} \tag{17}$$

To get P^i as a function in terms of H^i and the exogenous parameters $\hat{P}^i$, $\hat{H}^i$ and ε^i, function 15 and 16 is inserted in function 17 and gives the following function

$$P^i = \frac{\hat{P}^i}{\varepsilon^i}\left[\left(1 - \varepsilon^i\right) - \frac{\hat{H}^i}{H^i}\right] \tag{18}$$

By integrating the inverse demand function over H^i, the consumer surplus is obtained. The demand curve is integrated over H^i, from the demanded quantity to the origin. It is expressed as

$$\begin{aligned} \boldsymbol{B(H^i) = CS(H^i)} &= \boldsymbol{\int_{H^i}^{\hat{H}^i} \frac{\hat{P}^i}{\varepsilon^i}\left[(1 - \varepsilon^i) - \frac{\hat{H}^i}{H^i}\right] dH^i - \hat{P}^i\left(\hat{H}^i - H^i\right)} \\ &= \boldsymbol{\frac{\hat{P}^i}{\varepsilon}\left[\left(\left(\hat{H}^i - H^i\right) - \varepsilon\left(\hat{H}^i - H^i\right)\right) + \frac{\left(\hat{H}^i - H^i\right)^2}{2\hat{H}^i}\right]} \\ &\quad \boldsymbol{- \hat{P}^i\left(\hat{H}^i - H^i\right)} \end{aligned} \tag{19}$$

The annuity needs to be considered since buying a horse can be considered an investment, which means it will generate value every year and not only at the date of purchase. The annuity is calculated using a discount rate and the life span of the investment. In this case the discount rate is estimated to be 3 % and the life span of the investment is estimated to be 20 years.

When calculating the benefits, the number of horses per region was needed, as well as the average price of horses in the region. Data concerning county area and number of horses per county was collected from Statistics Sweden. To get the number of horses per square kilometer the number of horses from each county was divided by the area of the county. Since the area that is disposable for pastures vary between regions, data on land allocation was retrieved from the same source and was used to get an approximate of how much of the area that are used for horse pastures.

Data on the average price of a horse in different regions was calculated by observing prices of horses on one of the biggest Swedish websites for selling horses. The observations of prices were done by every region at the same date for the first 31 horses sold on the website. The collection of the data is random since the sorted by the date they are posted on the site and not by price or type of horse. Below, in table 1, the average price of horses per region is displayed as well as the initial number of horses in every region.

Table 1. The average price and number of horses per region in Sweden. Sources: Hastnet.se and Swedish Board of Agriculture (2017a).

Region	**Average price of horses (SEK)**	**Number of horses/ region**
Blekinge	54 258	7 400
Dalarna	45 371	18 800
Gotland	51 963	5 900
Gävleborg	46 790	11 700
Halland	71 581	18 600
Jämtland	48 565	7 000
Jönköping	87 871	18 900
Kalmar	68 774	14 700
Kronoberg	71 371	13 800
Norrbotten	49 855	5 700
Skåne	85 984	58 100
Stockholm	73 258	27 400
Södermanland	59 516	8 400
Uppsala	55 000	16 600
Värmland	34 000	11 900
Västerbotten	39 153	9 700
Västernorrland	40 226	7 200
Västmanland	54 516	9 900
Västra Götaland	50 193	56 400
Örebro	58 774	11 900
Östergötland	40 500	15 500

Furthermore, to calculate the demand function the elasticity of demand for horses is needed. The elasticity was retrieved from a paper concerning the supply and demand for quarter horses in the U.S. and is 0.71 (Vestal *et al.*, 2012). The same elasticity has been used for calculating the demand in different regions, since there are no county specific elasticities available.

The total cost in loss of consumer surplus can also be written as below

$$C^i = a^i + b^i H^i - c^i (H^i)^2 \tag{20}$$

Where the parameter a is the sum of the exogenous parameters from equation 19, consisting of the observed price of horses, the observed number of horses and the elasticity. Parameter b is the differential of the observed price and the observed price multiplied by two and divided by the elasticity. At last, the parameter *c* consists of the observed price divided by the elasticity times the observed number of horses and two. Here follows a table with the value of the parameters in every region.

Table 2. Values of the parameters a, b and c.

Region	***a***	***b***	**c**
Blekinge	45 240 473	32 096	5.16
Dalarna	96 109 837	26 839	1.70
Gotland	34 544 417	30 739	6.20
Gävleborg	61 683 718	27 679	2.82
Halland	150 017 645	42 344	2.71
Jämtland	38 304 789	28 729	4.89
Jönköping	187 128 101	51 980	3.27
Kalmar	113 912 992	40 683	3.29
Kronoberg	110 976 879	42 219	3.64
Norrbotten	32 019 549	29 492	6.16
Skåne	562 892 439	50 864	1.04
Stockholm	226 171 177	43 336	1.88
Södermanland	56 330 637	35 207	5.00
Uppsala	102 873 239	32 535	2.33
Värmland	45 588 732	20 113	2.01
Västerbotten	42 792 575	23 161	2.84
Västernorrland	32 634 051	23 796	3.93
Västmanland	60 812 214	32 249	3.88
Västra Götaland	318 979 335	29 692	0.63
Örebro	80 147 673	35 359	3.54
Östergötland	70 732 394	23 958	1.84

The cost of forgone consumer surplus can be calculated by inserting the reduced number of horses in function 20 along with the values of the parameters.

4.2 Leaching of phosphorus

The objective is to reduce the leaching of phosphorus from horse keeping. Hence it is essential to know the initial leaching associated with horse keeping as well as having a function that shows how the leaching of phosphorus is affected by the quantity of horse and the time spent on removing the manure. The function is created with data showing how the leaching of phosphorus changes with increasing horse density and the reduction of the leaching with every minute spent on removing the manure.

The data and functions on leaching from changes in horse density are gotten from Parvage et al. (2013) and Penn et al. (2006). Parvage et al. (2013) showed that the water-soluble phosphorus (WSP) in the soil increased with increasing horse density. The farms investigated had different horse densities and soil textures and they were all established more than 10 years ago. Hence, the stock of phosphorus in the ground has been built up for more than 10 years.

The function showing the correlation between water-soluble phosphorus (WSP) and horse density is defined as

$$WSP = x + z\ HD \tag{21}$$

Where *WSP* is water-soluble phosphorus in milligrams per kilogram of soil, *HD* is the horse density, *x* is the intercept and *z* is the coefficient multiplied with the horse density. The data and the function above for the leaching of phosphorus was found in a paper by Parvage, Ulén and Kirchmann (2013). Seven horse farms, that was established more than ten years ago in Uppsala county, were studied to find the soil P and N status in paddocks. The investigated farms had different horse densities and soil structures. The duration of outdoor keeping of the horses varied with the seasons, and in the winter season the horses had 7 hours outdoors and in the summer 18 hours. There was no removal of manure on five of the seven farms, and the other two removed manure once a year respectively once every two years. The paddocks were divided in three zones, feeding, grazing and excretion areas. As reference areas natural grasslands nearby the tested paddocks, that had not been grazed was selected. Samples were collected from the topsoil (0-20 cm). Weighted means were calculated by multiplying the sample mean for each section with the size of the section in relation to the paddock area. The loading per horse per day were 0.032 kg total P and 0.009 kg phosphate P. The results showed that the highest concentrations of WSP were found in the feeding areas and excretion areas, whereas the concentrations in both the grazing area and the reference area were much lower. The weighted mean for concentration of P in the paddocks range from 1.9-10.5 mg WSP per kg soil. The annual mean input of total P was 60 kg per hectare and 17 kg phosphate P. However, accumulation was affected by the horse density and the age of the paddock. Therefore, the total input was estimated to be 805-2 010 kg total P per hectare over 12-47 years of paddock management. The results also showed that the weighted concentrations of WSP was strongly correlated to the horse density of the paddock.

To get the relationship between the horse density and leaching, information of how the amount of WSP affects the leaching is needed. The relationship between WSP and the dissolved reactive P (DRP) is given by

$$Y = l + mWSP \tag{22}$$

Where *Y* is the DRP in mg P per liter, *WSP* is the is water-soluble phosphorus in milligrams per kilogram of soil, *l* is the intercept of the function and *m* is the coefficient. The relationship between WSP and the dissolved reactive phosphorus in the runoff, as well as the parameters, was obtained from a paper by Penn et al. (2006). The study was carried out in the U.S. and the results showed a linear relationship between the DRP runoff and the WSP.

To get the function that describes the relationship between DRP and the horse density equation 21 is inserted in equation 22 which gives the following function

$$Y = c + e\ HD \tag{23}$$

The variable *HD*, horse density has to be expressed in the same variable as the demand function, hence it is put as the number of horses is divided by the observed area of each region. The effect of removal also needs to enter the function and is expressed in the time it takes to muck dung from one horse for a whole year. The time of mucking the dung from one horse per day is 1.9 minutes (Wallertz & Bendroth, 2010). The time of mucking all dung from one horse per year is the 11.58 hours. Hence the function of leaching becomes

$$Net\ leaching\ Y^i(H^i, t^i) = 0{,}97 + 0{,}008\ \frac{H^i - \frac{1}{11.58}t^i}{\hat{A}^i} \tag{24}$$

To decrease the leaching, the manure can be removed. Hence, the net leaching is affected both by the horse density and removal of manure. The function for net leaching of phosphorus, Y, consists of the intercept which is the background leaching, a coefficient that gives the leaching per horse per hectare, the variables for number of horses, H^i, time, t^i, and the area of the region that is expected to be used as pastures for horses, $\hat{A}^i$. The reduction of leaching from the mucking enters the function as the constant multiplied with the time spent on mucking, t. The area, $\hat{A}^i$, has been estimated by taking the area of the region that is used for grazing land multiplied with the share of horses from all the farm animals that are using the grazing areas. Since the function only contains the water-soluble phosphorus runoff of water also has to be multiplied with the function. The data on the runoff water in Sweden was retrieved from a report from Linefur and Stjernman Forsberg (2018). They conducted a research based on data from the Swedish University of Agricultural Sciences. The mean value over a year of the areal specific runoff of water was calculated to 322 mm (Linefur & Stjernman Forsberg, 2018).

$$Y^i(H^i, t^i) = \left(0.97 + 0.008\ \frac{H^i - 0.09t^i}{\hat{A}^i}\right) * \hat{A}^i * 3220 \tag{25}$$

The final function for net leaching is expressed as above. The function will be used to calculate the leaching in every region separately and then a national target for reduction of the runoff will be set.

When set as the constraint for the Lagrangian, the reduction of the leaching will only be calculated on the part off the runoff that comes from the horses. Consequently, the background runoff, which is the intercept of the above function, will be excluded when calculating the amount of P reduction for every level.

4.3 Cost of removal

The cost of removal of the manure will be defined as the labor cost. The cost structure is straight forward and it depends on the chosen time to spend on removal and the wage.

To estimate the monetary value of the time spent on removing the manure the average wage of a worker in the region will be used and multiplied with the time that is required in the optimum. The cost of removal is a function of the exogenous parameters time spent on removal and hourly wage in the region.

$$C^{Ri}(H^i) = t\ w^i \tag{26}$$

Where t is the time it takes to muck the dung from one horse per year and w^i is the average hourly wage in the region.

The data on time spent on mucking was collected from a study done by Wallertz and Bendroth (2010) about mechanization of horse stables in Sweden. According to the study it takes about 1,9 minutes per horse and day to muck the pasture in a loose housing system (Wallertz & Bendroth, 2010). The time is assumed to be constant per horse, which is a simplified assumption since the time spent on mucking of course is dependent on the size of the pasture. The larger the pasture, the more time would be spent on mucking since the walking distances increases.

The average wage per hour in SEK of the different regions in Sweden was retrieved from Statistics Sweden (2018a) and is displayed in table 3 with the data on time spent on mucking.

Table 3. Cost of removal by every region in Sweden, based on the average hourly wage in the region. Source: Statistics Sweden (2018a) and Wallertz and Bendroth (2010).

Region	**Average hourly wage**	**Cost of mucking/horse/day**	**Cost of mucking/horse/year**
Blekinge	166	5.26	1918.68
Dalarna	167.2	5.29	1932.55
Gotland	160.3	5.08	1852.80
Gävleborg	167.2	5.29	1932.55
Halland	169.6	5.38	1960.29
Jämtland	167.2	5.29	1932.55
Jönköping	160.3	5.08	1852.80
Kalmar	160.3	5.08	1852.80
Kronoberg	160.3	5.08	1852.80
Norrbotten	173.2	5.48	2001.90
Skåne	166	5.26	1918.68
Stockholm	166.6	5.28	1925.62
Södermanland	166.2	5.26	1920.99
Uppsala	166.2	5.26	1920.99
Värmland	167.2	5.29	1932.55
Västerbotten	173.2	5.48	2001.90
Västernorrland	167.6	5.31	1937.18
Västmanland	166.2	5.26	1920.99
Västra Götaland	169.6	5.37	1960.29
Örebro	166.2	5.26	1920.99
Östergötland	166.2	5.26	1920.99

The annual cost of mucking per horse ranges between 1919.9 SEK to 2000.2 SEK in the different regions, since the hourly wages differs between the regions.

5 Results and discussion

The result has been calculated with a set levels of reductions of the runoff that is caused by the horses, from a 10 % reduction to a 60 % reduction.

In the following section the results of the model are presented. Firstly, some data of horse grazing and leaching are presented. Secondly, the results of different levels of reduction on a national scale are shown in terms of reduction of horses and time spent on removing the dung, as well as the total cost for each reduction level. Thirdly, the total cost and the marginal costs for the 10 % level of reduction are presented. Fourthly, the marginal cost of the reduction will be compared to the marginal costs of other measures to reduce phosphorus to find if this measure is cost-efficient or not.

5. 1 Results

The results have been obtained using Microsoft Excel. In the current state, with the present number of horses, the total leaching for all regions of phosphorus from horse pastures is 403, 31 kilogram per year. The regions contribute with different amounts of leaching based on the number of horses and the area of the region that is used for grazing for horses. Below are some figures showing data on the grazing area that is assumed to be used for horses in each region.

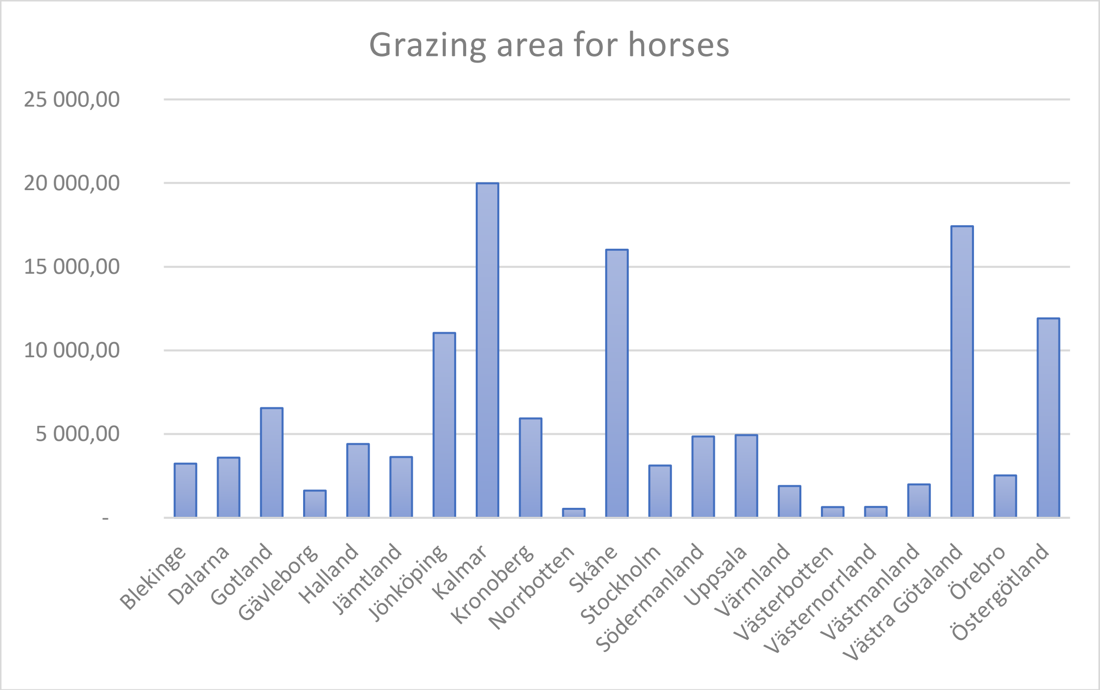

Figure 3. The diagram shows the grazing area in hecaters for horses in each region. Source: Statistics Sweden (2018b).

The initial leaching is also dependent on the density of the horses per hectare. Figure 2 shows the initial leaching of phosphorus and the amount of horses per hectare. As can be seen the number of horses per hectare has a minor effect on the initial leaching.

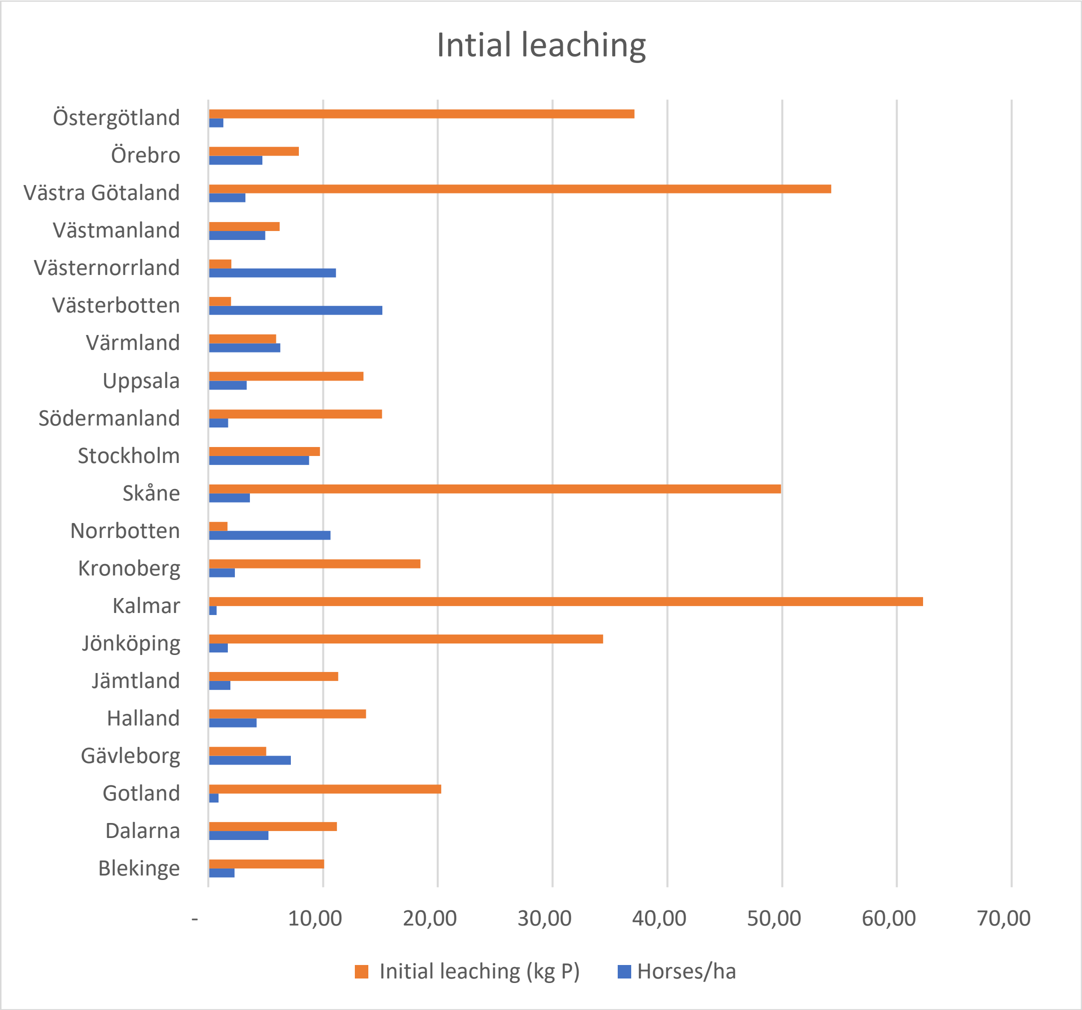

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Figure 4. The area that is used for grazing of horses and the initial leaching from the grazing areas. The leaching is expressed in kg P.

The regions that uses a big share of the total area for grazing of horses are the ones that has the most leaching. The number of horses in the region do not affect the leaching as much as the area used for grazing. This is given because of the initial leaching that exists even if there are no horses grazing the area.

Since the horses only contribute with a small share of the total leaching, the reduction of the leaching is calculated only on the share that is actually caused by the horses. To calculate the results of the model Microsoft Excel was used. The results are presented as the optimal reduction in number of horses and the optimal time spent on removal of the dung. The leaching is reduced by 10%, 20% and so on until a level of reduction of 60%.

In figure 4, the decrease in number of horses and the total cost are shown aggregated for Sweden. The model also included mucking, but for no reduction level and no region did the minimum cost give any time spent on mucking. This causes the total cost to follow the optimal reduction of horses. The reason for no mucking is that it is more expensive than decreasing the number of horses.

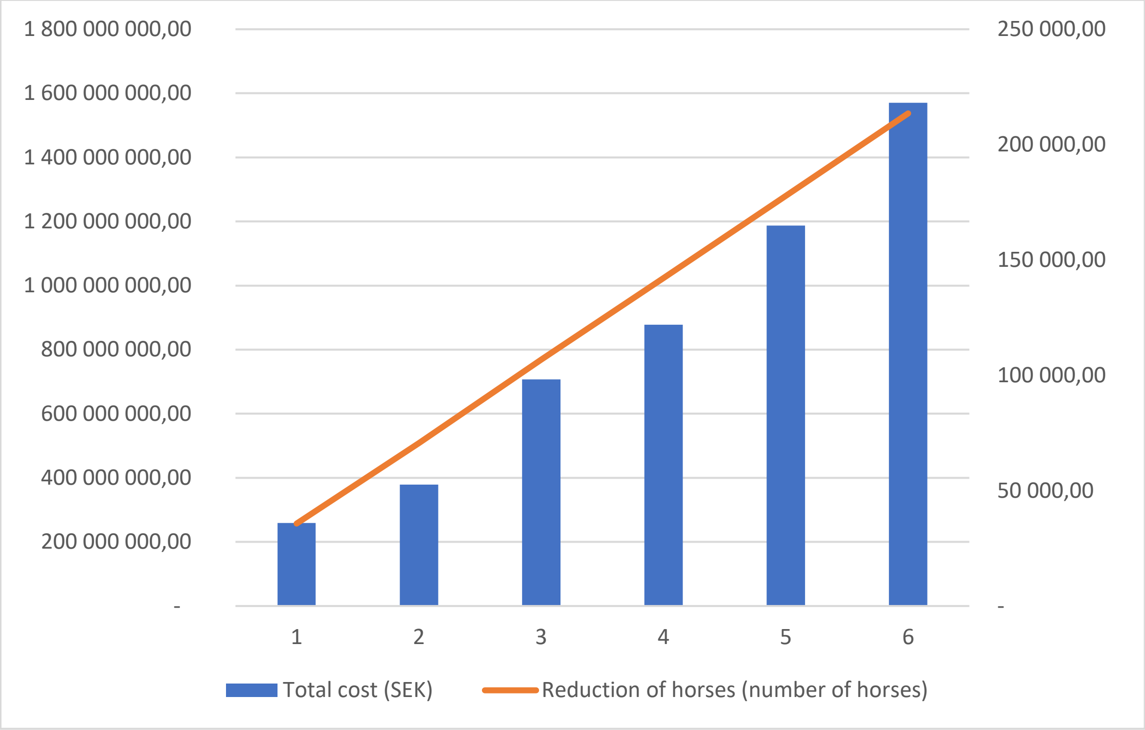

Figure 5. The total cost and the total reduction of horses and for different levels of reduction. The x-axis is graded from a 10% reduction to 60% reduction level.

The columns show the total cost and the line shows the reduction of horses. Starting from the left in the figure the reduction of leaching of phosphorus is 10% and ends in a reduction level at 60 %. The decrease in number of horses in percent equals the level of reduction, i.e. when the reduction of leaching of phosphorus is reduced by 10% the number of horses is also reduced by 10%. This is also a result off the time spent on mucking being zero in every scenario.

However, the allocation of reduction of number of horses show some diversity. This is due to the fact that value of horses varies among the regions. Below are two figures showing the allocation of reduction of horses in the regions for 10 % and 60 % runoff reduction.

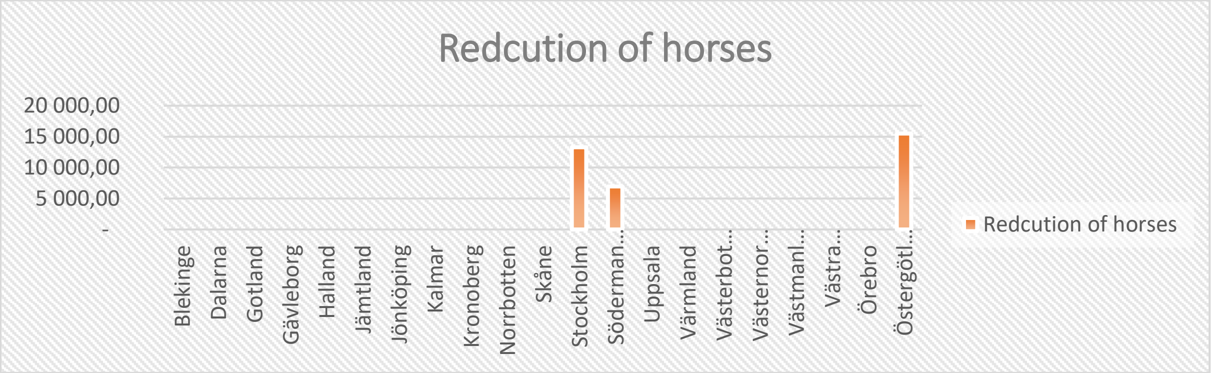

Figure 6. The allocation of reduction of horses between the different regions for a reduction of phosphorus by 10%.

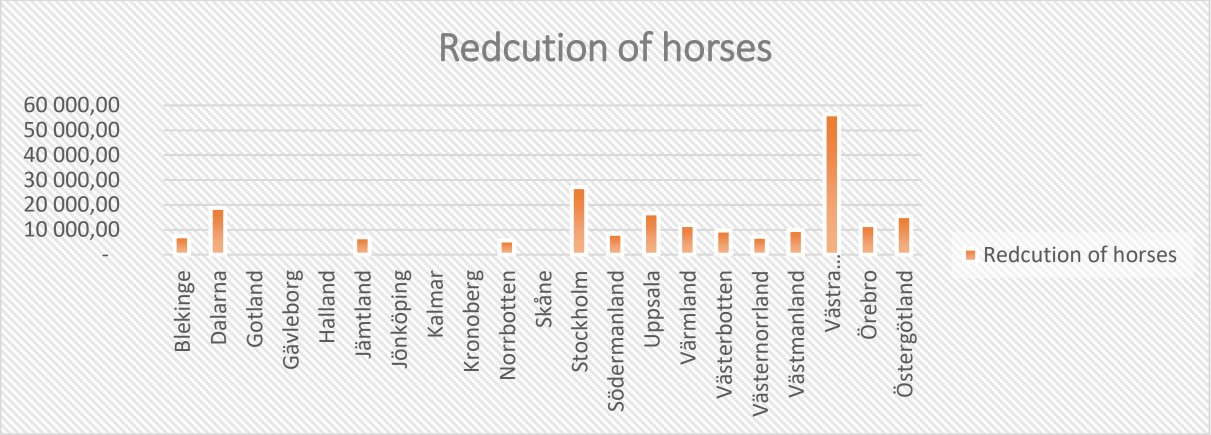

Figure 7. The allocation of reduction of horses between the different regions for a reduction of phosphorus by 60%.

For example, as can be seen in Table 1, Skåne has amongst one of the highest average prices of horses. Which results in that Skåne do not have to decrease the number of horses in any scenario. The initial leaching in Skåne is also small which enables no reduction of the number of horses since their share of the leaching is small. This might seem to be contradictive since Skåne is one of the regions with the highest number of horses. However, as have been emphasized earlier, the number of horses have a minor impact on the total leaching.

5. 2 Marginal costs

To determine the cost efficiency of the measures investigated in this thesis, the marginal cost needs to be calculated. Thereafter, the marginal cost is compared to marginal costs of other measures of reducing the leaching of phosphorus. If the marginal cost of in this thesis is higher than the marginal costs from other studies, it will imply that reduction of horses is not a cost-efficient measure to reduce leaching of phosphorus. If the marginal cost were to be lower compared to other studies, the measure of this thesis could be considered cost-efficient.

The marginal cost shows the additional cost of reducing another unit of phosphorus and can be found by dividing the differences in cost by the difference in leaching for two reduction levels. For a reduction level at 10 % of the leaching caused by the horses the marginal cost is calculated to 281 559 710 Swedish crowns.

5.3 Other studies

The results of the marginal cost of reducing the leaching of phosphorus is to be compared to the marginal costs that is associated with other measures to reduce the leaching of phosphorus. Some of the studies used to compare marginal costs considers retention, which this study does not. When retention is considered in the model, for every unit of leaching that is reduced there has been an even bigger amount emitted from the begging since some of the phosphorus has been caught by vegetation or sediment on its way to the water. This means that the marginal cost is higher when the retention is included in the model.

In a study by Elfosson (2010) the marginal cost of reducing phosphorus leaching was calculated to be 6 861 SEK/kg. The study included 8 different measures for phosphorus abatement and the reduction was set to 50% (Elofsson, 2010). Gren et al. (1997a) estimated the marginal costs from land use to be between 526- 6 600 SEK/kg phosphorus. Another study by Gren et al. (2008) estimated the marginal cost from different measures, amongst them livestock reductions. They derived a marginal cost at 11 183- 42 687 SEK/kg phosphorus from livestock reductions (Gren *et al.,* 2008). Since the study analyzed marginal costs of reduction with different measures it was evident in the paper that the marginal cost of reducing livestock the compared to the other measures were the most expensive.

As stated above, the marginal costs from different measures of reducing P leaching very between 526- 42 687 SEK per kg of phosphorus. The marginal cost of reducing horses are substantially higher than for any of the other measures from the compared studies. However, the total cost of reducing phosphorus by horse reduction are closer to the total cost of the other measure. Furthermore, the total load from the horses are smaller than the total loads from other types of sources of leaching. This is the cause for the marginal cost being considerably larger than for the compared papers. Since the difference between the marginal costs of this study are substantially larger than for the other papers, the fact that retention is not included here would not change the conclusion that horse reductions, or mucking, are unlikely to be cost-efficient in an overall strategy to reduce P runoff.

5.4 Discussion

The results show that decreasing the number of horses is a very expensive measure to reduce the leaching of phosphorus. Horse keeping and riding is one of the most popular sports in Sweden with about 164 000 practicing users (Riksidrottsförbundet, 2018). In the past horse keeping was necessary for agriculture and as transportation. Today there are few horses that are actually used for tasks of that character, and the bigger part are kept for hobby and recreational purposes. Therefore, they are also highly valued, since it is not a necessary good for the consumer but can be thought of as a luxurious good. This leads to a high price of horses, which in turn creates a high consumer surplus. When decreasing the number of horses, there are great losses in consumer surplus and the decrease becomes expensive from a social economic point of view. Thus, trying to limit the leaching of phosphorus by decreasing the number of horses is not a cost-effective measure.

The marginal cost of this study is very large, which is explained by the amount of leaching being small compared to the total cost. In the study by Gren et al. (2008) livestock reductions were the most expensive measure among the investigated measures. This could indicate that reducing horses would also be an expensive measure. However, the marginal cost might suffer from scale problems because of the large costs and little effect on the leaching. One significant problem with the credibility of the results is the initial leaching that is given by the function Y. According to Parvage (2015) the leaching from each hectare in a pasture for horses is 1.1 kg of phosphorus per year with the area that has been estimated in this thesis. With Parvages number the leaching would be 146 700 kg phosphorus per year (Parvage, 2015). The calculated net leaching of this thesis is only 7 273 kg per year. If the function of leaching could be adjusted to reflect the true value of the runoff, it is more likely that this measure indeed could be considered cost-efficient. The leaching that is actually caused by the horses is too small in this model.

Furthermore, the results illustrate big differences in the reduction of horses between the regions. This would mean that the population of the regions would be affected unequally if a policy were to regulate the number of horses. Those regions that have high initial number of horses causes more runoff, hence it requires higher reduction in horses to meet the reduction target. The regions that experience higher prices of horses are those who are less likely to have to reduce their horse numbers, since the loss in consumer surplus is greater than in the regions who have lower prices of horses. The regions that have the highest average price is Jönköping, Skåne and Stockholm. These regions also have the highest numbers of horses, except for Västra Götaland. In the results, both Jönköping and Skåne are not to reduce the horses for any reduction level, because it would be expensive in those regions. Västra Götaland is the region that needs to reduce the most horses at a reduction level of 60 %, which is expected since it is among the regions that have the highest numbers of initial horses and an average price that is below the mean of the average prices.

The elasticity used in the demand function for horses is from a study done in U.S., and it is uncertain if the elasticity would be the same for the Swedish market. How this would affect the result is unclear, it depends on whether the elasticity is larger or smaller than the one used in this thesis. This would either create a bigger loss or a smaller loss of consumer surplus and could hence affect the total and marginal costs. If the elasticity were to be closer to zero than the one used in this thesis, the demand curve would be flatter, and the loss of consumer surplus would be smaller. The costs would thus be smaller, and it could affect the cost-efficiency compared to other measures. Research of the Swedish market is needed to be able to use an elasticity that is based on the Swedish consumers.

The cost of removal has been calculated in a very straight forward manner. To make the cost of removal more complex, and expensive, other assumptions could have been made. The cost of removal of manure could have been assumed to increase exponentially with increasing size of the pasture. With larger the pastures, the distance increases and hence the time spent on removal. The increasing distance affects the time you have to spend walking between the piles of manure. Furthermore, the cost of removal might be underestimated in this thesis. For example, one important aspect that has not been considered in this thesis is the heavy workload that people in the horse industry are already experiencing. Research has shown that 91% of the riding teachers in Sweden suffer from joint injuries and muscle damage (Pinzke & Löfqvist, 2008). This could be considered additionally a cost from removing the manure and would hence increase the cost of removal. The result has shown that mucking already was too expensive as opposed to reducing horses. If the two suggestions above were to be considered, the cost of mucking would become even more expensive in relation to reducing horses.

6 Conclusions

Using an optimization model, this thesis tries to find the costs of reducing the leaching of phosphorus caused by horses in Sweden. The model considered the costs from the 21 regions of Sweden and were then minimized on a national scale for certain reduction levels of P runoff. The main finding of the study is that reducing horses and mucking is not a cost-efficient measure of reducing the runoff of phosphorus. The results showed a total cost that was in line with previous research, but the marginal cost was considerably larger compared to other studies.

Furthermore, it can be concluded that the model of this thesis has underestimated the leaching from horse pastures. This causes the central problem of the study, which is the scale, the total cost is high while the effect on the leaching is small. Thus, this leads to the marginal cost to be very high and hence the measure to not be cost efficient compared to other measures.

6. 1 Further research

One assumption that could have been incorporated in the thesis is that the amount of runoff in the regions are different. The model of this thesis uses the same runoff function while most likely the runoff causes damage of different magnitudes in different areas due to multiple factors. In some regions where the horses are held in urban areas, the runoff rate would be affected by other parameters than in suburban areas. This would make the regional effects on mucking and reduction of horses more accurate, which in turn which in turn would help meet the targeted reduction of p runoff since the reduction of horses and mucking would be highest where it would be most needed.

Moreover, the cost of reducing the number of horses is calculated in the framework of revealed preferences. Revealed preferences is preferable when a market exists that can be observed to get real prices, which makes the monetary valuation easier and more reliable. Despite this, there are other possible ways to estimate the value of horses. As well as the monetary value of horses that can be estimated from market prices, horses bring other benefits too. For example, just like cows are considered to keep an open landscape and contribute to nature conservation, horses can have similar benefits. These types of benefits could further increase the value of horses.

Recently, the Swedish government have published a new report that amongst other things deal with the effects of horse keeping on the environment. The report has resulted in some propositions to reduce runoff of nutrients. The propositions could potentially become difficult and expensive to comply for horse owners. More research could be done on the economic effects of the propositions and how they compare to the environmental effects of the regulations.

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