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RESEARCH

Food security and the value of game animals—a study of Sweden

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Abstract

The food security value of wild meat is calculated by combining proxy methods for quantifying game animal abundance with shadow pricing techniques for assessing the unit values of food security. This study calculated the food security values of moose, roe deer, wild boar, and fallow deer for Sweden overall and for individual counties. The results showed that meat from these animal populations accounts for approximately 9% of meat consumption in Sweden and for 1.2% of the minimum energy food consumption during periods of crisis for the whole of Sweden, while in some counties it can be as much as 8%. The calculated unit value, or shadow price, of the minimum energy requirement ranged between € 0.1 and € 4.2/mcal, depending on the magnitude of the crisis scenario. At most, the total food security value of actual animal population sizes amounted to 0.50 billion euros, but this was unevenly distributed, with high values in counties that have an abundance of moose and wild boar.

Keywords Food security · Value · Game animals · Shadow pricing · Sweden

Introduction

Game animals have been an important source of food and nutrients since the earliest days of mankind and in several countries are necessary for indigenous people today. Agricultural development has replaced game animals as a source of nutrients in many countries, with game animals such as wild boar now being regarded as a nuisance (e.g. Massei et al. 2015). However, climate events and geopolitical circumstances are highlighting the vulnerability of agriculture to provide diets with the necessary nutrients, and expensive changes in agricultural production and food diets might be necessary if there are disruptions to the supply of agricultural inputs and/or consumption foods (e.g. Andersson et al. 2022). Game animals may then be a less expensive source of nutrients to ensure minimum nutritional diets. Despite the large body of literature on the economics of food security (Tweeten 1999; Saravia-Matus et al. 2012; Li and Song 2022) and the value of game animals (review in Gren and Kerr (2023)), there has only been one study on the economic value of wild game meat for food security (Nunes et al. 2019), which was applied to game populations in Brazil.

The purpose of this study was to calculate the value of game animals for food security in Sweden. In general, food security refers to when all people have physical and economic access to sufficient safe and nutritious food (FAO 2006). A limitation of the present study is its focus on physical access to animal game as a food resource. The value of food security then includes the benefits of avoiding food shortages in the event of different crises. In principle, this value can be calculated by multiplying the unit value of game animals for food security by the corresponding animal population sizes. Although simple in principle, there are two main challenges with this. One is the lack of data on the unit value of game animals for food security. There is a market for wild game meat in Sweden, the market price of which reflects the meat value of different game animals. The supply of this meat in the food chain complies

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with the EU legislation on the hygiene of food stuff (European Commission 2004a, b) and the Swedish regulations (Swedish Food Agency 2005). The hunters must then deliver the game handling facilities approved by the Swedish Food Agency, which are available in different countis. However, the additional value of food security in the event of a crisis is not subject to market transactions or available in the literature. The other challenge is the quantification of the population sizes of game animals, data that are lacking for game animals in most countries.

Wildlife population models are numerous in the ecological literature, with a variety of scopes and methods (see Munns (2006) for a review). The most common approach for estimating game animal populations over extensive areas such as counties or nations has been to use hunting bag statistics. However, this approach requires good information on the amount of effort put in to capturing or killing the animals. In many cases the problem of using hunting statistics for estimating population growth models is the difficulty of obtaining appropriate effort variables, such as the number of active hunters and the time spent hunting. Therefore, the present study applied a method developed by Gren and Jägerbrand (2019) for estimating population abundance, which uses occurrences of animal-vehicle-collisions (AVC) in relation to traffic load. Traffic load as a pressure variable has an advantage compared with, for example, the number of hunters since it reflects actual traffic by vehicles on the roads, and not just the number of cars that would be the correspondence with the number of hunters.

The valuation of non-market goods and services has a long tradition in economics, which has developed various methods based on revealed and hypothetical preferences and provision cost approaches (see reviews in Endalwe et al. (2018) for example). A few studies have been applied to food security (Chavas 2017; Nunes et al. 2019; Wang et al. 2020; Carman et al. 2021). The study of Nunes et al. (2019) is most similar to the present study in its quantification of the food security value of wild meat in rural Amazonia. It differs from the present study by its focus on the economic access dimension of food security, where the food security value was calculated as the income needed to replace consumption of wild game meat with bovine beef for local people in rural areas. Chavas (2017) developed a conceptual framework that defined the food security value as a risk equivalent, i.e. the willingness to pay (WTP) for a certain food supply compared with an uncertain supply of the same quantity. Wang et al. (2020) used the contingent valuation method to estimate the WTP for fresh food reserves in China, while Carman et al. (2021) estimated WTP with a field experiment on meal kit reserves in the USA.

The present study calculated the food security value of game animals in Sweden using the shadow prices of minimum dietary constraints. Shadow pricing has a long tradition in economics where it refers to estimates of inputs or outputs for which no other price exists, such as market price (e.g. Kanbur 1987). There is a large body of literature on the shadow prices of pollutant emissions in particular (see de Bruyn et al. (2010) for a survey). These are usually defined as marginal abatement costs and are calculated using numerical optimisation models. In the present study, the shadow price constituted the cost of a marginal increase in the minimum dietary needs, which was calculated using an agricultural sector model for Sweden.

In the authors' view, the main contribution of this study is twofold: the calculation of the food security value of game animals, which has only previously been done for one country, and the selection of quantitative methods for calculating animal population sizes and the unit value of food security. This study is organised as follows: the conceptual approach for calculating animal abundance and food security shadow prices is presented in the "Conceptual approach" section, and data retrieval is described in the "Description of data" section; the results are given in the "Results: food security value of game animals" section and then discussed in the "Discussion" section. The study ends with a summary and concluding comments.

Conceptual approach

The value of game animals in conditions of heightened alert was calculated by multiplying the animal population size by the food security unit value. The choice of game species was determined by their potential contribution to meeting dietary needs and the possibility of quantifying population sizes at county level in Sweden. According to Wiklund and Malmfors (2014), the harvest of four species—moose (*Alces alces*), roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa*) and fallow deer (*Dama dama*)—accounted for 95% of the total carcass meat harvested in 2012/13, and these game animals are therefore included in this study.

Data on population sizes at county level are not available for any of these game animals. There have been a few studies with estimates for Sweden (Jansson and Antonsson 2011; Gren et al. 2016; Gren and Jägerbrand 2019; Bijl and Csányi 2022; Kalén et al. 2022). Jansson and Antonsson (2011) presented population data for 2005 for moose, deer, wild boar and fallow deer of 230, 375, 40 and 110 thousand animals respectively. Gren and Jägerbrand (2019) used traffic and hunting data to calculate the populations of moose, roe deer and wild boar in 2015 (416, 470 and 238 thousand respectively). Estimates by Bijl and Csányi (2022) indicated a population of fallow deer of approximately 126 thousand animals in 2010, and Kalén et al. (2022) simulated a moose population of 313 thousand animals for 2020.

In order to obtain county level estimates of the abundance of the four game animals in this study the method developed by Gren and Jägerbrand (2019) was used. It is based on the assumption that the population of a game animal, w where $w = 1,\ldots,4$ game animals, in county i, $i = 1,\ldots, n$ counties at a certain time t,P_t^{wi}, is determined by population growth, animal-vehicle collisions,AVC_t^{wi}, and harvest by hunting,H_t^{wi}. The population growth function is assigned a simple logistic form, with the population dynamics then written as:

$$P_{t+1}^{wi} = P_t^{wi} + r^w P_t^{wi}\left(1 - \frac{P_t^{wi}}{K^{wi}}\right) - AVC_t^{wi} - H_t^{wi} \tag{1}$$

where r^w is the intrinsic growth rate and K^{wi} is the maximum population size in the county. The mortality from AVC is determined by traffic load, T_t^i, and population size in each county according to:

$$AVC_t^{wi} = \alpha^w T_t^i P_t^{wi} \tag{2}$$

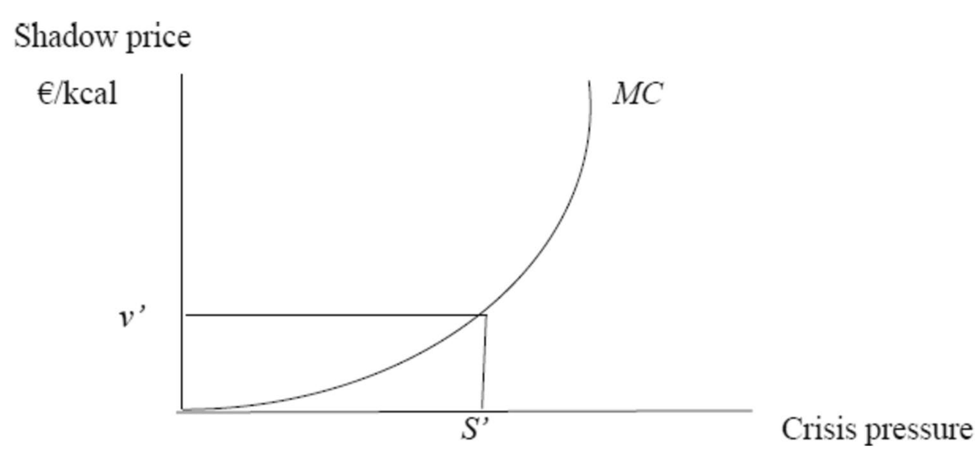
where α^w is an average mortality coefficient. Thus, with information on α^w and data on T_t^i and AVC_t^{wi}, it is possible to quantify P_t^{wi}. Data on traffic load and accidents are available from official statistics, but not mortality coefficients α^w. In order to estimate this coefficient, Gren and Jägerbrand (2019) applied an approach much used in fishery economics where there are poor data on fish populations. An essential assumption was that the relative development over time of the animal game population is the same as the change in relative mortality from AVC (Appendix 1). Statistical methods were then used to estimate a regression equation that delivers an estimate of α^w. Admittedly, the AVC number is determined by other factors, such as fences along roads, landscape characteristics, speed limits and driver behaviour. The present study made use of available estimates that account for landscape characteristics and fences, which are described in more detail in the "Game animal populations" section.

The food security value of the population of each game animal was calculated using the shadow price of meeting a certain minimum dietary need in a crisis. The shadow price is defined as the marginal cost for the food sector to provide the minimum dietary needs. Dietary needs include sufficient energy, protein and nutrients such as iron, vitamin D and folate. The Swedish Food Agency (2021) recommends the prioritisation of energy provision since this is necessary for the body to maintain a good nutritional status. Therefore the dietary constraint in the present study is expressed in terms of minimum kcal/person/day.

The shadow price was determined by the dietary constraint, type and pressure of the anticipated crisis, and the functioning of the food sector. In the literature, different types of crisis are considered. These include barriers to trade due to geopolitical situations or pandemics such as COVID-19 and environmental disasters (Folkesson 1973; Saravia-Matus et al. 2012; Bené 2020). The choice of crisis scenarios in this study was based on Andersson et al. (2022) who identify barriers to trade of agricultural inputs and consumption foods as potential threats to society. Therefore, calculations were made for a scenario with simultaneous decreases in the trade of both agricultural inputs and consumption goods. Regarding the magnitude of crisis pressure, measured as the percent reduction in trade from a situation without a crisis, Andersson et al. (2022) identified different levels up to a 50% reduction. The shadow price of food security at a certain crisis scenario, ν', is based on the marginal cost function, MC, for the food sector to ensure the minimum dietary needs at different crisis levels, as illustrated in Fig. 1.

The MC curve in Fig. 1 illustrates the minimum marginal cost for the food sector to provide the minimum dietary needs at different crisis pressures. The cost was obtained from an agricultural sector model that maximises total net revenues of farming and the food industry, and the curve

Fig. 1 Illustration of the shadow price, ν', of a minimum energy intake (kcal/person/day) at the crisis pressure level S'



then shows the decrease in net revenues due to the dietary constraint at increasing levels of crisis pressure.

At relatively low crisis pressures, such as a 5% decrease in the imports of agricultural inputs and consumption foods, the provision of minimum dietary needs may not be threatened because of available production and substitution possibilities. This is not the case at higher pressure levels, and the shadow prices can then differ between the scenarios, as illustrated at S' by the shadow price ν'. The shadow price increases at pressure levels exceeding S', the speed of which depends on the shape of the marginal cost curve.

Given the quantified population abundance and shadow price, the food security value of the game population in a county, $V^{iS'}$, and at the national level, $V^{S'}$, for each crisis pressure is calculated as.

$$V^{iS'} = \sum_w v^{S'} e^w P^{wi} \text{ and } V^{S'} = \sum_i \sum_w v^{S'} e^w P^{wi} \quad (3)$$

where e^w is the energy content (kcal) per game animal. Since the shadow price is the same for all counties, differences in $V^{iS'}$ depend on the abundance of the different game animals and their energy content.

Description of data

Game animal populations

The mortality coefficient of animal-vehicle collisions (AVC), i.e. α^w in Eq. (2), was obtained from Gren and Jägerbrand (2019) who applied a random effect regression model on a panel dataset with counties and years. The regression equations included landscape characteristics measured as areas of forest, arable land and grassland, and fences along main roads. In addition, hunting bags were included as an explanatory variable, which implies that the mortality coefficient, and thereby the population sizes, are calculated at actual harvest levels. Estimates were made for moose, roe deer and wild boar. The results showed significant impacts of traffic load at the 95% confidence interval. The estimated mortality coefficient for roe deer was approximately five times greater than that for moose and wild boar because of the large number of AVC (Table 3 in Appendix 2). The corresponding mortality coefficient for fallow deer was not available but was assumed to be the same as for wild boar because of the similar rapid increases in AVC and hunting bags during 2015 and 2020 (NCWA 2022; Viltdata 2023).

Regarding AVC in Sweden, it is mandatory to report AVC to the police, with the accident investigated at the location by a contracted hunter. The number of accidents with different animals, A^{wi}, is reported to a national database, from which county-level data are obtained (NCWA 2022). Data on traffic load, T^i, as measured in millions of driven km, were obtained from a public body of regional cooperation (RUS 2022). For both datasets, the annual average between 2016 and 2021 was used (Table 4 in Appendix 2). This relatively short time perspective was applied because of the rapid increase in AVC for wild boar and fallow deer in the last five years, and the population of these game animals might therefore be underestimated with a longer time perspective. The AVC with moose and roe deer was more stable over a 10-year period.

The estimated population of game animals was converted into slaughter weight since this provides the basis for the calculation of the energy content. The total slaughter weights depend on the age structure of the animals in the populations. Such data are not available, but only on the composition of adults and yearlings in the harvest of the animals (Wiklund and Malmfors 2014). It is assumed that the composition of the populations is the same as that for the harvest. A weighted average of the slaughter weights of the two age classes is then calculated for each game animal with number of animals in each age class as weights. Given all the assumptions, the calculated total animal population sizes, slaughter weight and potential wild meat per person for Sweden are as presented in Table 1.

The estimated population size of moose (298 thousand animals) was larger than that reported in Jansson and Antonsson (2011), but lower than the estimates of Gren and Jägerbrand (2019) and Kalén et al. (2022). The population

Table 1 Calculated populations and slaughter weight of game animals in 2020

Animal	Number of animals, thousand	Slaughter weight, kg/animal[a]	Total slaughter weight, thousand tonnes	kg/person/year[b]
Moose	298	122	36.36	3.51
Moose	512	12	6.14	0.59
Wild boar	490	51	24.99	2.41
Fallow deer	229	26	6.00	0.58
Total			73.49	7.10

[a]Slaughter weight (Wiklund and Malmfors 2014, Table 1)

[b]Swedish population in 2020 from Swedish Statistics (2023)

estimate of roe deer was close to the estimate of Gren and Jägerbrand (2019). It should also be noted that the density of roe deer, expressed as animals/1000 ha productive forest land, ranges between a few and 60 (Svenska Jägarförbundet 2022). The estimate in the present study equated to an average of 20 animals/1000 ha, which is thus within the reported range. The calculated wild boar population was considerably higher than the estimate of 238 thousand animals in 2015 by Gren and Jägerbrand (2019). This can be explained by the increase in AVC with wild boar of approximately 70% from the 2015 level. There has also been a steady increase in AVC with fallow deer, from 805 in 2010 to 3245 in 2020. This could be one reason for the larger population estimate than that of Bijl and Csányi (2022), who reported 126 thousand animals in 2010.

The calculated quantity of wild game meat (slaughter weight) per person and year in Table 1 can be compared with the actual consumption of 1.91 kg/person/year wild meat in 2021 (SBA 2023a). This accounts for 2.4% of the total meat consumption (80 kg/person/year) in Sweden. The potential wild game meat from the calculated populations then corresponded to 9% of meat consumption. Meat from moose and wild boar accounted for 83% of this contribution.

Calculations of the slaughter weight of each animal game population were made for each county (see the map of counties in Fig. 6 in Appendix 2) with data on AVC and traffic load (Table 4 in Appendix 2). The mortality coefficients were calculated for each game animal for the whole of Sweden and thus show the average for the counties. Therefore, the county-level estimates were calibrated at the level of the total number of animals for Sweden as a whole. The results indicated large differences between the counties in terms of the quantities and composition of game meat (Fig. 2).

The number of AVC and traffic load determined the differences in animal abundance between the counties (Table 4 in Appendix 2). Calculated animal abundance was therefore relatively low in the three most densely populated regions of Stockholm, Skåne and Västra Götaland. Wild boar dominates in regions in the south of Sweden and moose dominates in the north.

Energy supply from game animals

The energy content per slaughter weight unit provides the link between game population sizes and their food security value. Energy content is calculated separately for the different edible parts (meat, fat, blood and edible entrails) based on data in Swedish Food Agency (2022). However, for the game animals included, data are available only on the proportions of meat and fat in the carcass (Wiklund and Malmfors 2014), which does not include edible by-products. Owing to the lack of data, blood and edible entrails are assumed to have the same proportion to slaughter weight for moose, roe deer and fallow deer as for cattle, and the same proportion for wild boar as for pigs (Alsterberg 2012). With all edible parts included, the energy content was 1956 kcal/kg slaughter weight for wild boar and 1311 kcal/kg slaughter weight for moose, roe deer and fallow deer. The total energy supply then amounted to 116 billion kcal, which corresponded to an average of 30.4 kcal/person/day if the total game populations were harvested and consumed within one year. When relating the supply of energy from game animals to the human population in each county (Swedish Statistics 2022), large differences appeared between the counties (Fig. 3).

The supply of energy per capita from wild game meat was low in densely population regions (Stockholm, Skåne, Västra Götaland), but high in some northern regions because of the large supply of moose and the low human population density. It was also relatively large in counties in the south (Södermanland, Kronoberg, Kalmar, Blekinge) owing to the abundance of wild boar.

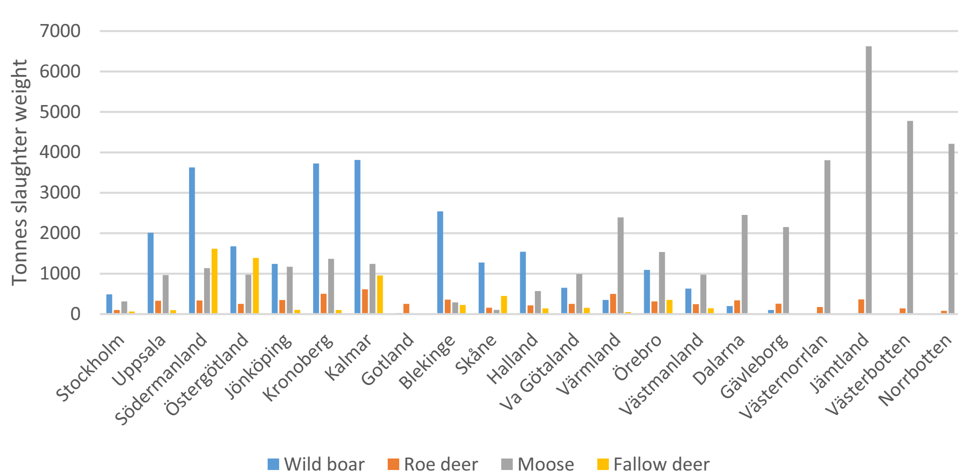


Fig. 2 Allocation of wild game meat between different game animals and counties

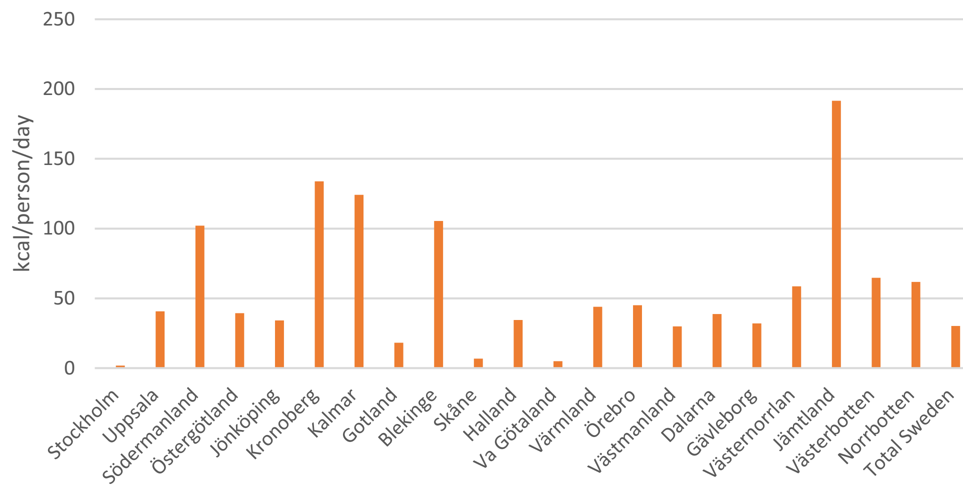


Fig. 3 Edible energy supply of calculated game animal populations in different counties and in total for Sweden (kcal/person/day)

Shadow price

The dietary constraint in this study was based on the recommendations by Swedish Food Agency, which reports a minimum amount of 2450 kcal/person/day (Swedish Food Agency 2021). This gives a minimum of 9296 Tcal for the total Swedish population of 10.4 million, which corresponds to 79% of the actual consumption of 11,834 Tcal in 2021, and slightly below the supply from the agricultural sector, which amounts to 9557 Tcal. The calculated supply of energy from wild game meat corresponds on average to 1.2% of the dietary needs but can account for approximately 8% in the north of Sweden (Jämtland).

The shadow price of game animals was calculated using a static computable partial equilibrium model of the Swedish food sector, the Swedish Agricultural Sector Model (SASM), which is described in detail in Jonasson (2018). SASM is the only sector model with trade between different regions, which is highly relevant for an elongated country such as Sweden. It is a mathematical programming model where total producer and consumer surplus is maximised with respect to constraints on land use, crop rotation and, in this study, minimum dietary requirements. The shadow price of the minimum dietary needs was then obtained as the Lagrange multiplier of the dietary constraint at the optimal level (e.g. de Bruyn et al. 2010).

SASM is divided into three spatial layers: the local level with 95 local regions where primary production takes place, the regional level with six market regions where dairies and slaughter houses are also located, and the national level for trade in inputs such as fertilisers and fuel. The local division is based on homogenous conditions regarding climate conditions, and each local region is represented as a large farm with 14 animal products and 32 crop, fruit and vegetable products for both conventional and ecological farming. The 95 local regions interact with each other and with consumers in six different market regions. Depending on the relationship between demand and supply, trade occurs between the market regions and internationally, which incurs a transport cost. The model is static, and all simulations are made with the current production technologies in the food sectors.

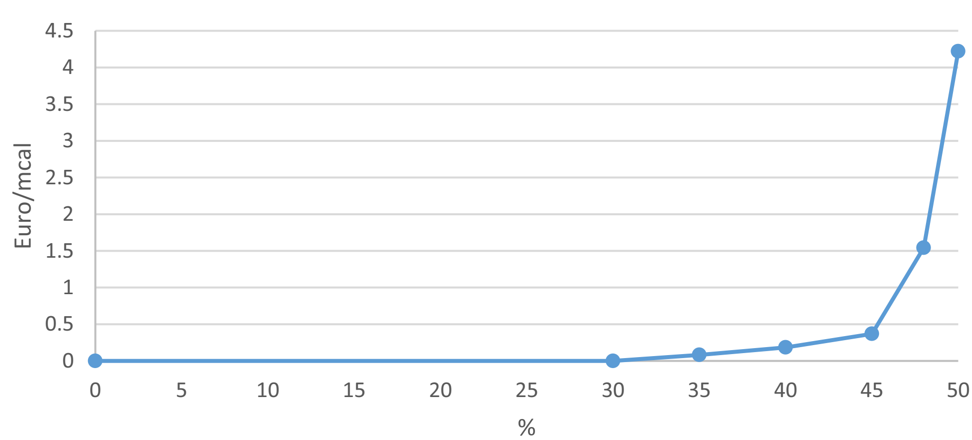


Fig. 4 Shadow price of minimum energy consumption of 2450 kcal/person/day under different crisis pressures in terms of % decrease in the imports of agricultural inputs and consumption foods

Table 2 Calculated value of game animal populations under different crisis pressures (million euros)

Animal	Crisis pressure:				
	35	40	45	48	50
Moose	4.32	9.57	19.21	80.34	219.72
Roe deer	4.21	1.54	3.10	12.96	35.45
Wild boar	0.67	9.39	18.86	78.11	215.41
Fallow deer	9.90	1.49	2.99	12.50	34.18
Total	9.90	21.99	44.16	183.91	504.76

The shadow price was calculated at the actual consumption of game animals, which corresponds to 0.34% of the minimum calorie needs. The calculations with the sector model showed that the shadow price is zero at crisis pressures below 30%. Although such decreases will affect the equilibrium prices of the inputs and consumption foods, a marginal change in the dietary constraint has no impact on the optimal solution since the energy provision exceeds the minimum dietary needs. However, with reductions in imports of both agricultural inputs and consumption foods exceeding 30%, the shadow price is positive (Fig. 4).

The shadow price ranged between € 0.1 and € 4.2/mcal. It rises rapidly for crisis pressures when trade is reduced by 45% or more from the base case.

Results: food security value of game animals

Given the data presented in the "Description of data" section, the food security value varied between € 0.1 and € 5.6/kg slaughter weight of moose, roe deer and fallow deer and between € 0.19 and € 8.30/kg slaughter weight of wild boar. The total value of different game animals then depends on the abundance of the animals and their energy content, ranging between 10 and 505 million euros depending on crisis pressure (Table 2).

Moose and wild boar accounted for the largest share of the total value under all crisis pressures because of their relatively large slaughter weight and, in the case of wild boar, their abundance.

The allocation of values between counties was characterised by relatively large values of wild boar in the south of Sweden and moose in the north (Fig. 5).

The total food security value was highest in Södermanland and Kalmar, where it amounted to 49 million euros. The lowest value was for Gotland, an island in the Baltic Sea east of Sweden, where there are populations of roe deer only. The results in Fig. 5 also show that wild boar accounted for approximately 30 million euros in Södermanland, Kronoberg and Kalmar county, and moose for the same amount in Jämtland.

Discussion

The estimated food security values of up to € 5.6/kg slaughter weight of moose, roe deer and fallow deer, and € 8.3/kg slaughter weight of wild boar can be converted into a maximum value per animal to give € 683/moose, € 67/roe deer, € 146/fallow deer and € 465/wild boar. These so-called stock values of the populations are higher or in the same order of magnitude as the recreational hunting values per animal of wild boar, roe deer and moose, but lower than that for fallow deer (Table 6 in Appendix 2).

However, the results rest on the underlying assumptions, data and parameter values. The calculation of the shadow price of the minimum dietary needs was based on a given

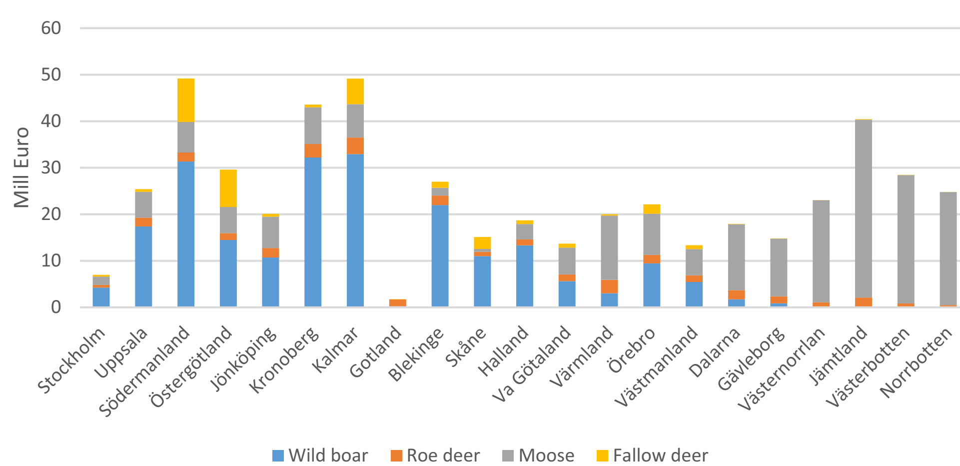


Fig. 5 Allocation of food security values between game animals and counties (millions of euros)

restriction. Andersson et al. (2022) showed that a reduction in the restriction by 10% reduces the cost for the food sector by approximately 30% at the highest crisis pressure. However, the same percentage increase in dietary need would not be feasible with current technologies in the food sector. Future technological development in the food sector is likely to increase production and thus reduce the shadow price of a given dietary constraint. Another assumption is that of perfectly competitive food markets in Sweden. In practice, this is not likely to be the case for all products because of the relatively large concentration of a few firms, particularly in the dairy and meat markets (Andersson et al. 2022). It is well known that distorted market competition raises the social cost of foods and other commodities, which may also increase the shadow price of the dietary constraint.

The calculation of game abundance was based on official statistics on AVC. According to Seiler and Jägerbrand (2016), the underreporting of accidents corresponds to approximately 15% of official statistics, and does not differ between the game animals. If this is correct, the population sizes and thus the calculated food security value would increase by 15%. The value was calculated at estimated current population sizes, and increases/decreases would then raise/reduce the calculated value. In the extreme cases of maximum population sizes, the total values could increase to approximately 1014 million euros based on calculations of carrying capacity levels (Table 5 in Appendix 2).

Another limitation of the current study is its focus on physical access to food. The economic access dimension was addressed by Nunes et al. (2019) who estimated a food security value of wildlife meat for local people in Amazonia as the income needed to replace game meat with bovine beef without a food supply crisis. The value was then estimated as the consumer price of bovine beef, which amounted to € 10.1 /kg consumption wildlife meat (at 2020 prices, adjusted for purchasing power parity).

The restricted physical access to food under the different crisis scenarios in the current study will raise the prices of food and thereby limit economic access to food for households with relatively low incomes. The wild meat consumed corresponds to 64% of slaughter weight (SBA 2023a), and the consumer prices in the base case without any crisis amount to € 10.8 /kg and € 6.5/kg for cattle and pigs, respectively (Säll and Gren 2015). Using the same approach as Nunes et al. (2019), the food security value of moose, roe deer and fallow deer in an economic access framework would then be at most € 16.9/kg consumption meat and for wild boar € 10.2 /kg consumption meat. However, these values can be up to 75% higher when considering price increases due to food shortages (Andersson et al. 2022). The economic access dimension of the food security value of game meat is then increased. This is of particular relevance for counties with an abundance of game meat but relatively low incomes. The results showed that Södermanland, Kalmar and Jämtland have an abundance of large game but relatively low economic performance, as measured by gross domestic product per capita, which is at least 20% lower than the average for Sweden (Swedish Statistics 2022).

Summary and conclusions

The purpose of this study was to calculate the food security value of game animals (moose, wild boar, roe deer and fallow deer) for Sweden overall and for its different counties. Two challenges were identified: the calculation of population sizes of the game animals included and the estimation of food security unit values. Population sizes at actual harvest levels were estimated using data on traffic load and animal vehicle accidents, and the shadow pricing method was used to calculate unit values of minimum dietary needs. Food security was defined in terms of minimum availability of kcal/person/day, and the shadow price per unit kcal was obtained with an agricultural sector model for Sweden. Crisis scenarios were measured as different decreases in the trade of agricultural inputs and foods.

The results showed that the game meat of the calculated animal populations could amount to approximately 9% of total meat consumption and 1.2% of minimum dietary needs. There was a wide variation in energy provision between counties based on population density and the abundance of game animals, particularly wild boar and moose, and ranged from 0.1% to 8.0% of the minimum intake of 2450 kcal/person/day. The results also showed that a marginal change in dietary constraint does not change the optimal net benefits from the agricultural sector for trade decreases up to 30% since production is above the dietary constraint, which implies that the shadow price is zero. Thereafter, the food security unit value, i.e. the shadow price, ranged between € 0.1 and € 4.2/mcal depending on crisis pressure.

Given the calculated animal populations and the calculated shadow prices of food security, the total food security value ranged between 10 and 505 million euros, depending on crisis pressure, and increased rapidly at crisis pressures exceeding a 45% decrease in trade. Moose and wild boar accounted for the largest shares of all values. The relative importance of moose was high in the north of Sweden with large moose populations, with the relative importance of wild boar high in the south of Sweden where there is an abundance of wild boar. It was shown that the value of game populations could increase by 118% if they were allowed to reach their maximum levels. However, the value of the stock over time depends on the harvest: a decrease in harvest from the actual levels increase the future stock and associated food security value because of larger reproduction, and vice versa. In the extreme case of a total elimination of the stock of game animals in an emergency crisis, the future food security value becomes zero since there is no reproduction.

The results highlight the possibility of managing wildlife populations to ensure the availability of game meat for the purposes of food security. One advantage over meat from livestock is the relatively simple storage facilities. However, it is well known that populations of game animals generate different types of costs (review in Gren et al. (2018)). Costs are borne by the forest and agricultural sectors from grazing, which can be in the same order of magnitude per animal as this study's calculated maximum food security values (Table 6 in Appendix 2). Similarly, the cost to society in general of AVC can be high, particularly for moose where the risk of a fatality is large (Table 6 in Appendix 2). The introduction of wildlife diseases, such as African swine fever with a high mortality rate for infected pigs, poses a threat to wild boar populations and domesticated pigs. The diseases generate costs to society in terms of the detection and prevention of spread and adaptation in the agricultural sector. Lost recreational values from a reduced harvest in order to increase the population constitutes another cost.

The efficient provision of minimum dietary needs requires a comparison of the net cost of preserving animal game populations with the net cost of other food security measures, such as holding emergency stocks of food and agricultural inputs, which would be an interesting topic for future research. Another field, which was not included in the current study, is the consideration of food security in the two interlinked dimensions of physical and economic access. Policies promoting physical access are likely to reduce economic access for some regions and households, which can be mitigated by compensation payments, for example, to exposed households or price regulations relating to critical foods.

Appendix 1. Derivation of traffic mortality coefficients

The relative change in population size is obtained by inserting Eq. (2) into Eq. (1) and dividing the expression with P_t^{wi}, which gives

$$\frac{P_{t+1}^{wi} - P_t^{wi}}{P_t^{wi}} = r^w\left(1 - \frac{P_t^{wi}}{K^{wi}}\right) - \alpha^w T_t^{wi} - \frac{H_t^{wi}}{P_t^{wi}} \tag{4}$$

Based on Eq. (2), the following equation is defined:

$$p_t^{wi} \equiv \alpha^w P_t^{wi} = \frac{AVC_t^{wi}}{T_t^{wi}} \tag{5}$$

By replacing P_t^{wi} in Eq. (4) with p_t^{wi} in Eq. (5), an expression is obtained that can be estimated with statistical methods on available data and allows for the derivation of the mortality coefficient:

$$Q_t^{wi} = \beta^{w1} + \beta^{w2} p_t^{wi} + \beta^{w3} T_t^{wi} + \beta^{w4} \frac{H_t^{wi}}{P_t^{wi}} + \varepsilon_t^{wi} \tag{6}$$

where $Q_t^{wi} = \frac{p_{t+1}^{wi} - p_t^{wi}}{p_t^{wi}}$ and ε_t^{wi} is the error term. The mortality coefficient is of main interest in this study and is given by $\beta^{w3} = \alpha^w$. The intrinsic growth rate can also be obtained from regression Eq. (6) as $\beta^{w1} = r^w$, and the coefficient of p_t^{wi}, $\beta^{w2} = \frac{r^w}{\alpha^w K^{wi}}$, allows the quantification of K^{wi}.

The coefficients in Eq. (6) were estimated by Gren and Jägerbrand (2019) with a random effect regression model on a panel dataset on counties during the period 2003–2015. Significant results at the 95% confidence interval were obtained for the average mortality coefficients, which are presented in Table 3.

Appendix 2. Tables 3, 4, 5 and 6 and Figs. 6 and 7

Table 3 Traffic mortality coefficients (per animal and million driven km), AVC and traffic load on average from 2016-2021, and calculated populations in Sweden.

Animal	Traffic mortality coefficient[a]	AVC, animals[b]	Traffic load, mill. driven km[c]	Population/ county[d]	Total for Sweden
Moose	0.00000607	5490	63725	14193	298054
Roe deer	0.0000307	47657	63725	24360	511564
Wild boar	0.00000445	6622	63725	23352	490389
Fallow deer	0.00000445[e]	3090	63725	10897	228828

[a]Gren and Jägerbrand (2019)

[b]NCW (2022)

[c]RUS (2022)

[d]AVC/(traffic load * mortality coefficient)

[e]assumed to be the same as for wild boar

Table 4 Traffic load, animal vehicle accidents with different game animals, annual average between 2016 and 2021

County	Traffic load[a], driven mill. km	Animal-vehicle accidents[b] Moose	Row deer	Wild boar	Fallow deer	Total
Stockholm	13154	234	4160	654	154	5202
Uppsala	2248	145	2310	459	40	2954
Södermanland	1867	224	1969	688	544	3425
Östergötland	2855	118	2258	486	716	3578
Jönköping	2465	417	2677	311	46	3451
Kronoberg	1355	280	2124	513	25	2942
Kalmar	1673	213	3209	648	288	4358
Gotland	386		710	1	1	712
Blekinge	1034	55	1151	267	42	1515
Skåne	8467	135	4200	1097	685	6117
Halland	2252	159	1527	353	57	2096
Va Götaland	10447	764	8226	691	290	9971
Värmland	1971	450	3075	70	18	3613
Örebro	1909	179	1879	212	121	2391
Västmanland	1719	82	1319	110	45	1556
Dalarna	2094	349	2231	42	7	2629
Gävleborg	1866	160	1496	19	3	1678
Västernorrland	1642	254	906	1	1	1162
Jämtland	945	457	1072	0	3	1532
Västerbotten	1656	407	728	0	3	1138
Norrbotten	1718	408	430	0	1	839

[a]RUS (2022)

[b]NCWA (2022)

Table 5 Calculated maximum population sizes (thousands of animals) and associated food security values under different crisis pressures (millions of euros)

Animal	Maximum population size	Crisis pressure: 35	40	45	48	50
Moose	596[a]	7	16	33	137	375
Roe deer	1023[a]	1	3	6	23	62
Wild boar	1226[b]	10	21	43	177	487
Fallow deer	572[b]	1	3	7	28	77
Total		22	48	97	402	1104

[a]Based on the assumption of current harvest at the maximum sustainable yield at the calculated population size, which implies that P^{Max} is twice as large (e.g. Tsikliras and Froese 2018)

[b]Maximum population about 150 % higher than the calculated size (Gren and Jägerbrand 2019)

Table 6 Recreational values of hunting and costs of traffic accidents, agricultural and forestry damage in Sweden (euros/animal at 2020 prices)

	Wild boar	Roe deer	Moose	Fallow deer
Recreational value[a]:				
Mensah and Elofsson (2017)	255			284
Engelman et al. (2018)	32	48	192	
Traffic accidents[b]	107	661	610	
Agricultural damage[c]	360			
Forestry damage [d]			379	

[a]Value per animal harvest

[b]probability of accident (AVC/total population in Table 3) times expected cost per AVC (weighted average of fatality, serious injury, mild injury and property damage) and animal from Gren and Jägerbrand (2019)

[c]wild boar cost of € 3000/farm (Gren et al. 2020) multiplied by the number of farms in Sweden of 58,791 (SBA 2023b) divided by the animal population size in Table 3

[d]Total damage cost of moose 113 million euros (Swedish Forest Agency 2019), divided by the calculated population size in Table 3

Fig. 6 Counties in Sweden. Source: www.lansstyrelsen.se

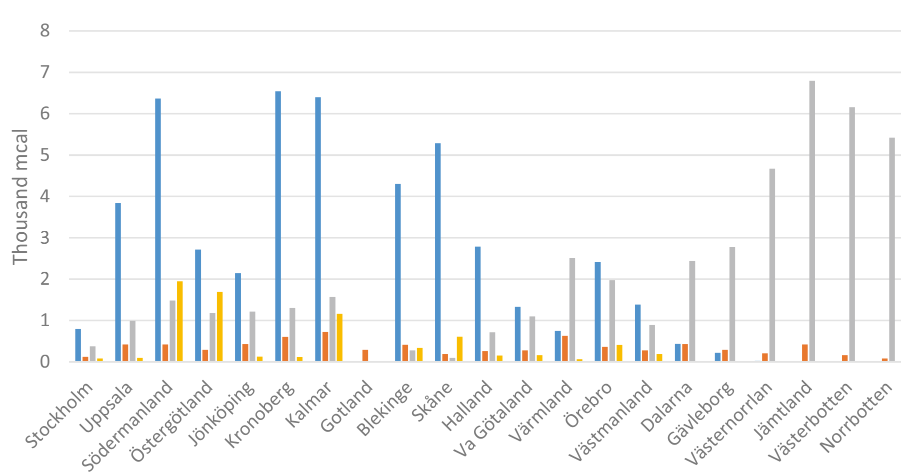


Fig. 7 Energy supply from estimated populations of game animals in Swedish counties (thousand mcal)

Author contribution All authors contributed to the investigation and design of the study. I.G. calculated game animal populations. L.J. was responsible for the calculation of shadow prices of constrains on dietary needs. All authors validated the results. I.G. wrote the first draft. All authors co-edited the manuscript and approved the final version for submission.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval No approval of research ethics committees was required to accomplish the goals of this study.

Competing interests The authors declare no competing interests.

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