The dynamics of the Eurasian lynx population in the county Västerbotten

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Abstract
As large carnivores are protected by law, management regimes must be implemented that keep populations of large carnivores at viable levels without causing extensive damage to domestic and semi-domestic livestock. The Eurasian lynx is one example of such a carnivore, and it has proven to be a pickle to manage. The population of lynx in the county Västerbotten fluctuates for unknown reasons and this increases the difficulty of management. The population size of lynx in Västerbotten is determined by the inventory of reproductive units, i.e. family groups. The aim of this thesis was therefore investigating the potential role of possible causative variables such as prey densities and abiotic factors. In addition, a model would be constructed in respect to any significant variables. With this model hunting pressures would also be tested, to investigate how different hunting pressures could possibly affect the population. The multiple regressions revealed a statistically significant relationship between the average snow depth and number of family groups (p: 0,014) and also a significant relationship with mountain hare densities within one region (p: 0,041). The model constructed added biological data such as potential number of lynx mothers and survival rates. However, the multiple regression revealed a stronger relationship than the model, suggesting that the number of family groups was independent of the number of potential mothers. This strong relationship between snow depth and number of family groups could be an important link in solving the management of the lynx population in the county of Västerbotten.

Key words: Population dynamics, Lynx lynx, management, modeling, Västerbotten.
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1 Introduction

An increasing amount of large felids suffer from exploitation. Their habitats are reduced at often alarming rates and at the same time they often are victims of illegal hunting.

The Eurasian lynx (*Lynx lynx*) is an example of a felid that globally is least concern according to the IUCN red list, but locally more vulnerable. It is included in the European Union’s Habitat Directive and therefore Sweden is obligated to follow this directive and ensure that the Eurasian lynx population is preserved at a viable state. As lynx predates on semi-domestic reindeer (*Rangifer tarandus*), roe deer (*Capreolus capreolus*) and to some extent other live stock, the conservation of this felid may cause large conflicts if not managed carefully. A balancing act must be performed to ensure that conservation of Eurasian lynx prevails parallel to the conservation of the Sami people’s traditional reindeer husbandry.

Since the start of annual lynx inventory in 1996 in Västerbotten, it has been observed that the number of reproductive units (family groups) of lynx fluctuates from year to year (Figure 1). These fluctuations can be problematic, especially when the numbers of family groups are not within the County Administrative Board of Västerbottens decided limits of family groups. It is important to find ways to maintain a viable population that falls within the set limits of family groups, to avoid as many conflicts as possible. Identifying the causes of these fluctuations may ease the management of this predator.

As the causation of these fluctuations is so far unknown, the aim of this thesis was to investigate different variables that may cause these fluctuations and then model the population with respect to possible causes such as prey densities, hunting pressure and abiotic factors.

In a historical context, an interesting example of a more extensively studied population dynamics in the Lynx genus is the classic example of the cyclic dynamics between the Snowshoe hare (*Lepus americanus*) and the Canadian lynx (*Lynx canadensis*). There, a clear relationship between the densities of snow shoe hare and densities of Canadian lynx has been found, leading to years of studies and models based on the data from these two species (Krebs, 2011). However, as the ecology of the Eurasian lynx and the Canadian lynx differs a bit, there may be few similarities between these two species in this aspect.

![Family groups of Lynx](image_url)

Figure 1. Number of reproductive units based on inventory results in Västerbotten from 1996-2015, with family groups on the y-axis and year on the x-axis.
2 Method

2.1 Study species

The Eurasian lynx is the largest species within the Lynx genus. It is as most other felids, a solitary organism, except during mating and when the females raise their kittens. They are territorial, with female territories ranging between 135 and 440 km² and male territories ranging between 440 and 1270 km² (Schneider, 2006). The preferred habitat is forest habitats, with an uneven terrain that offers several retreats (Schneider, 2006). Eurasian lynxes are long lived, and both captive and wild individuals have been observed to reach 17 years (Schneider, 2006). Even if such high ages are exceptional, adult lynx do have a low mortality, at least if only natural causes are included (Andrén 2006). The survival rate for the other age classes is generally lower for the lynxes in age class 1-2 and lowest for the lynxes in age class 0-1 (Andrén et al. 2006). Lynx can reproduce when they reach the age of 2 years, but the reproductive rate of 2 year olds is lower than the reproductive rate of older individuals (Nilsen et al. 2012). In the current study area, mating takes place in late February/early March. The pregnancy lasts for about 70 days, and kittens are born in May/June (Schneider 2006). The number of kittens per litter has an optimum at about two kittens per litter (Gaillard et al. 2014). They stay with the mother through summer, fall, and most of the winter (Figure 2). Therefore, the number of females with kittens can be estimated from tracks in the snow in the period just before the mating season: tracks of multiple individuals at the same place are almost certainly tracks of mothers with her offspring from the previous year.

![Figure 2. A time line demonstrating a year in the lives of Eurasian lynxes.](image)

As all felids, it is a strict carnivore. Estimates of prey included in Eurasian lynxes diet have been made during snow tracking and GPS-tracking, where leftovers of lynxes victims were tracked down (Sunde et al. 2000, Odden et al. 2006, Mattisson et al. 2011). It is an opportunistic generalist predator, but specialized in medium sized ungulates (Odden et al., 2006, Mattisson et al. 2011). This is one of the major differences between the Eurasian lynx and the Canadian lynx, since the Canadian lynx is an extreme specialist, and almost exclusively predate on snow shoe hares (Krebs, 2011). Examples of medium sized ungulates predate on by the Eurasian lynx would be roe deers and semi-domestic reindeers. A third, less common prey species is the mountain hare (Lepus timidus). Additional prey species include grouse (Tetrao sp, Tetrastes sp and Lagopus sp) and rodents (Microtus sp, Myodes sp and Sorex sp) (Sunde et al. 2000, Odden et al. 2006, Mattisson et al. 2011). As revealed by
The different proportions of prey can vary. Variations depend mostly on the preys occurrence in an area. If roe deer are available, they will be a very large proportion of the lynxes diet, even at low densities of roe deer (Odden et al. 2006). The kill rate on roe deer by lynx is relatively high, and the kill rate may increase with abiotic factors such as snow depth (Nilsen et al. 2009). However, if no roe deer are present in the area, lynx will depend on reindeers, mountain hares and grouse (Odden et al. 2006, Mattisson et al. 2011). And as the reindeers migrate throughout the season, other prey densities become important for the maintenance of the lynx population such as mountain hares, grouses, rodents and red foxes. Red foxes are known to be included in the lynx diet, but they won’t necessarily feed on red foxes they have killed (Helldin et al. 2006). Rodents such as voles and shrews have been proposed as alternative prey for lynxes (Sunde et al. 2000, Mattisson et al. 2011), it may however be hard to estimate how many they eat as they most probably eat the whole animal and therefore leave few evidence of consumption.

Table 1. Estimated proportions of different prey in Eurasian lynxes diet, based on data from Odden et al. 2006 and Mattisson et al. 2011.

<table>
<thead>
<tr>
<th>Prey</th>
<th>Estimated proportions of diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reindeer</td>
<td>6-86%</td>
</tr>
<tr>
<td>Roe deer</td>
<td>0-71%</td>
</tr>
<tr>
<td>Mountain hare</td>
<td>8-34%</td>
</tr>
<tr>
<td>Grouse</td>
<td>0-30%</td>
</tr>
<tr>
<td>Red fox</td>
<td>1-6%</td>
</tr>
<tr>
<td>Rodents</td>
<td>0-1%</td>
</tr>
</tbody>
</table>

Even when examining a simplified trophic web (Figure 3), it is apparent that there are several factors that are involved in the Lynx’s population dynamics. As fluctuating prey densities may very well cause fluctuations in the predators population (as for example in the Canadian lynx-Snow shoe hare case), it is important to include the potential resources for Eurasian lynx when investigating the observed fluctuations. One perhaps particularly interesting relationship is the one between the Eurasian lynx and the red fox, as they may both compete for prey and at the same time the lynx may predate on the red fox (Helldin et al. 2006).
An important threat to remember is the occurrence of illegal hunting. The otherwise high survival rate of adult lynx decreases rapidly if poaching is included, and has been stated as one of the main causes of adult lynx mortality (Andrén et al. 2006). Illegal hunting can be hard to detect without extensive monitoring, and the number of lynxes that are illegally shot are not well documented in Västerbotten (Schneider 2006). However, illegal hunting is not the only cause of mortality in lynxes. Natural causes such as starvation, lethal interactions with other carnivores and sarcoptic mange all occur in lynxes in Scandinavia. Lynx males may also lethally injure other males during the season of reproduction (Andrén et al. 2006, Mattisson et al. 2013). Another common cause of death is legal hunting, a consequence of the current management regime. But a large portion of lynx mortality is due to unknown causes, especially in the youngest age class. More than 70% of the mortality in both male and female (0-1 years old) was classed as unknown by Andrén et al. in 2006.

2.2 Study area
The study area consists of the county of Västerbotten. It is the second largest (55 000 km²) and second most northern county in Sweden 64°20′41″N 18°18′51″Ö (Figure 4). The area of Västerbotten was divided into three different regions (A, B and C), based on climate, infrastructure, the density of the human population and other parameters. C is the coastal region, B the central region and A is the region closest to the Norwegian border (Figure 2). The topography is varied, with an alpine region in the west on the border to Norway and gradient of boreal forests down to the coast of the Baltic Sea, and a scattered distribution of exploited forests in the central region. This division has been used in management of brown bears (Ursus arctos) in Västerbotten, but is also applicable on Eurasian lynx (Schneider, 2015). Dividing the area of Västerbotten enabled an analysis based on more specific variables, as the number of family groups are not evenly distributed over the county.

Figure 4 The three different regions used in Västerbotten, the black lines marking different hunting districts with a smaller map showing where in Sweden the county of Västerbotten can be found. Illustrations from the County administrative board of Västerbotten.
2.3 General method
To investigate what variables could have an impact on the number of family groups from year to year, multiple regressions were performed with a number of potential explanatory variables in relation to the number of family groups.

2.4 Lynx inventory
Data on lynx was obtained from the County Administrative Board of Västerbotten and was based on results from annual inventories of lynx. The inventory consists of snow tracking and is performed in January-February, before the kittens have left their mother. Since the lynx is a solitary animal with strict territories (Saether et al. 2010), snow tracks that seem to be from a group of lynx rather than only one individual can be assumed to be from a family group. These tracks are followed and counted, and then from those results the number of family groups can be estimated.

2.5 Prey densities
The prey densities for red fox, roe deer, capercaillie, hazel grouse and mountain hare were assessed using the quantities of each specific species that was shot in the different hunting districts of Västerbotten, which was received from the Swedish Association for Hunting and Wildlife Management. These quantities are not direct estimates of the number of individuals present in each species, but are often used as indicators of the densities of these species (Nilsen et al. 2009, Sunde et al. 2000).

2.6 Rodent densities
Densities for the species were obtained from the monitoring of small rodents and lemmings within the Swedish National Environmental Monitoring Programme. These densities are based on the results from about 3000 traps spread over a 100 km² large area in Västerbotten. The traps are evenly distributed over a grid in the area. The traps are baited and used during two periods each year, May-June and August-September. For the time series analysis an average value for each year was used, based on the two periods for each year. As the data for rodents is taken from only one area in Västerbotten, this data was excluded from the multiple regressions performed on the three different areas.

2.7 Reindeers
The number of reindeers was downloaded from the internet pages of the Sami Parliament, and is based on the sums of reindeers in the herds that live in Västerbotten. As the data for reindeers is simply the sum of all reindeers in Västerbotten, and not from specific areas, this data was excluded from the multiple regressions performed on the three different areas. Since the herds of reindeer move across the area of Västerbotten, spending the summers in the mountain region, the winters in the coastal region and only brief periods of time in the central region during the spring and fall they were not included in the regional multiple regressions (Saether et al. 2010, Schneider 2015).

2.8 Snow depth
Snow depth data was downloaded from the Swedish Meteorological and Hydrological Institute (SMHI, 2015). The snow depth data was collected from different weather stations from all over Västerbotten. To estimate the average snow depth, a script in R was written, which collected the values >0 m between 1/7 one year until the 1/7 the next year, and from those values an average snow depth for each winter could be estimated. So for an example,
the average snow depth for the winter 1996 was based on values from 1/7-1996 until 1/7-1997.

2.9 Mange

Number of cases of mange in lynx was obtained from SVA, based on collected deceased lynx from Västerbotten who have been sent to the SVA and autopsied to determine the cause of death. As no cases of mange had been found in lynx from Västerbotten during the time period 1996-2015, mange was excluded from the analysis.

2.10 Time series analysis

Since the inventory of lynx family groups are performed in January-February, they only include the kittens from the reproduction the previous year. Therefore when analyzing the time series, the lynx inventory results were compared to the prey densities and snow depth data from the previous year, since that would reflect the number of prey available and the snow depth during the kittens first year. Prey densities for roe deer, red fox, capercaillie, mountain hare and hazel grouse were only available from the time period of 1997 – 2013, so only lynx inventory results from 1998 and forwards could be used.

2.11 Multiple regression

Four multiple regressions were performed in Microsoft Excel 2007, one for the entire area of Västerbotten and one for each subsection of the county to see if any statistical relationship could be found between the lynx population and one or more of the potential explanatory variables (table 1).

Table 1. The variables used in the multiple regressions. Variables in italics only used in the regression for the whole area of Västerbotten.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Independent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynx</td>
<td>Roe deer</td>
</tr>
<tr>
<td></td>
<td>Red fox</td>
</tr>
<tr>
<td></td>
<td>Mountain hare</td>
</tr>
<tr>
<td></td>
<td>Capercaillie</td>
</tr>
<tr>
<td></td>
<td>Hazel grouse</td>
</tr>
<tr>
<td></td>
<td>Average snow depth</td>
</tr>
<tr>
<td></td>
<td>Reindeers</td>
</tr>
<tr>
<td></td>
<td>Rodents (Field vole, Bank vole and Grey red-backed vole).</td>
</tr>
</tbody>
</table>

2.12 Model

In addition to the multiple regressions, a discrete model was constructed, incorporating variables that had statistically and/or biologically significant relationships with the number of family groups. The model was constructed in Microsoft Excel. Only females were modeled, as males are assumed to be unlimited and also there was mostly data on females. Since females cannot reproduce until they are two years old (Nilsen et al., 2012), an age structure was added to the model. The number of juveniles, \( J^t \), at time \( t \), is determined by the number of adult females \( A^t \), at time \( t \) and the fraction \( f \) of adult females that reproduces at that time, \( f^t \):

\[
Equation 1. J^t = A^t * f^t * 1
\]

The factor 1 indicates that the expected number of juveniles per reproducing female is two (Gaillard et al. 2014), so that the expected number of female offspring is one. The fraction of
reproducing females was assumed to have a linear relationship with the average snow depth $D_s$ at time $t$, $D_s^t$:

\[ f^t = c \cdot D_s^t + d \]

Where $c$ and $d$ are the unknown parameters of the linear relationship between $f$ and $D_s$. The survival rate of juveniles, $S_j^t$, at time $t$, was also assumed to have a linear relationship with snow depth:

\[ S_j^t = a \cdot D_s^t + b \]

Where $a$ and $b$ are unknown parameters of the linear relationship. The number of adult female lynx’s the following year, $A^{t+1}$, was a result of the previous year’s number of females plus the previous year’s number of subadult female lynx’s, $T^t$, and the number of known shot (adult and subadult) females that year, $H^t$, subtracted, multiplied with a fixed survival rate, $S$ (equation 4):

\[ A^{t+1} = (A^t + Su^t - H^t) \cdot S \]

The numbers of known shot females were based on real data. By later replacing the number of adult female individuals shot, $H^t$, with different values, a sense of how sensitive the modeled population was to hunting could be provided. The number of subadult female lynx’s the following year was a result of the fraction of juveniles who survived their first year, $S_j^t$ (equation 5):

\[ Su^{t+1} = f^t \cdot S_j^t \]

For a glimpse of how the model looked in Microsoft Excel, see table 4.

The above equations assume that the number of adult and subadult females ($A$ and $Su$) are known for the first year of the analysis, but these numbers are unknown. Therefore, the initial number of adult and subadult females was calculated by using average proportions of each age group (based on Andrén et al. 2002, table 3) on the total population of lynx’s (equation 6). Number of family groups multiplied with 6.14 produces a rough estimate on the number of lynxes in the total population (Andrén et al. 2002). Adding or subtracting with 0.44 (standard error) gives the maximum or minimum of lynxes in the estimated total population, this was however not implemented in this model and only the mean (Family Groups * 6.14).

\[ \text{Equation 6. Total population} = \text{Family Groups} \cdot 6.14 \pm 0.44 \text{ (Andrén et al 2002)} \]

Thus, five unknown parameters remained: the relation between snow depth and juvenile survival/reproduction rate, governed by parameters $a$, $b$, $c$, $d$, and survival rate $S$. To find these values the add-in Solver in Microsoft Excel was used. The Solver enables the search for unknown parameters, by using a goal cell and adjustable parameters. The goal cell can be set to a specific value, or to be as low (or high) as possible with the adjustable parameters given.

\[ \text{Equation 7. } \Sigma(\text{Expected value produced by model} \cdot 2 - \text{Observed from inventory results})^2 \]

The sum of equation 7, with the expected values being the number of kittens the model produced for each year and the observed values the actual number of kittens from inventory results was calculated and set as goal cell in Solver, and the goal cell was set to be as low as possible, minimizing the difference between the observed number of kittens and the expected number of kittens. Then the parameters $a$, $b$, $c$, $d$ and $S$ were set as adjustable parameters, and with that the Solver could produce values for the unknown parameters $a$, $b$, $c$, $d$ and $S$. 

7
Table 2. The estimated proportions of females in populations (Andrén et al. 2002)

<table>
<thead>
<tr>
<th>Age class (years)</th>
<th>Sarek</th>
<th>Hedmark</th>
<th>Bergslagen</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>21,09%</td>
<td>18,18%</td>
<td>25,68%</td>
<td>21,65%</td>
</tr>
<tr>
<td>1-2</td>
<td>10,16%</td>
<td>16,67%</td>
<td>9,46%</td>
<td>12,9%</td>
</tr>
<tr>
<td>&gt;2</td>
<td>13,28%</td>
<td>19,7%</td>
<td>12,16%</td>
<td>15,4%</td>
</tr>
</tbody>
</table>

Table 3. The model in its Excel form, with the initial values and only the two following years presented here.

<table>
<thead>
<tr>
<th>Year</th>
<th>A</th>
<th>Su</th>
<th>f</th>
<th>J</th>
<th>Sj</th>
<th>S</th>
<th>H</th>
<th>Snow depth&lt;sub&gt;t&lt;/sub&gt; (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>41</td>
<td>33</td>
<td>c+Snow depth&lt;sup&gt;x&lt;/sup&gt; * d</td>
<td>A&lt;sup&gt;t&lt;/sup&gt;*f&lt;sup&gt;x&lt;/sup&gt;</td>
<td>a+Snow depth&lt;sup&gt;t&lt;/sup&gt; * b</td>
<td>0.89</td>
<td>0</td>
<td>0.5974</td>
</tr>
<tr>
<td>t+1</td>
<td>(FA&lt;sup&gt;t+1&lt;/sup&gt;*F&lt;sup&gt;T-H&lt;sup&gt;h&lt;/sup&gt;&lt;/sup&gt;) * S</td>
<td>J&lt;sup&gt;t&lt;/sup&gt;* Sj</td>
<td>c+Snow depth&lt;sup&gt;t+1&lt;/sup&gt; *d</td>
<td>A&lt;sup&gt;t+1&lt;/sup&gt;*f&lt;sup&gt;t+1&lt;/sup&gt;</td>
<td>a+Snow depth&lt;sup&gt;t+1&lt;/sup&gt; *b</td>
<td>0.89</td>
<td>5</td>
<td>0.4929</td>
</tr>
<tr>
<td>t+2</td>
<td>(FA&lt;sup&gt;t+2&lt;/sup&gt;*F&lt;sup&gt;T-H&lt;sup&gt;h&lt;/sup&gt;&lt;/sup&gt;) * S</td>
<td>J&lt;sup&gt;t+2&lt;/sup&gt;* Sj</td>
<td>c+Snow depth&lt;sup&gt;t+2&lt;/sup&gt; *d</td>
<td>A&lt;sup&gt;t+2&lt;/sup&gt;*f&lt;sup&gt;t+2&lt;/sup&gt;</td>
<td>a+Snow depth&lt;sup&gt;t+2&lt;/sup&gt; *b</td>
<td>0.89</td>
<td>1</td>
<td>0.4882</td>
</tr>
</tbody>
</table>

3 Results

3.1 Multiple Regressions

Not all of the multiple regression performed revealed statistically significant relationships between the dependent variable (number of family groups) and the various independent variables. In the multiple regression performed on the variables for all of Västerbotten the independent variable average snow depth (Figure. ure. 5) was significant (p=0.014). This was however not the case for A, the mountain region nor C, the coastal region, where no significant statistical relationships could be found. However, two statistical significant relationships could be found in the multiple regression performed on the variables for B, the central region. There the independent variables mountain hare (p=0.041) and snow depth (p=0.012) were significant (Figure. ure. 6 and 7). For the regression graphs, see appendix. The revelation of these statistically significant relationships indicate that the average snow depth and potentially also the density of mountain hares could be relevant to include in a model of the lynx family groups in Västerbotten.
Figure 5. The number of family groups and the average snow depth for all of Västerbotten. The number of family groups (primary axis), shown as the black line with diamonds and the average snow depth in meters (secondary axis) shown as the blue line with squares. The year is on the x-axis.

Figure 6. The number of family groups and the average snow depth for B, the central region. The number of family groups (primary axis), shown as the black line with diamonds and the average snow depth in meters (secondary axis) shown as the blue line with squares. The year is on the x-axis.
Figure 7. The number of family groups and the densities of mountain hares for B, the central region. The number of family groups (primary axis), shown as the black line with diamonds and the density of mountain hares (secondary axis) shown as the orange line with triangles. The year is on the x-axis.

3.2 Model

The model produced numbers of female juveniles that followed the number of observed female juveniles (Figure 8). The model produced a reproductive rate ranging between ~0.53 and ~0.65, an adult survival rate at ~0.90, and a juvenile survival ranging between ~0.31 and ~0.36 (Table 5). Increasing the number of females shot each year with 1 more individual caused an evident decline in the population and extinction after 16 years (Figure 9). If the hunting was based on a percentage of the number of females, the population responded differently. If the number of females shot was 10% of the number of adult females, the population was steady and the number of adult females ranged between 41 and 43 individuals (Figure 7). However, shooting more than 10% caused an instant decline, and the number of adult females sunk to less than half of the initial value (Figure 9). Adding a threshold to the proportional number of adult females shot still caused a decrease in the population, unless the threshold was set high (threshold at 40 individuals).
Figure 8. Number of female juveniles each year. Light grey squares are the expected values produced by the model, dark grey diamond’s the number of female juveniles based on inventory results (number of juveniles divided by two). The year is on the x-axis, the number of female juveniles on the y-axis.

Table 4. The results for the different parameters and variables produced by the model. The numbers have been rounded to 2 decimals.

<table>
<thead>
<tr>
<th>A</th>
<th>S</th>
<th>f</th>
<th>J</th>
<th>s_j</th>
<th>s</th>
<th>H</th>
<th>snow depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>33</td>
<td>0.65</td>
<td>26.69</td>
<td>0.35</td>
<td>0.90</td>
<td>5</td>
<td>0.59</td>
</tr>
<tr>
<td>40.68</td>
<td>9.29</td>
<td>0.62</td>
<td>25.33</td>
<td>0.35</td>
<td>0.90</td>
<td>1</td>
<td>0.49</td>
</tr>
<tr>
<td>43.55</td>
<td>8.8</td>
<td>0.62</td>
<td>27.07</td>
<td>0.36</td>
<td>0.90</td>
<td>2</td>
<td>0.49</td>
</tr>
<tr>
<td>46.06</td>
<td>9.72</td>
<td>0.65</td>
<td>30.06</td>
<td>0.33</td>
<td>0.90</td>
<td>8</td>
<td>0.60</td>
</tr>
<tr>
<td>43.23</td>
<td>10.07</td>
<td>0.59</td>
<td>25.43</td>
<td>0.34</td>
<td>0.90</td>
<td>9</td>
<td>0.37</td>
</tr>
<tr>
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4 Discussion

4.1 Multiple regression

The results from the multiple regressions suggest that there may be a relationship between number of family groups and the average snow depth (Figure 3, Figure 5), and also a relationship between the number of family groups and density of mountain hares in B, the central region (Figure 4). No relationships could be found within region A and region C. Perhaps the number of family groups within A and C, the mountain and coastal region, were too small (average number of family groups in region A~9,2 , B~16,4 and C~2,6), complicating the search for evident trends. Also the density of mountain hare is largest for the central region (average density of mountain hares in region A~1041, B~3513 and C~2232), increasing the sample size.

However, this would not explain why a relationship between number of family groups and mountain hare density could be found for only B, the central region but not for all of Västerbotten. This may indicate that the density of mountain hare is more important for the lynx in this specific region. One reason could be the relatively short periods of time that the reindeer herd spends in the central region compared to the two other regions, which could cause the lynx to be more dependent on other resources of prey (Schneider, 2015). It is also not unreasonable that mountain hare is relevant for lynx’s survival (and more specifically also juvenile survival), as mountain hares are one of the prey densities that increase in importance for the lynx population (in the absence of medium sized ungulates)(Sunde et al. 2000, Mattisson et al. 2011, Odden et al. 2006)

Nilsen et al. 2009 found that there could be a positive relation between lynx’s kill rate on roe deer and abiotic factors, such as snow depth. That is partly because lynx has a relatively low sinking depth in snow, in comparison to roe deer (Nilsen et al. 2009). This could support the
result of a statistical relationship between number of family groups and average snow depth, indicating that the average snow depth has a positive effect on juvenile survival.

4.2 Model

It is important to remember that the Solver add-in of Microsoft Excel has no concept of what values that are biologically sensible. So the biological concepts must be added in the interpretation of these values. The reproductive rates produced by the model were not unreasonable, as the reproductive rates in female lynx has been estimated to between ~0.69 and ~0.90 (Nilsen et al. 2012). An addition that could be made to the model is a separate age category for 2 year old females, as the fraction reproducing at that age differs from the fraction reproducing at an higher age (Nilsen et al., 2012). This is something that could improve the model as it would better reflect the possible recruitment of new females to the population each year. The model produced a low female juvenile survival rate, ranging between ~0.31 and ~0.36. The survival of female juveniles is probably a bit higher, as it has been estimated to between ~0.407 and ~0.593 in female juveniles (Andrén et al. 2006).

One could argue that including a linear relationship between juvenile survival/fraction reproducing and snow depth is simplifying the system. But one could also argue that with the strong statistical relationship between the average snow depth and number of family groups (p= 0.014), it could in fact be quite reasonable to include snow depth in the model. Also, when constructing a model it seems reasonable to begin with a simpler relationship and then perhaps adding complexity that could better reflect what is actually going on. As the linear relationship in this model could produce a number of kittens that followed the observed numbers, it is perhaps not unreasonable.

The multiple regressions performed found a strong relationship between snow depth and number of family groups, but the results of the discrete model were weaker than the regression. What the discrete model has, and the multiple regressions has not, is the inclusion of number of females, suggesting that taking the number of potential mothers into account weakened the model. This could mean that perhaps the number of adult females isn’t limiting the population. Perhaps the number of territories with a sufficient snow depth instead is limiting, as the average snow depth seems to have such a strong relationship with the number of family groups.

What would be interesting to further investigate are perhaps the details of the statistical relationship between lynx and the average snow depth, more specifically how the average snow depth causes these effects on juvenile survival and reproduction rates. As previously mentioned, it has been found that the average snow depth can have a positive effect on lynxes kill rate of roe deer (Nilsen et al. 2009). Perhaps the average snow depth also has a positive effect on lynxes kill rates on other prey, facilitating juvenile survival rate and also the rate of reproduction.

Exchanging snow depth for another variable such as prey density could also be interesting, to further investigate what kind of impact different prey densities could have on the reproduction rate and juvenile survival. The positive effect of average snow depth on kill rates wouldn’t be very helpful unless there is anything there to kill. Adding another variable (constructing a model with linear plane equation) and thus including the average snow depth as well as a prey density could be valuable, but makes the model instantly more complex, and the number of unknown parameters will increase (equation 8).

Equation 8. Juvenile survival = a * Snow depth + c * prey density + b

The testing of how sensitive the model was to hunting revealed that a low hunting quota based on a percentage of the number of adult females could be very stable. But this requires
extensive knowledge of how many lynxes there actually are in the population. As the estimation of lynx population sizes is only based on inventory of family groups, it may be hard to estimate the actual population size. Increasing the number of individuals shot with only one caused a rapid decline and ultimately extinction. This could be alarming, as the number of lynxes illegally hunted is not known in Västerbotten, and it isn’t impossible to imagine that the illegal hunting exceeds 1 individual per year. However, the model does not include any migration or immigration, so drawing conclusions of extinction may be extreme, since lynx in adjacent counties very well disperse to the county of Västerbotten. But the opposite could also occur, so even though one year seems to have a large number of family groups, does not necessarily mean that the kittens will stay within the county. Dispersal rates could perhaps be a valuable addition to future models.

Saether and colleagues found in 2012 that the best harvest method for Eurasian lynxes in Norway was either a threshold or proportional threshold strategy than only a proportional strategy. However, an addition of a threshold to the model constructed in this thesis did not do much of a difference. The model was more sensitive to increasing the proportion of adult females shot. Adding a threshold still caused a decrease in the population, unless the threshold was set high (>40) and the proportion shot was <10% of adult females.

4.3 Conclusion

As the multiple regressions revealed a statistically significant relationship between the number of family groups and average snow depth, this should be further investigated for longer time periods but also if this relationship can be found in other locations than the county of Västerbotten. In the perspective of management, the average snow depth should perhaps not be overlooked when deducting the optimum number of individuals that may be shot without causing harm to the system.

5 Acknowledgements

To Michael Schneider for asking something I wanted to investigate, Folmer Bokma for the help and support, Julia and Amanda for encouragement and insightful discussions and finally all members of the Felidae for being awesome.

6 References

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Appendix 1

Snow depth Regression

Regression graph for the statistical relationship between number of lynx family groups and average snow depth for the whole area of Västerbotten.

Snow depth regression

Regression graph for the statistical relationship between number of lynx family groups and average snow depth for B, the central region.
Regression graph for the statistical relationship between number of lynx family groups and mountain hare densities for B, the central region.