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Re-evaluation of distance criteria for classification of lynx family groups in Scandinavia

NINA Report

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Abstract

Gervasi, V., Odden, J., Linnell, J.D.C., Persson, J., Andrén, H. & Brøseth, H. 2013. Re-evaluation of distance criteria for classification of lynx family groups in Scandinavia. – NINA Report 965. 32 pp.

Monitoring of lynx populations in Scandinavia have largely been based around unreplicated minimum counts of family groups. Observations are accumulated from October 1st to February 28th in all parts of Scandinavia. Distance rules are used to separate or cluster observations of family groups when observations cannot be separated from each other on the basis of back-tracking in the snow. The aim of this report was to present a description of movement patterns of female lynx across the Scandinavian Peninsula, and to re-evaluate distance rules for classification of lynx family groups.

The maximum distance travelled by lynx females rapidly increased with time, up to about 10 days, after which it flattened to an asymptotic value, which approximates home range diameter. This suggests that different distance criteria should be applied for each of the first 10 days after the first observation of a family group, whereas a unique value should be applied for all subsequent observations. We found large variation in movement patterns across Scandinavia, and we propose a classification of Scandinavia into 4 “eco-regions” based on predicted movement patterns. New distance rules for each of the four different “eco-regions” were calculated. Finally we provide an empirical validation of distance rules for the monitoring system. The distance rules are based on maximum travelled distances, and are therefore, by definition, conservative against the risk of overestimating the number of family units. The simulations showed that, while the estimator is unbiased when only one family unit occupies a given area, it becomes prone to underestimation when other neighbouring family units are present. The Swedish study sites had a higher probability of having neighbours compared to the Norwegian side, most likely as a result of a higher hunting pressure in Norway, and were therefore more likely to be affected by the risk of underestimating family units, when applying distance rules. We recommend that future data on the spatial arrangement of family units in Scandinavia should be used to validate these results. We also see a need for further evaluation of the distance rule method from areas where there are no movement data from GPS-collared female lynx in Scandinavia, and especially from areas in Sweden with high reported densities of family groups.

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Sammendrag

Gervasi, V., Odden, J., Linnell, J.D.C., Persson, J., Andrén, H. & Brøseth, H. 2013. Reevaluering av avstandskriterier for beregning av antall familiegrupper i Skandinavia. – NINA Rapport 965. 32 s.

Overvåking av gaupe i Skandinavia er i hovedsak basert på å registrere antall familiegrupper hver vinter. Observasjoner av familiegrupper samles inn kontinuerlig gjennom hele registreringsperioden fra 1. oktober til 28. februar. Ut fra alle bekreftede observasjoner blir det beregnet hvor mange familiegrupper som lever i Norge det enkelte år før jakta starter. Beregningene tar utgangspunkt i såkalte avstandskriterier (AK) som benyttes til å skille eller gruppere familiegrupper. Avstandskriteriene er basert på maksimale forflytningsavstander hos radiomerkede gauper i Skandinavia. Målet med denne rapporten var å analysere forflytningsmønsteret hos radiomerkede hunngauper samlet inn fra ulike deler av Skandinavia, og beregne nye avstandskriterier for klassifisering av familiegrupper gjeldene for hele Skandinavia.

De maksimale forflytningsavstandene hos hunngaupene økte raskt over tid, opp til 10 døgn, hvoretter forflytningsavstandene flatet ut til en asymptotisk verdi, som tilsvarer leveområdenes diameter. Basert på dette foreslår vi at ulike avstandskriterier benyttes for hver av de første 10 døgn etter første observasjon av en familiegruppe, mens en unik verdi benyttes for alle påfølgende døgn. Vi fant stor variasjon i forflytningsmønstre fra ulike deler av Skandinavia, og vi foreslår en klassifisering av Skandinavia til fire "øko-regioner". Vi beregnet nye avstandskriterier for hver av de fire "øko-regionene". Til slutt gjorde vi en empirisk validering av avstandskriteriene. Avstandskriterier er basert på maksimale forflytningsavstander og simuleringene viser at avstandskriteriene er konservative mot risikoen for å overestimere antall familiegrupper. Simuleringene viste videre at sannsynligheten for å underestimere antall familiegrupper øker med antall nabogrupper. De svenske studieområdene hadde høyere sannsynlighet for å ha flere nabogrupper enn de norske, sannsynligvis som følge av et høyere jakttrykk i Norge. Vi understreker at dette er simuleringer, og anbefaler en videre validering basert på forflytningsdata på nabogrupper i fra ulike deler av Skandinavia. Vi ser også et behov for en videre evaluering av avstandskriteriene med forflytningsdata fra områder der det til nå ikke er fulgt hunngauper med GPS-sendere i Skandinavia, og da spesielt fra områder i Sverige med høye rapporterte tettheter av familiegrupper.

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Contents

Foreword

The Norwegian Institute for Nature Research (NINA) and Grimsö Wildlife Research Station (the Swedish University of Agricultural Science, SLU) has since 1993 conducted research which for the last decade has been under the umbrella of a Scandinavian cooperation called Scandlynx. Scandlynx had been funded by the Swedish Environmental Protection Agency, the Norwegian Directorate for Nature Management, the Research Council of Norway, the Swedish Association for Hunting and Wildlife Management, the county environmental authorities from Hedmark, Oppland, Akershus, Østfold, Buskerud, Telemark, Troms and Finnmark counties (Norway), the Regional Management Board from Region 2, 3, 4 and 8 (Norway), the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas), the World Wildlife Fund (Sweden), and the Swedish University of Agricultural Sciences.

We are grateful to all the personnel who have helped in the field to capture lynx and collect the telemetry data that forms the basis of this analysis.

Trondheim, June 2013

John Odden (sign.) Jens Persson (sign.)

John Linnell (sign.) Henrik Andrén (sign.)

Scandlynx leader group

1 Introduction

Monitoring of lynx (*Lynx lynx*) populations in Scandinavia have largely been based around unreplicated minimum counts of family groups (adult females with dependent kittens) (Andrén et al. 2010; Brøseth & Tovmo 2012; Kjørstad et al. 2012). The Norwegian Directorate for Nature Management and the Swedish Environmental Protection Agency are presently reviewing the monitoring systems for large carnivores in Scandinavia, and in 2012 a committee developed a proposal for a standardised lynx monitoring methodology in Scandinavia (Kjørstad et al. 2012). The committee recommended that the annual monitoring of lynx populations in Scandinavia should still be based around unreplicated minimum counts of family groups, i.e. adult females with dependent kittens, given existing methods and present political population goals. Observations of family groups are to be accumulated all through the registration period from 1.October to 28.February in all parts of Scandinavia. When observations cannot be separated from each other on the basis of back-tracking in the snow or DNA, they recommended using distance rules to separate observations of groups that are so far apart that they are unlikely to be derived from the same group.

Lynx home range sizes vary dramatically within Scandinavia (Linnell et al. 2001; Herfindal et al. 2005). Linnell et al. (2007) developed distance rules for Norway based on movement data from VHF collared lynx females from 1994 to 2002 in two different areas in Sweden (Sarek and Bergslagen) and three areas in Norway (Nord-Trøndelag, Hedmark and Østfold/Akershus). Separate distance rules were made for 3 subjectively chosen “eco-regions” of Norway, areas with “low roe deer density”, areas with “high roe deer density”, and areas with “domestic reindeer herding”. Furthermore, Linnell et al. (2007) developed two different distance rules, (1) a dynamic distance rule - to separate between observations made temporally close to each other, and (2) a static distance rule – to be used on accumulated data from a whole season.

Since 2002 data on movement patterns of individual female lynx have been collected from larger parts of Scandinavia, also using new GPS-technology allowing a more intensive sampling effort compared to the VHF technique. In this report we present a description of movement patterns across the Scandinavian Peninsula based on data on movement patterns of individual female lynx from a large part of Scandinavia from 1994 to 2012. We re-evaluate the distance rules for classification of lynx family groups in Norway and Sweden, and propose a new classification of Scandinavia according to predicted movement patterns. Finally we provide an empirical validation of distance rules for the monitoring system.

2 Material and Methods

2.1 Study areas

This study is based on long-term research by the joint Swedish and Norwegian lynx research project Scandlynx (http://scandlynx.nina.no). Individual data obtained from female lynx with VHF radiocollars or GPS collars were collected from study areas across the Scandinavian Peninsula from 1994 to 2012 (**Figure 1**). The northernmost study area (“Troms/Finnmark”) consists of the northern parts of Troms County and the western parts of Finnmark County. The area is dominated by mountain birch forest (*Betula* sp.) and alpine tundra. The Sarek study area is partly located within the Sarek National Park around Kvikkjokk in the county of Norrbotten (67°00’ N, 17°40’ E) and consists of a mixture of coniferous forests, mountain birch forest and alpine tundra in mountainous terrain. In addition female lynx were followed scattered around the counties of Jämtland, Västerbotten and Norrbotten Counties (hereby called “Northern forested area”).

The “Hedmark study area” is located at the south-eastern edge of the Scandinavian mountain range in the central part of Hedmark County. The area is dominated by boreal forest with limited farmland along valley bottoms. The “Akershus” study area is situated southeast of the Norwegian capital, Oslo, in Oslo, Akershus and Østfold Counties. The area is similar to the Hedmark area although the proportion of farmland and human density is much higher and the topography is less hilly. The area called “Østafjells” is located west of Oslo in Buskerud, Vestfold, Telemark and Oppland Counties. The “Østafjells” area also encompasses a north-south gradient in topography and habitat structure, with the highest proportion of farmland in the south.

Most of the female lynx followed in the “Southern Sweden” study area were followed around Grimsö Wildlife Research Station in Bergslagen, south-central Sweden. In addition some females were followed further south towards the areas at the very south of Sweden. The Bergslagen area is dominated by coniferous forest, and the proportion of agricultural land is higher in the southern parts (about 20 %) and decreases towards the northern parts (< 1 % of the area). The areas south of Bergslagen are characterized by greater proportions of agricultural lands and greater densities of humans.

Semi-domestic reindeer (*Rangifer tarandus*) are the main prey in the 3 northern areas whereas roe deer (*Capreolus capreolus*) are the main prey of lynx in the 4 southern areas ((Pedersen et al. 1999; Odden, Linnell & Andersen 2006; Nilsen et al. 2009; Mattisson et al. 2011). Hares and birds are important secondary prey items in all study areas and, on the Norwegian side, free-ranging sheep are also available as prey in summer (Odden et al. 2002; Odden, Linnell & Andersen 2006). Red deer (*Cervus elaphus*) become an important secondary prey in the Østafjells area (Gervasi et al. Submitted). For further description of the study areas see Nilsen et al. 2012b and Samelius et al. 2012.

2.2 Lynx capture and collaring

Lynx were captured using several methods, including darting from helicopters, box-traps, foot-snares placed at fresh kills, and by using dogs to chase lynx into trees. The captured lynx were immobilized and equipped with a radio-collar or an implanted radio-transmitter, usually with a mortality function (Arnemo et al. 1999; Arnemo et al. 2006). The handling protocol for lynx has been examined by both the Swedish and the Norwegian Experimental Animal Ethics Committee and fulfills their ethical requirements for research on wild animals. From 1995 to 2006, most lynx were collared with VHF radio-transmitters. Lynx were radio-tracked at least 2-4 times per month, but normally more often. Since 2006 most lynx have been followed with GPS-GSM collars programmed to take from 1 to 48 positions per day.

2.3 Data analysis

The dataset used to calculate descriptive statistics about female lynx movement patterns in Scandinavia comprises 76 individual female lynx, all older than 2 years. Some individuals were followed for more than one winter, so that the total number of home ranges available for analysis was 110. Out of them, 64 belonged to female lynx with kittens, 46 to lynx without kittens. A linear regression analysis revealed no differences in the average distance travelled during the sampling period between females with and without kittens ($z = -0.593$; $p = 0.544$). Therefore, data were pooled for subsequent analyses. Statistics were calculated using locations between October 1st and February 28th. Out of 64 individual lynx, 10 were monitored in Hedmark, 8 in Akershus, 11 in Østafjells, 10 in Troms/Finnmark, 10 in Sarek, 16 in Jämtland, Västerbotten and Norrbotten län (outside Sarek), and 11 in Southern Sweden.

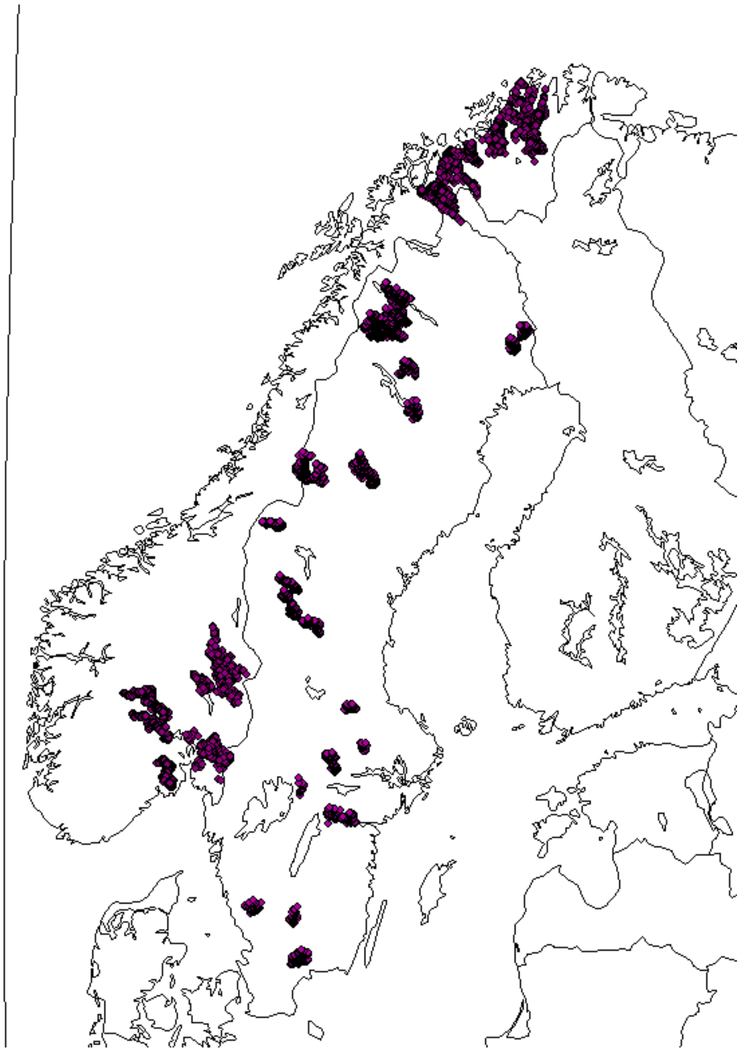

Figure 1*.Map showing locations of 76 radio-collared female lynx in Scandinavia*

First, for each individual and each day of monitoring, we selected the location closest in time to midday. Then, we calculated all linear distances between each location and all following locations for a given individual (day 1 – day 2; day 1 – day 3; day 1 – day 4 etc.). Finally, for each time interval (n. of days), we generated a histogram of the observed distances and calculated the 95th percentile of the distribution. Furthermore we plotted the observed 95th percentile values as a function of time. Histograms for each study area were also generated, to reveal variations in movement patterns across geographical areas.

The second objective of the study was to explain variation in movement patterns across Scandinavia, using broad geographical and ecological variables, in order to produce a map predicting such patterns. We divided the dataset into 2 main geographical areas:

1- Roe deer / red deer areas (Akershus-Østfold, Hedmark, Østafjells, Southern Sweden)
2- Reindeer areas (Central-Northern Sweden, Troms-Finnmark)

For each area and each individual, we calculated the asymptotic distance (95th percentile of the distribution derived from locations between 11-150 days), which was used as dependent variable. Then, we produced a set of competing linear regression models, explaining variation of such a variable among individual lynx. A Poisson GLM model was used, and individual lynx were included into the analyses using the number of monitoring years as weights, to account for pseudo-replication.

For the roe deer / red deer areas, the following explanatory variable were tested: roe deer density index (n. shot roe deer / km^2), red deer density index (n. shot red deer / km^2), prey density index (roe deer + red deer / shot km^2), prey biomass index (kg meat shot / km^2), altitude, latitude, study area. For all variables, linear, quadratic, logarithmic, and inverse relationship were tested. For both countries, we used average hunting bag statistics at the municipality level, available from Statistics Norway (www.ssb.no), as an index of local roe and red deer density. In particular, for each municipality we used the average number of roe and red deer shot during the period 2000-2010. We assumed that the spatial variation in hunting stats broadly reflected the variation in prey density. This assumption has previously been investigated and confirmed by Grøtan et al. (2005).

For the reindeer areas, the following explanatory variables were tested: latitude, longitude, altitude, study area. Also in this case, linear, quadratic, logarithmic, and inverse relationship was tested. The analysis for the reindeer areas was limited by the lack of explanatory variables describing prey or biomass density inside each lynx home range.

The last objective of the study was to use empirical data to validate the distance rules and estimate the expected success rate in classifying family units in Scandinavia. To this aim, we performed a set of Monte Carlo simulations for each of the 4 management regions (roe deer / red deer high biomass, roe deer / red deer low biomass, Southern reindeer areas, Northern reindeer areas). Simulations were run to assess how the structure of the lynx population and the characteristics of the sampling process can affect the effectiveness of classification criteria. In particular, we evaluated the effect of the number of days between family group observations, of the degree of overlap between neighbouring family units, and of the number of neighbouring family groups in a given area. Unfortunately, no empirical data were available about the average number of neighbouring family groups. Still, we expected this to be a function of several factors, such as home range size, lynx density, fecundity and kitten survival. Therefore, for each area we applied a theoretical model (Ferriere et al. 2004), based on a Poisson distribution of lynx home ranges in the study area, and predicting the number of neighbouring family groups in winter, based on lynx home range size, density, fecundity, and kitten survival in each study area, as shown in **table 2**. The predicted probability of having zero, one, and two neighbouring family units in each study area was then used as an input for the simulations.

For each of the 4 "eco-regions", we performed 3 sets of simulations:

1. Extracting data from only one home range at a time, thus testing the performance of the criterion when no neighbouring family groups are present;
2. Extracting data from two neighbouring home ranges at a time, thus testing the performance of the criterion when 2 neighbouring family groups are present;
3. Extracting data from three neighbouring home ranges at a time, thus testing the performance of the criterion when 3 neighbouring family groups are present;

For each set of simulated parameters, we ran 5000 iterations, and summarized the results in terms of success rate, underestimation rate, and overestimation rate.

3 Results

3.1 Description of movement patterns across the Scandinavian Peninsula

The expected maximum distance travelled by an individual lynx female rapidly increased with time, up to about 10 days, after which it flattened to an asymptotic value, which approximates home range diameter (**Figure 2**). This suggests that different distance criteria should be applied for each of the first 10 days after the first observation of a family group, whereas a unique value should be applied for all subsequent observations.

In **Figure 3-9** we have plotted histograms for each study area to reveal variations in movement patterns across Scandinavia. The histograms show a large variation in movement patterns across geographical areas. In particular, the asymptotic distance was 40 km in Hedmark, 23 km in Akershus-Østfold, 27 km in Østafjells, 22 in Southern Sweden, 34 in the Northern forested areas (AC – BD – Z), 33 in Sarek, 42 in Troms-Finnmark. Moreover, calculating the same histograms for the Swedish study areas, using only data from January and February, did not change the calculated asymptotic distances.

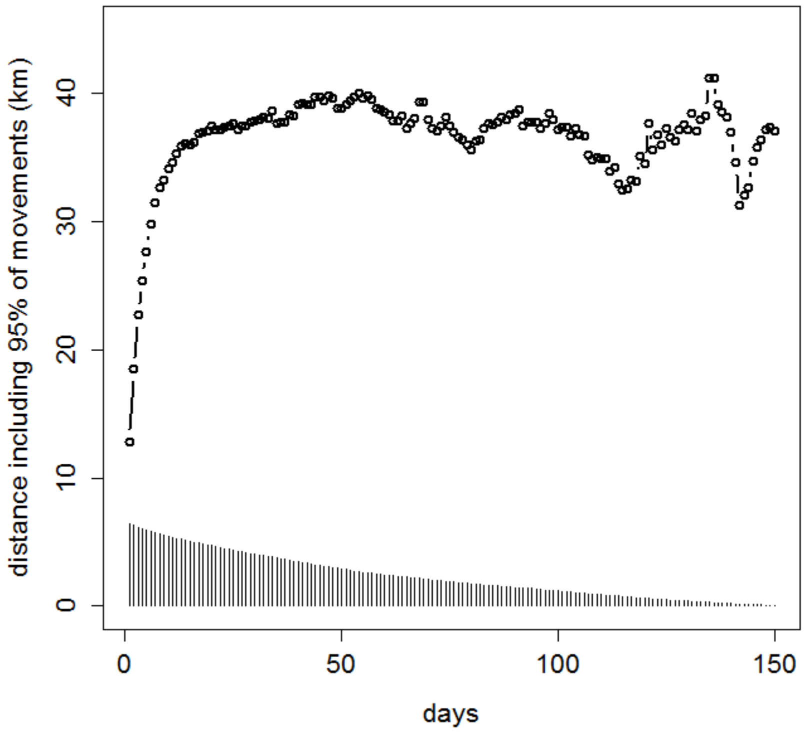

Figure 2. *The expected maximum straight line distance travelled by individual lynx females from 1 to 150 consecutive days. The bars at the bottom of the figure show the amount of data available for each day.*

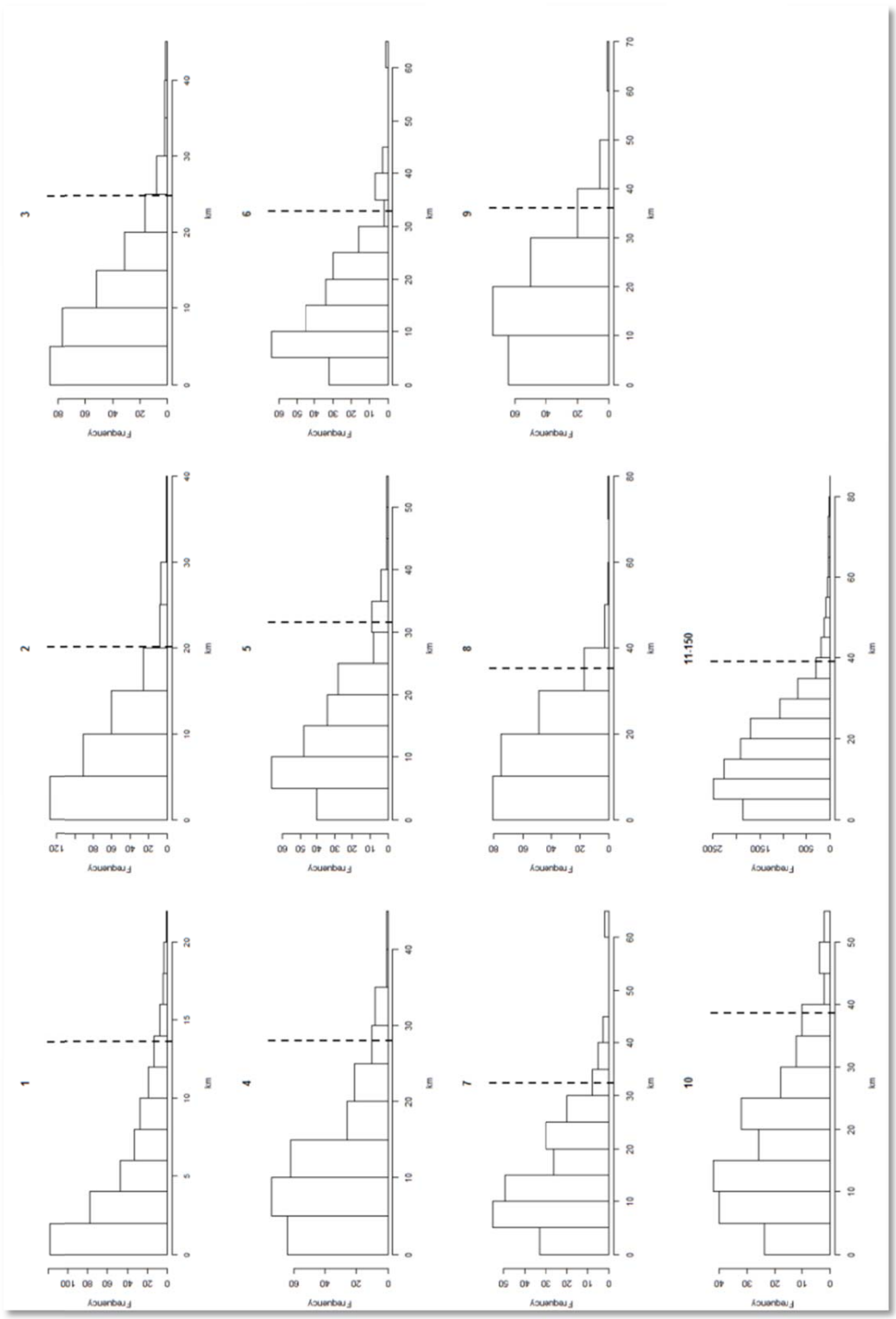

Figure 3. *Histogram showing observed daily distances moved for 10 females in Hedmark. Dotted line represents the 95th percentile of the distribution. Distances calculated as linear distances between each location and all following locations for a given individual (1 = one day movement, 2 = straight line from day one to day three, 3 = straight line from day one to day four, etc.).*

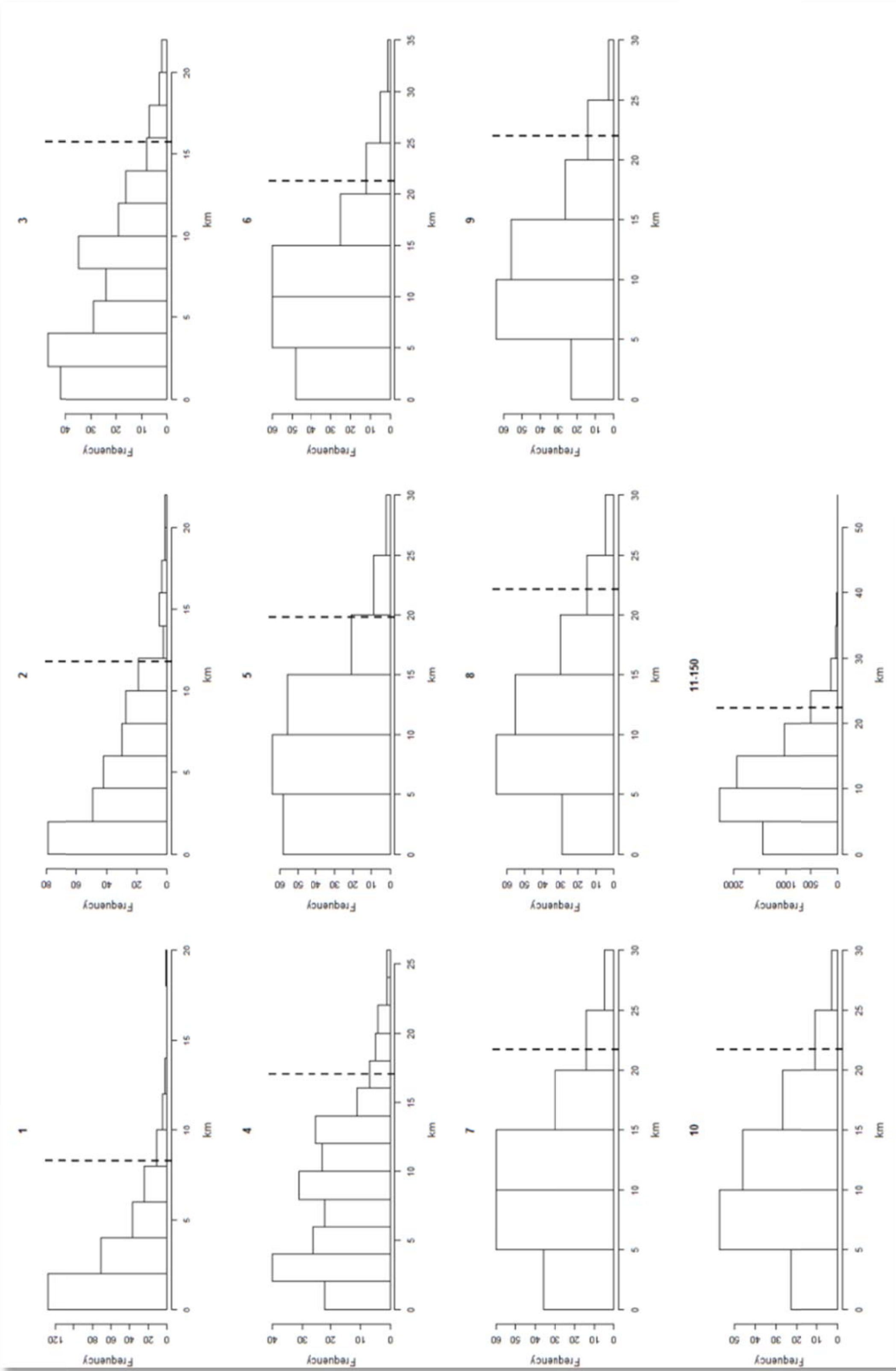

Figure 4. *Histogram showing observed daily distances moved for 8 lynx females in Oslo, Akershus and Østfold. Dotted line represents the 95th percentile of the distribution. Distances calculated as linear distances between each location and all following locations for a given individual (1 = one day movement, 2 = straight line from day one to day three, 3 = straight line from day one to day four, etc.).*

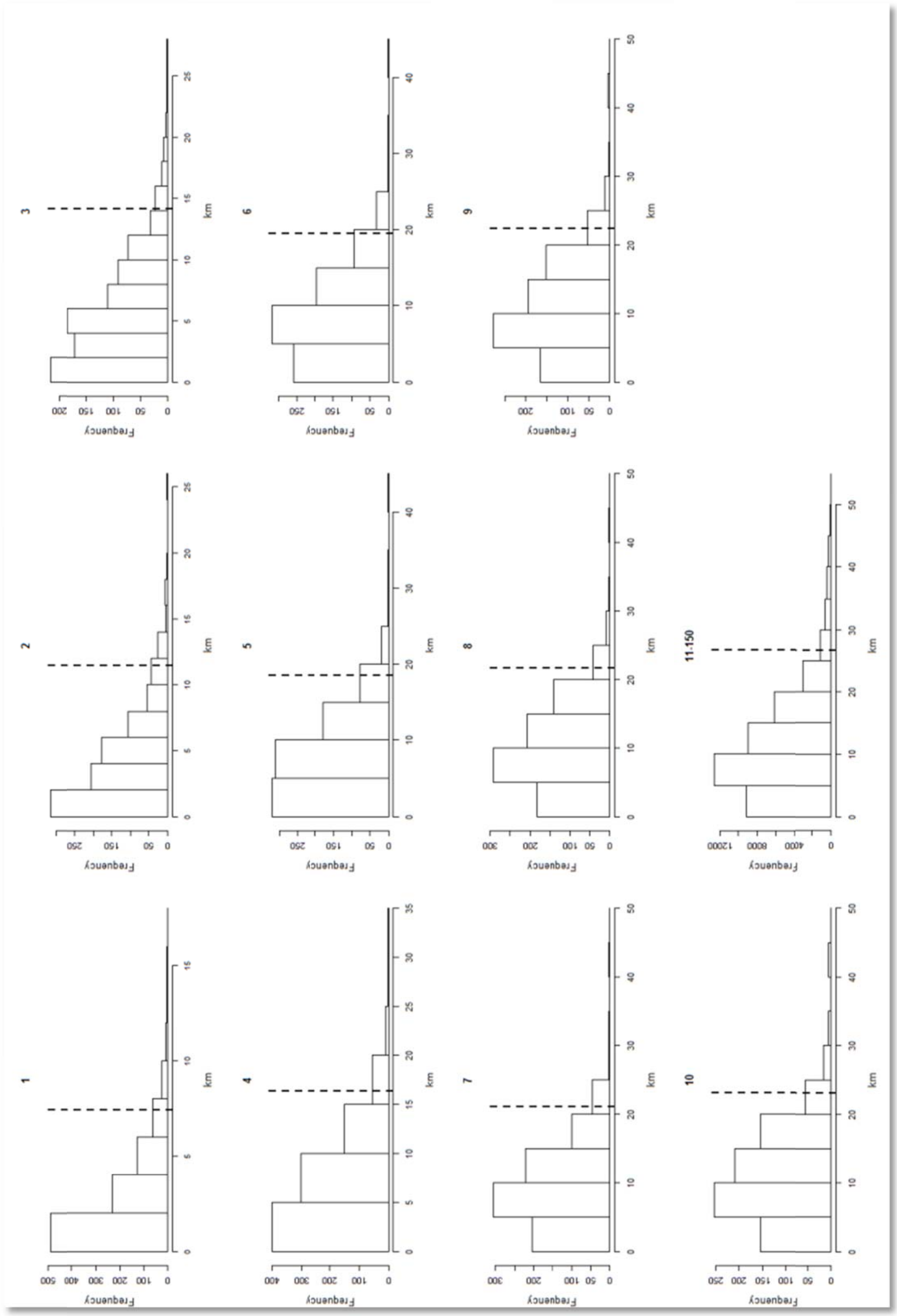

Figure 5. *Histogram showing observed daily distances moved for 11 lynx females in Buskerud, Vestfold and Telemark ("Østafjells"). Dotted line represents the 95th percentile of the distribution. Distances calculated as linear distances between each location and all following locations for a given individual (1 = one day movement, 2 = straight line from day one to day three, 3 = straight line from day one to day four, etc.).*

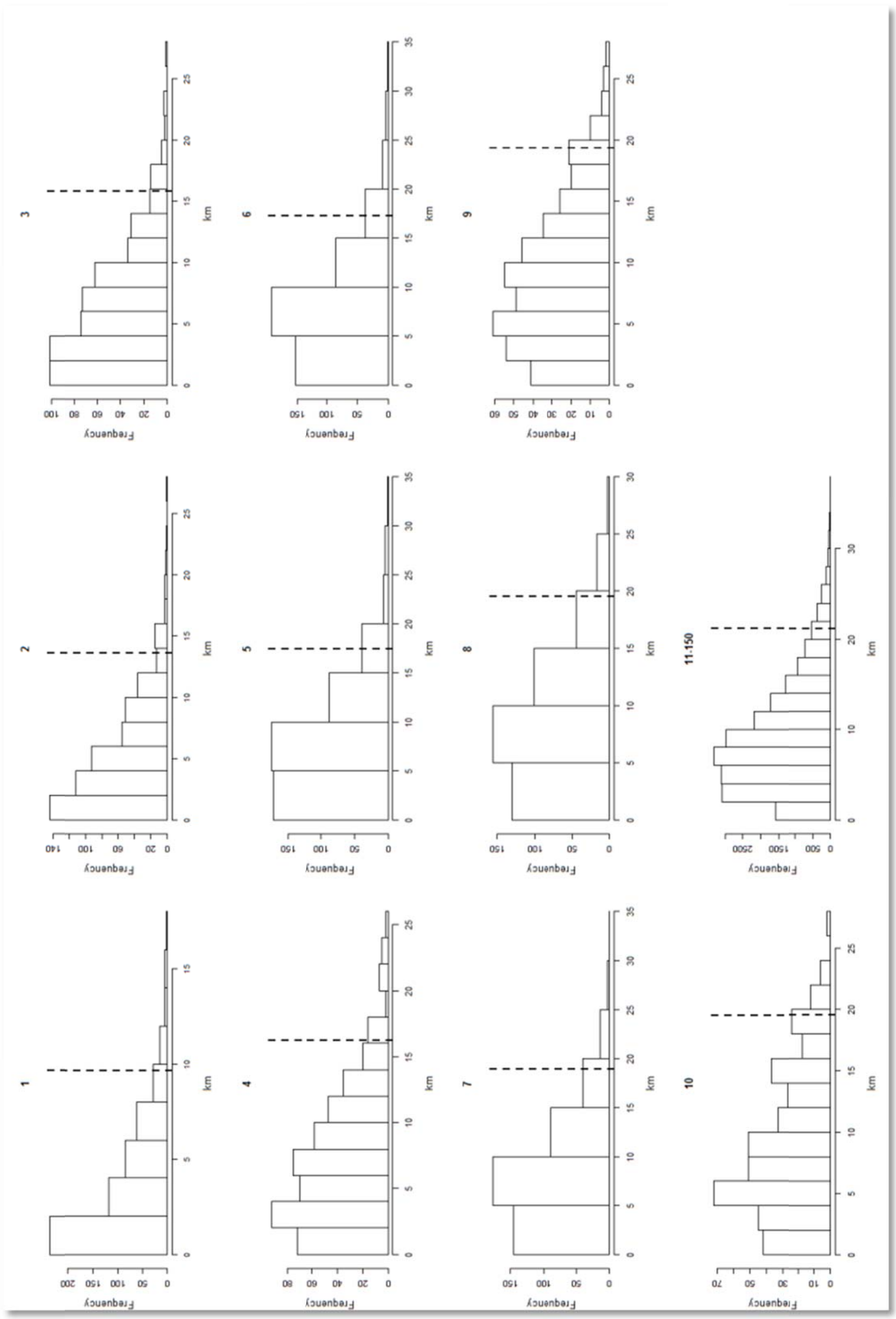

Figure 6. *Histogram showing observed daily distances moved for 11 lynx females in "Southern Sweden" (Sweden south of reindeer herding areas). Dotted line represents the 95th percentile of the distribution. Distances calculated as linear distances between each location and all following locations for a given individual (1 = one day movement, 2 = straight line from day one to day three, 3 = straight line from day one to day four, etc.).*

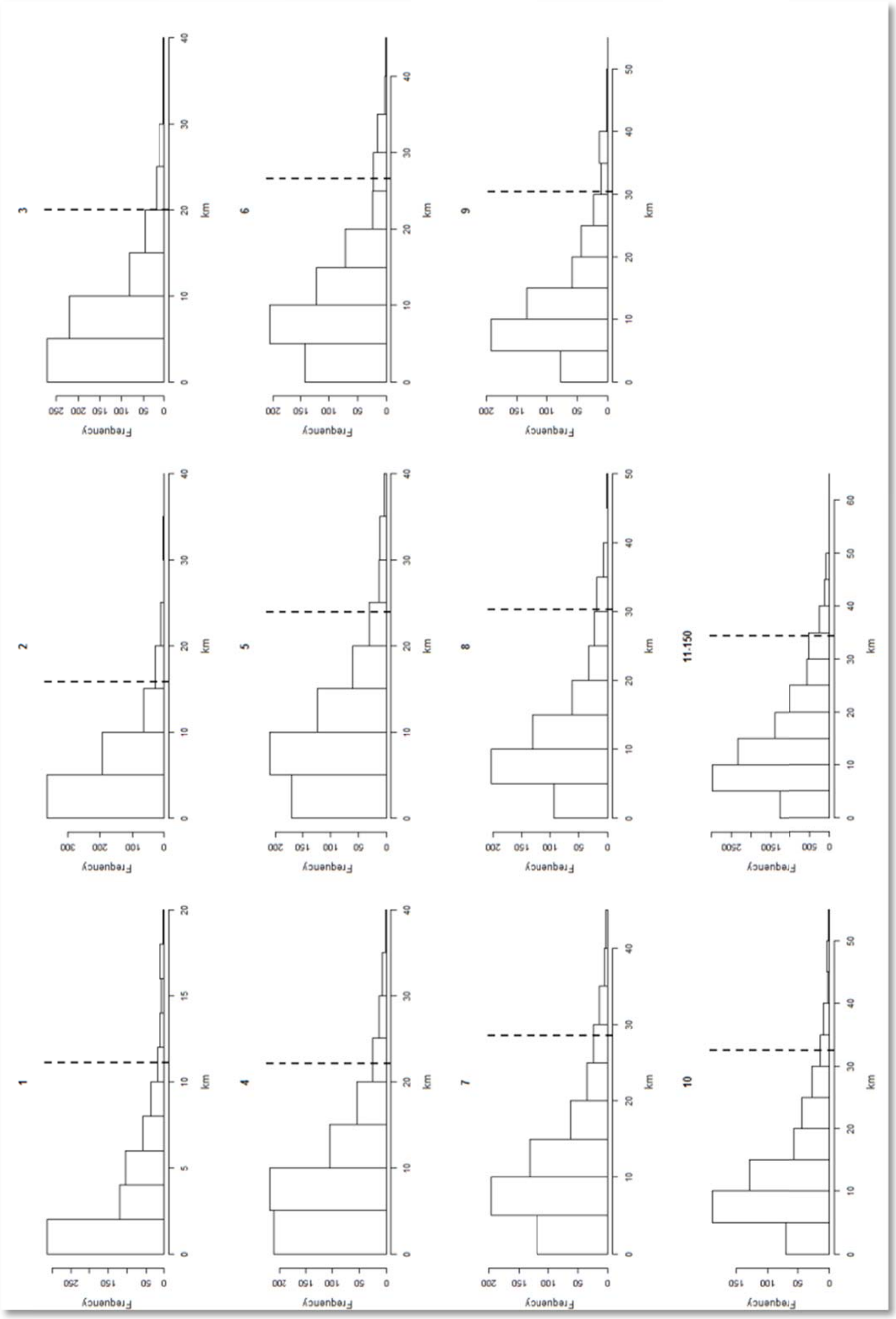

Figure 7. *Histogram showing observed daily distances moved for 16 lynx females in Jämtland, Västerbotten and Norrbotten län (outside Sarek). Dotted line represents the 95th percentile of the distribution. Distances calculated as linear distances between each location and all following locations for a given individual (1 = one day movement, 2 = straight line from day one to day three, 3 = straight line from day one to day four, etc.).*

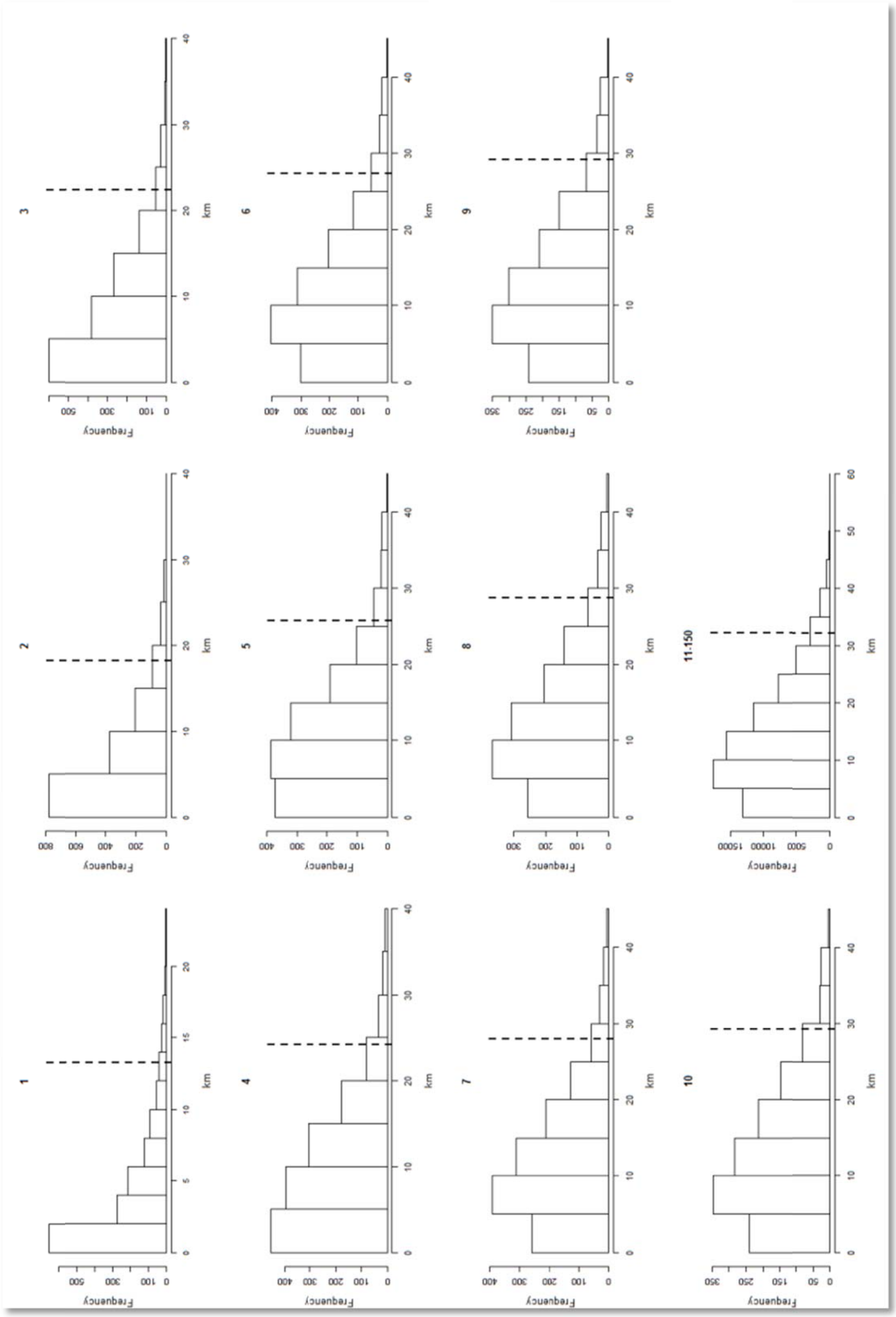

Figure 8. *Histogram showing observed daily distances moved for 10 lynx females in the Sarek study area. Dotted line represents the 95th percentile of the distribution. Distances calculated as linear distances between each location and all following locations for a given individual (1 = one day movement, 2 = straight line from day one to day three, 3 = straight line from day one to day four, etc.).*

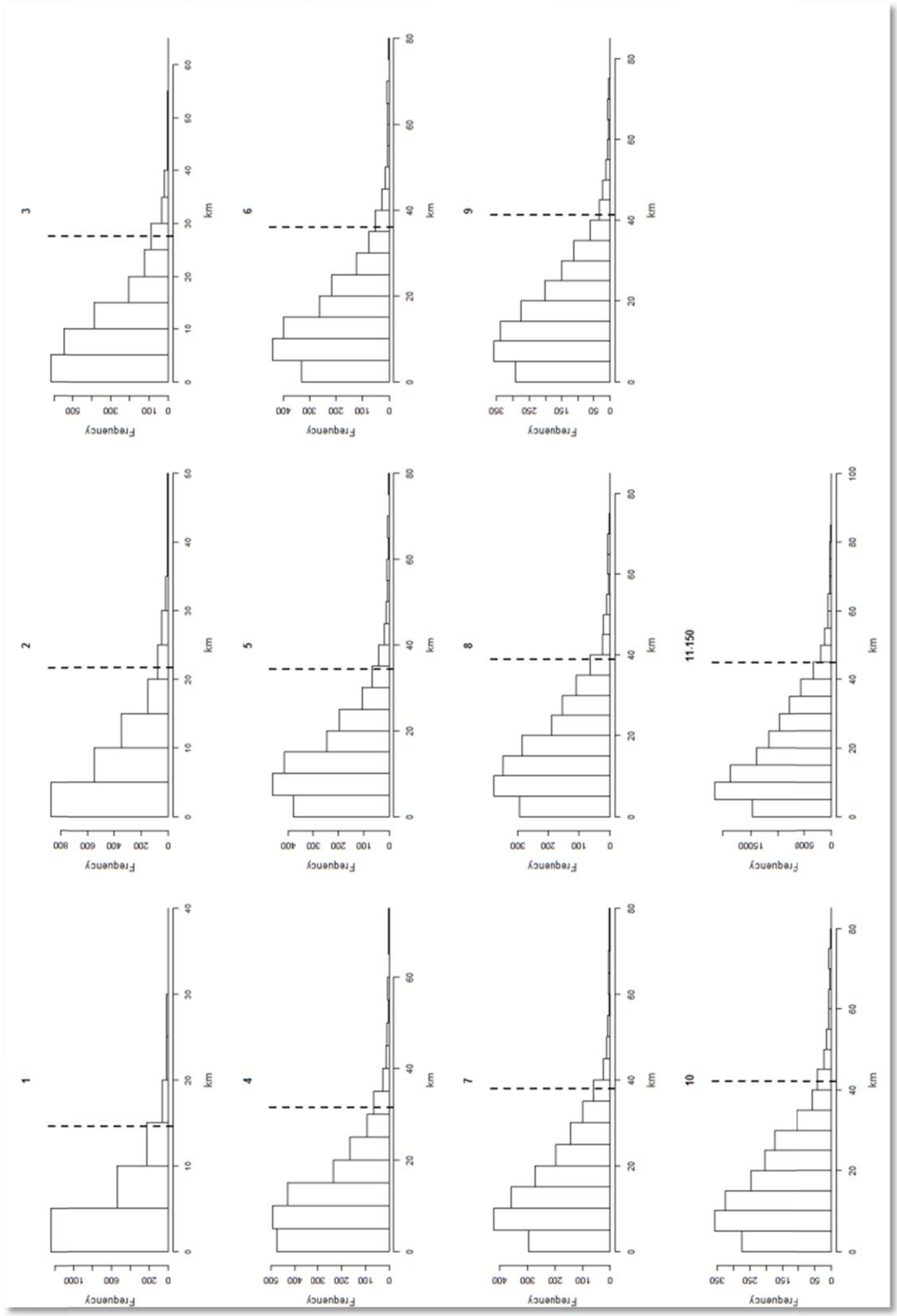

Figure 9. *Histogram showing observed daily distances moved for 10 lynx females in the Troms and Finnmark. Dotted line represents the 95th percentile of the distribution. Distances calculated as linear distances between each location and all following locations for a given individual (1 = one day movement, 2 = straight line from day one to day three, 3 = straight line from day one to day four, etc.).*

3.2 Classification of Scandinavia according to predicted movement patterns

For the roe deer / red deer areas, the most supported model comprised the log(prey biomass) as explanatory variables. This model was significantly more supported then all the other tested models (ΔAIC > 4) and it explained 54% of variation in the dependent variable.
The resulting regression function is:

$$D = 3.567 - 0.408\ [0.053] * Log(prey\ biomass)$$

Where D is the asymptotic distance travelled by an individual lynx in a 150 days period. The number in brackets shows the standard error of the slope estimate. The relationship between prey biomass and the asymptotic travelled distance for each lynx is shown in **Figure 10**.

Based on the predictive curve in **Figure 10**, we tested two possible classifications for the Scandinavian Peninsula. In the first classification, a distance rule was generated for each municipality, with no subjective break. In the second classification, a subjective break was set at 8 kg meat shot / km^2, based on the shape of the predictive curve, which shows a high degree of stability in the asymptotic distance for values > 8, and a rapid increase of the same distance for values < 8. Then, we used simulations to test if one of the two classifications provided higher accuracy in the classification of family units. We randomly extracted pairs of locations from the dataset, and used both criteria to classify them, then calculating the success, underestimation, and overestimation rate for each method. Results showed that the two methods provide the same success rate (on average around 85%). Therefore, since the use of only two categories for classification of the southern part of the Scandinavian Peninsula makes the practical use of the map much more straightforward, we opted for such a method.

We re-pooled individual lynx according to the average biomass index in their home range, and calculated distance rules for each of the 2 biomass-based regions in Southern Scandinavia. As shown in **Table 1**, the asymptotic distance for low biomass areas (corresponding to the distance rule to be applied for observations between 11-150 days apart) was 40 km, whereas it was 22 km for high biomass areas.

For reindeer areas, two models were equally supported by the data. The first model described the asymptotic distance as a quadratic function of latitude, whereas the second model included the study area as a factor variable. **Figure 11** shows the positive, but not very strong relationship between latitude and distance travelled by each lynx. A post-hoc Tukey test showed that the only significant difference occurred between Troms-Finnmark and Sarek ($q = -11.568$; $p = 0.013$), and between Troms-Finnmark and the Northern forested areas in Sweden ($q = 16.214$; $p < 0.001$), whereas no difference was observed between Sarek and the Northern forested areas ($q = 4.646$; $p = 0.521$). The two most supported models for reindeer areas, explained much less variation than in roe deer / red deer areas, about 20%. We pooled individuals from Sarek and the Swedish forest area into one bin, individuals from Troms-Finnmark into a second bin, and calculated distance rules for each of the 2 groups. Then we extended Swedish rules to the Norwegian management areas located at the same latitude (Nordland and Trøndelag). As shown in **Table 1**, the asymptotic distance for the Southern reindeer areas (corresponding to the distance rule to be applied for observations between 11-150 days apart) was 32 km, whereas it was 44 km for Northern reindeer areas.

Finally, we reclassified the map after a validation using local radio-tracking data. We overrode the classification for all municipalities in which GPS data showed a different movement pattern than the one predicted by the model. Based on this, 8 municipalities in Scandinavia were reclassified. The complete classification for Norway and Sweden, comprising 4 “eco-regions”, is shown in **Figure 12**.

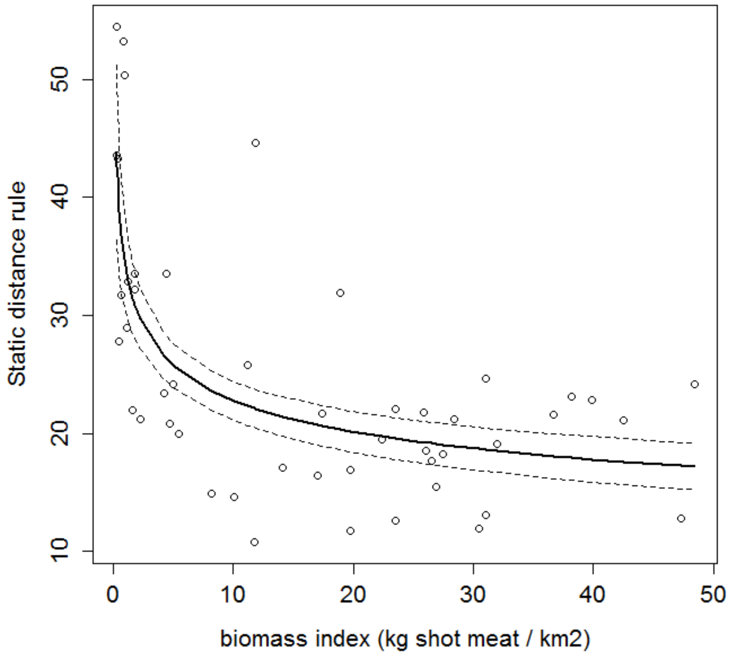

Figure 10. *The relationship between prey biomass and the asymptotic travelled distance for each lynx.*

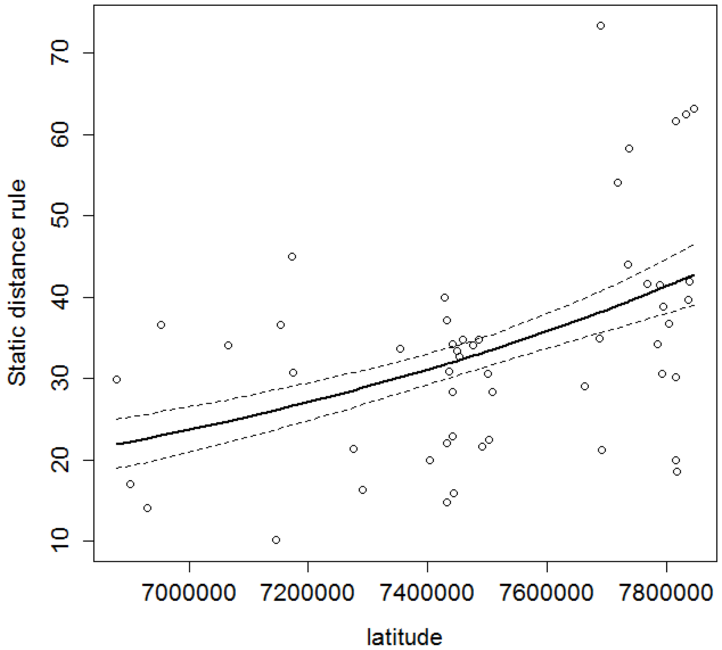

Figure 11. *The relationship between latitude and the asymptotic travelled distance for each lynx.*

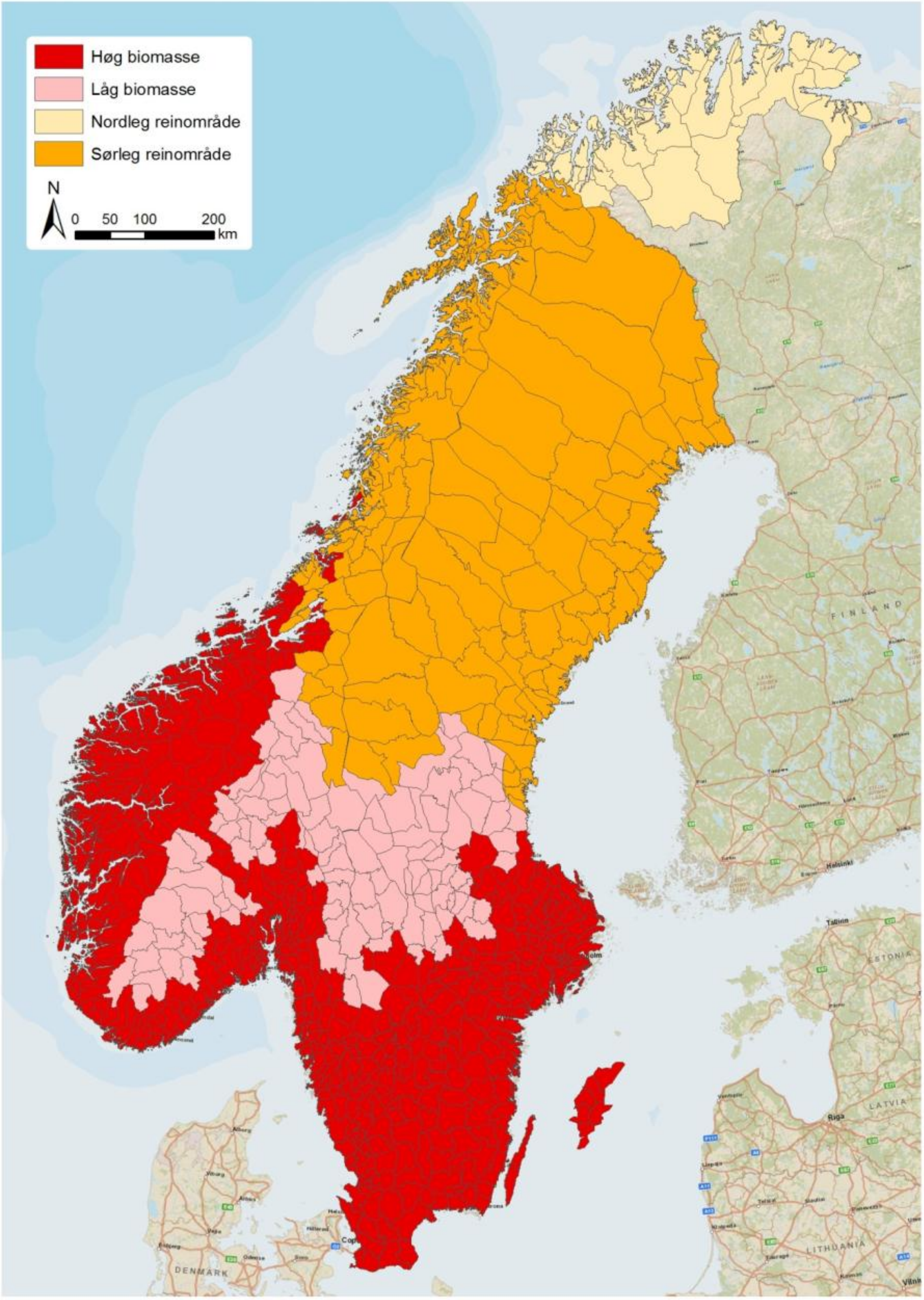

Figure 12. *Classification of Scandinavia into 4 "eco-regions" based on predicted movement patterns (red = high biomass; pink = low biomass; orange = southern reindeer area; yellow = northern reindeer area).*

***Table 1**. New distance rules for the four different "eco-regions" of Scandinavia.*

Area	Days	Old rule	New rule
Roe/red deer area – high biomass	1	8	8
	2	14	12
	3	16	15
	4	17	16
	5	18	18
	6	18	19
	7	18	20
	8		20
	9		21
	10		21
	Oct. – Feb.	22	22
Roe/red deer area – low biomass	1	17	14
	2	24	20
	3	28	25
	4	30	28
	5	32	32
	6	35	33
	7	37	34
	8		35
	9		36
	10		39
	Oct. – Feb.	42	40
Reindeer area - South	1	15	13
	2	17	18
	3	19	21
	4	23	24
	5	24	25
	6	27	27
	7	28	28
	8		29
	9		30
	10		30
	Oct. – Feb.	31	32
Reindeer area - North	1	15	15
	2	17	22
	3	19	27
	4	23	31
	5	24	34
	6	27	36
	7	28	38
	8		39
	9		41
	10		42
	Oct. – Feb.	31	44

3.3 Empirical evaluation of distance rules for the monitoring system

Resulting from the Poisson model, the area with the lowest predicted probability of having two neighbouring family groups was the Troms/Finnmark area, with about 80% of family groups having no neighbouring females with kittens. An intermediate range was predicted for Hedmark, Akershus, and Østafjells, where about 50-60% of family groups were “alone”, and the probability of having > 2 neighbouring family groups is < 5%. The predicted pattern is different for the Swedish study areas, where the majority of family groups are expected to have at least one neighbouring family units, and where the probability of having > 2 neighbouring females with kittens is non-negligible.

In all four “eco-regions” the modelled success rate declined with the increasing number of neighbouring family units (**Figure 14 - 17**). For example, in low biomass areas the success rate was about 95% when no neighbours were present, but it decreased to about 60% when 2 neighbouring family units were simulated (**Figure 14**). Moreover, almost all the error rate corresponded to underestimation, i.e. two family units were incorrectly classified as one. The error bars also show a high degree of variation in success rate, as a consequence of the fact that almost half of the variance in movement patterns remained unexplained by the most supported linear regression model.

***Table 2**. Data used in the theoretical model used to predict the number of neighbouring family units in winter in different study areas (This study, Andrén et al. 2002; Brøseth & Tovmo 2011; Nilsen et al. 2012)*

Area	***Home range size***	***Lynx density (lynx / 100 km^2)***	***Adult F***	***Prim. F***	***% F.G.***	***Kitten S***
Akershus	286	0.4	0.81	0.50	0.22	0.479
Østafjells	317	0.3	0.81	0.50	0.22	0.479
Hedmark	544	0.25	0.69	0.40	0.22	0.479
Finnmark and Troms	1173	0.1	0.4	0.1	0.10	0.468
Norrbotten, Västerbotten and Jämtland	362	0.5	0.76	0.22	0.21	0.468
“Southern Sweden”	259	1.3	0.90	0.74	0.27	0.474

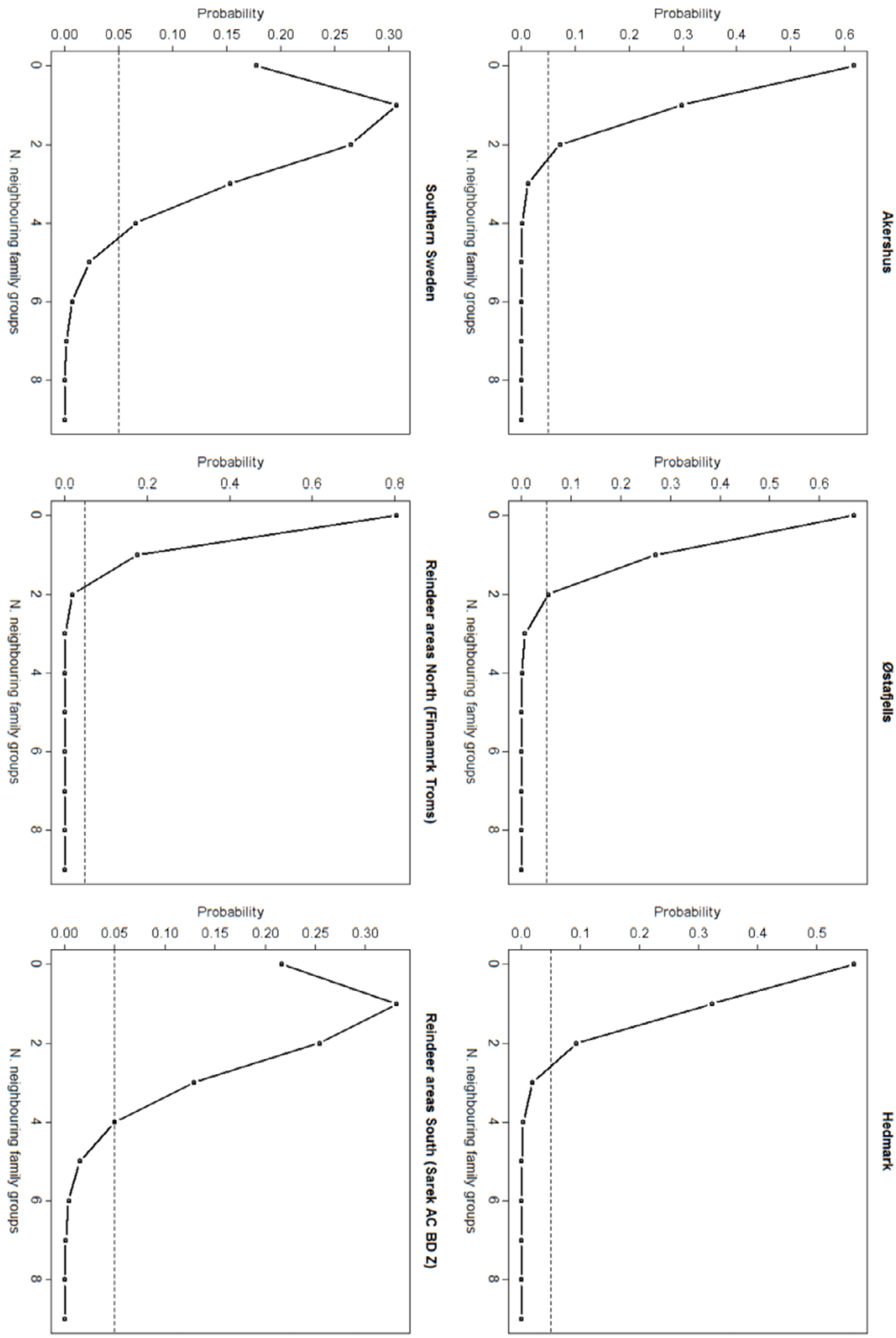

Figure 13. *Modelled probability of having neighbouring family groups for each study area*

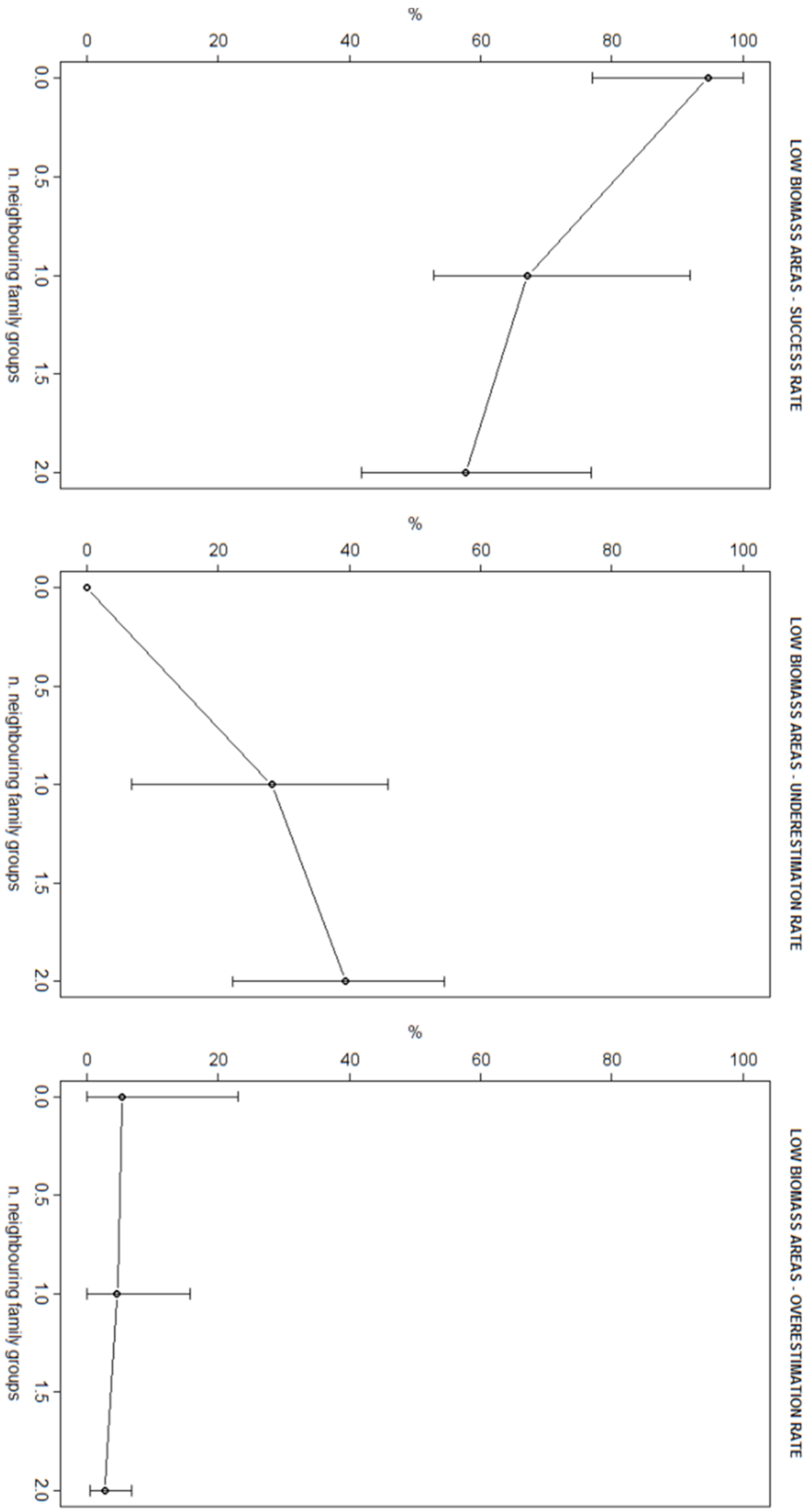

***Figure 14**. Modelled success rate in relation to number of neighbouring family groups in low biomass areas*

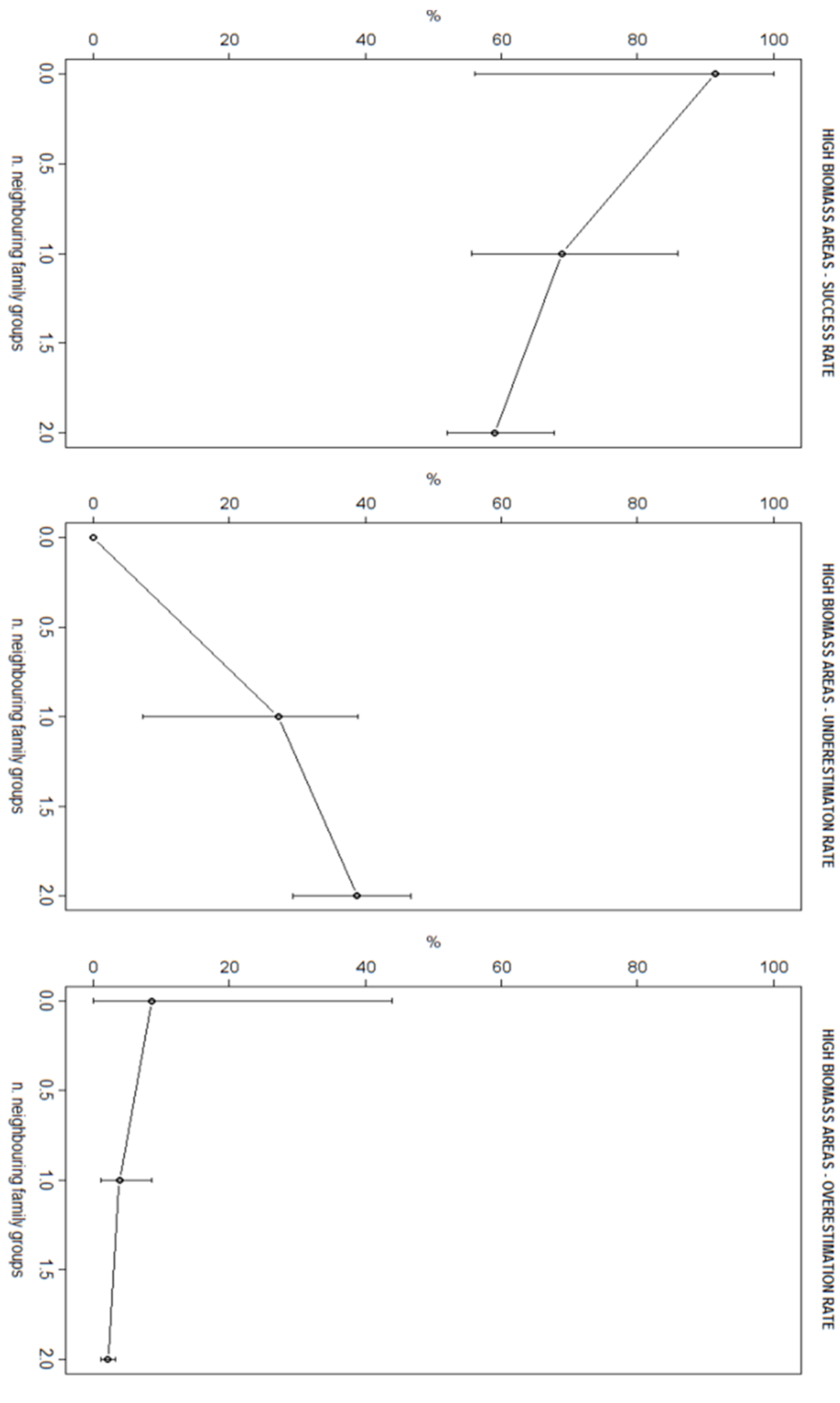

Figure 15*. Modelled success rate in relation to number of neighbouring family groups in high biomass areas*

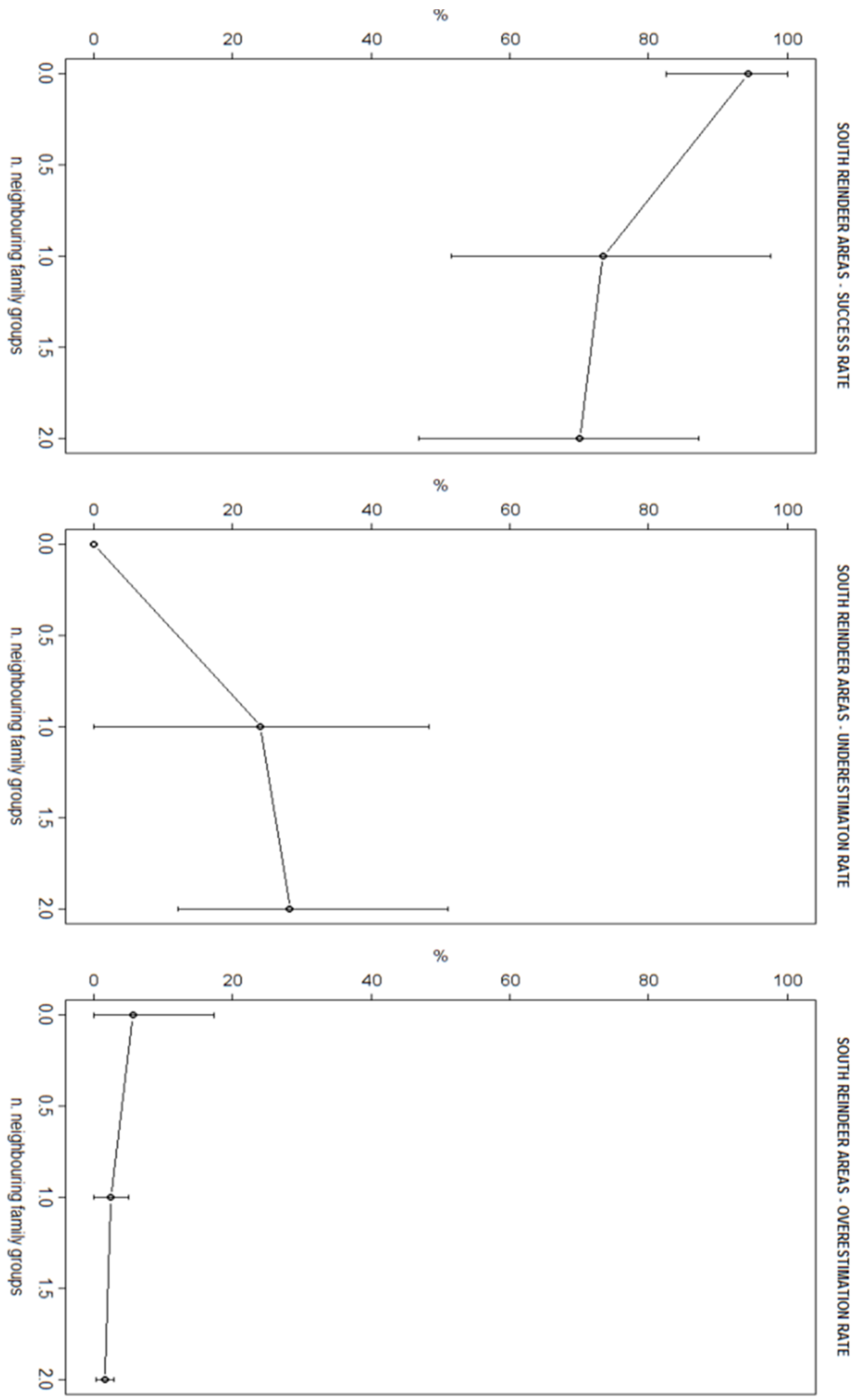

***Figure 16**. Modelled success rate in relation to number of neighbouring family groups in Southern reindeer areas*

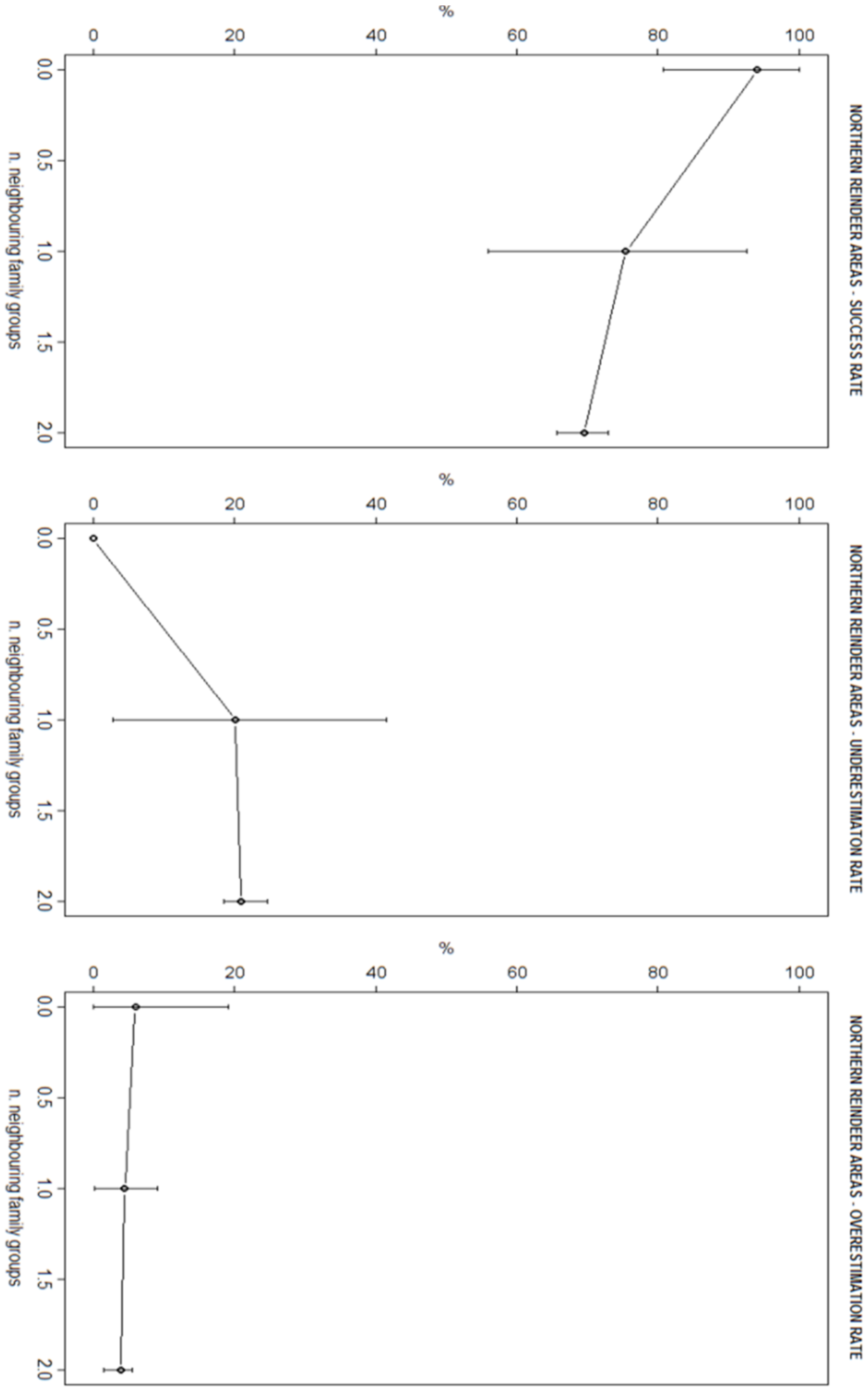

***Figure 17**. Modelled success rate in relation to number of neighbouring family groups in Northern reindeer areas*

4 Discussion

A population reconstruction of the Norwegian lynx population (1994–2004) based on a modified cohort analysis (Nilsen et al. 2012a) closely tracked the development of the official monitoring data based on distance rules, suggesting that the distance rule method gives relatively good information about the size and development of the population under Norwegian conditions. There is, however, a need for further evaluation of the distance rule method from areas where there are no movement data from GPS-collared female lynx in Scandinavia, and especially from areas in Sweden with high reported densities of family groups.

Lynx have irregular movement patterns, tending to be relatively sedentary during the days when they consume a kill, and then moving further while searching for prey (Pedersen et al. 1999; Jedrzejewski et al. 2002; Odden et al. 2010). This leads to much variation in daily movement distances, ranging within 0-55 km. The distance rules are based on maximum travelled distances, and are therefore, by definition, conservative against the risk of overestimating the number of family units. Simulations have shown that, while the estimator is unbiased when only one family unit occupies a given area, it becomes prone to underestimation when other neighbouring family units are present. Also, the degree of negative bias in the estimates is expected to increase when the probability of having a neighbouring family unit increases. The Swedish study sites had a higher probability of having neighbours compared to the Norwegian side, most likely as a result of a higher hunting pressure in Norway, and were therefore more likely to be affected by the risk of underestimating family units, when applying distance rules. Nevertheless, two notions should be added to these different patterns in Norway and Sweden: i) the estimated number of neighbouring family units in each area was derived from a theoretical model, which has not been validated with field data so far. Even though the predictions from the model are in line with the expectations derived from our previous knowledge of density, fecundity, and home range arrangement in each study area, the lack of a validation with real data limits the applicability of simulation results, as they are provided at the moment, for management purposes. Results should be interpreted more as the initial exploration of an issue (the performance of distance rules when multiple family units occur) which had not been taken into account so far. Future data on the spatial arrangement of family units in Scandinavia should be used to validate these results; ii) the relatively high risk of underestimating family units in the Southern reindeer areas is based on data derived from Sarek National Park, in which lynx live at a relatively high density. Such values could be not fully representative of the other parts of the reindeer husbandry area both in Norway and in Sweden, in which the risk of underestimating the number of family units could be lower. Still, the simulations highlight some limits of approaching the issue of counting family units without taking into account the actual spatial arrangement of lynx territories, and they call for a more extensive exploration of the subject. Also, they put in evidence that in some conditions (dense populations with high reproductive rates) the expected success rate of the single classification of lynx observations is expected to be relatively low (up to one wrong classification out of 3). Therefore, the aim of distance rules should rather be to try and balance the risk of overestimating and underestimating family units, so that the estimator will still result unbiased on a long time frame.

One alternative is to conduct one-day censuses where animals are separated based on backtracking in the snow (Liberg & Glöersen 2000). However, this method also has errors associated with it as there is always a risk that field personnel fail to connect track sequences that are in fact continuous. Another alternative in high density areas might be using camera traps. Camera trapping is a non-invasive sampling method allowing the use of capture-recapture (CR) models to estimate abundance while accounting for the difficulty of detecting individuals in the wild (O'Connell, Nichols & Karanth 2011; Blanc et al. 2013). The method is expensive, and needs to be tested under Scandinavian conditions before being recommended as a standard monitoring tool.

Distance rules may also overestimate number of family groups at very low densities. Long term data on movement of individual lynx during changing population densities are notoriously difficult to obtain. A few cases from radio-collared lynx in Norway suggest that some female lynx increase their home range size and movement rates as neighbours die.

Our classification of Scandinavia should be seen as a step forward in the effort of matching the observed lynx movement patterns in Scandinavia, with the criteria used for classifying family units. In Southern Scandinavia, the main improvement, with respect to the previous classification, was the inclusion of red deer density as a predictor of lynx movement pattern. This will be more and more important in the future, as the distributions of red deer and lynx in Scandinavia are likely to overlap more and more, thus the importance of accounting for the presence of one of lynx main prey species. In the Northern part of the study area, the main improvement with respect to the past was the use of a large number of GPS data from Northern Norway (Finnmark and Troms), which showed significantly different movement patterns, and justified the introduction of a new distance criterion for this geographic area. Still, two further improvements should be taken into consideration for the future: i) the collection of movement data from central-northern Norway (Trøndelag and Nordland counties). At the moment the classification of family units in these areas is still based on data collected in Sarek, which, as stated above, could be not fully representative of the movement patterns in the whole central Scandinavia; ii) the spatial distribution of semi-domestic reindeer in Northern Scandinavia should be made available and used to improve the understanding of how prey density and distribution affects lynx movement patterns in this area. The inclusion of prey density as a predictor of lynx maximum travelled distance in the North is likely to improve and substantially change the criteria for the family group classifications.

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965

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