Instruks for bruk av indekslinjer i overvåking av gaupebestander

DEL2 – utvikling av metodikk

Data simuleringer

Det skandinaviske gaupeprosjektet, SCANDLYNX (http://scandlynx.nina.no/), hadde i perioden 1995-2000 radiosender på en stor andel av gaupene innenfor de sentrale deler av Hedmark. For å vurdere hvor godt egnet indekslinjer er til å påvise endringer i gaupebestanden har vi benyttet data på forflytningene til de radiomerkede gaupene i et GIS system (geografisk informasjonssystem) der vi simulerer kryssingen av indekslinjer (med ulik tetthet og plassering). Vi har dermed kunne teste ut ulike metoder for utlegging av indekslinjer, og sett på hvilke endringer i bestandsstørrelse som fanges opp med ulike tettheter og plassering av linjer. Dette har vi igjen brukt til å utvikle en instruks for bruk av indekslinjer for overvåking av gaupebestander.

Nedenfor beskrives i korte trekk metodikk og resultater av disse datasimuleringene. En mer detaljert beskrivelse av analysene og resultatene er gitt i manuskriptet ”An evaluation of structured snow-track surveys to monitor Eurasian lynx *Lynx lynx* populations” (Linnell m. fl. i manus, appendiks).

Materiale og Metode

Data på forflytning hos radiomerkede gauper ble samlet inn i de sentrale deler av Hedmark fra 1995 til 2001. I studieområdet på 10 173 km^2 ble det plassert ut et tenkt nettverk av indekslinjer innenfor et GIS-system. Indekslinjene ble plassert ut på 2 måter. Først brukte vi vår egen erfaring fra vårt arbeid med gauper til å plassere ut linjer som vi mente økte sjansene for å finne gaupe (heretter kalt ”plasserte linjer”). I de fleste tilfellene ville dette si fra dalbunn og rett opp lia, gjerne i tilknytning til bratte åser vi erfaringsmessig viste ofte ble brukt som dagleier for gaupa. Linjene ble satt til å være 3 km lange i luftlinje mellom start og sluttpunkt, noe som erfaringsmessig er lik den lengden man kan forvente å få frivillige mannskaper til å gå i bratt og ulendt terreng. Totalt ble 264 linjer plassert ut innenfor studieområdet, noe som tilsvarer en tetthet på 1 linje per 38 km^2. I tillegg ble så 259 3-km linjer (1 per 39 km^2) plassert ut tilfeldig (tilfeldig plassering og orientering, men uten overlapp) utover hele studieområdet (heretter kalt ”tilfeldige linjer”).

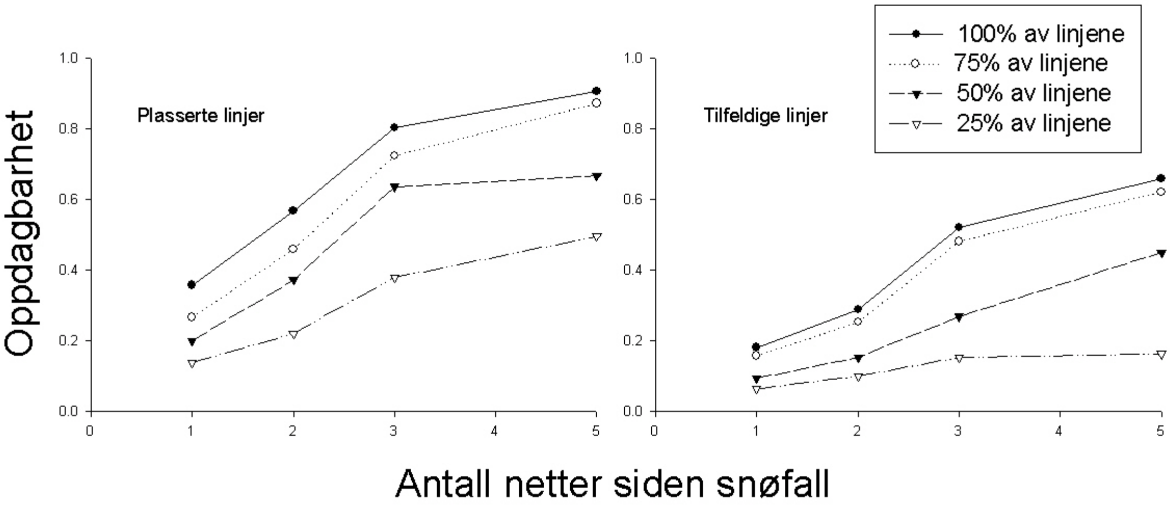
Vi benyttet data på forflytningen til 31 ulike gauper på vinterstid (november-mars). Gaupene ble i hovedsak lokalisert på dagleiet, og gaupenes forflytning ble satt lik en rett linje mellom dagleiene. På denne måten lagde vi 4 ulike datasett som skulle reflektere antall netter mellom siste snøfall og en tenkt registreringsdag. De fire datasettene tilsvarte forflytning (sporløype) i henholdsvis 1, 2, 3 og 5 netter siden snøfall. For hver forflytning beregnet vi så hvor mange av indekslinjene gaupene hadde krysset.

Et av målene var å beregne hvilket oppsett av linjer som er best i stand til å fange opp gauper. Dette ble gjort ved å beregne sannsynligheten for at en sporløype krysset minst en indekslinje. Beregningene ble gjort med tilfeldige og plasserte linjer for ulike netter etter snøfall (1, 2, 3 og 5), og for ulike tettheter av indekslinjer (100%, 75%, 50% og 25% av original tetthet).

Videre testet vi sannsynlighet er for at sporindeksen fanger opp en reduksjon i gaupebestanden mellom 2 registreringer. Vi antok en startbestand på 30 gauper innenfor studieområdet. Vi simulerte så en potensiell reduksjon i bestanden ved å ta ut et gitt antall individer (med tilbakelegging), og kjøre gjentatte simuleringer av hvor mange linjer som hadde kryssende spor. Simuleringene ble gjort 1000 ganger. Indekslinjene skal gås over mange år. Vi testet derfor også hvordan et takseringsoppsett er i stand til å oppdage trender i bestanden over flere år.

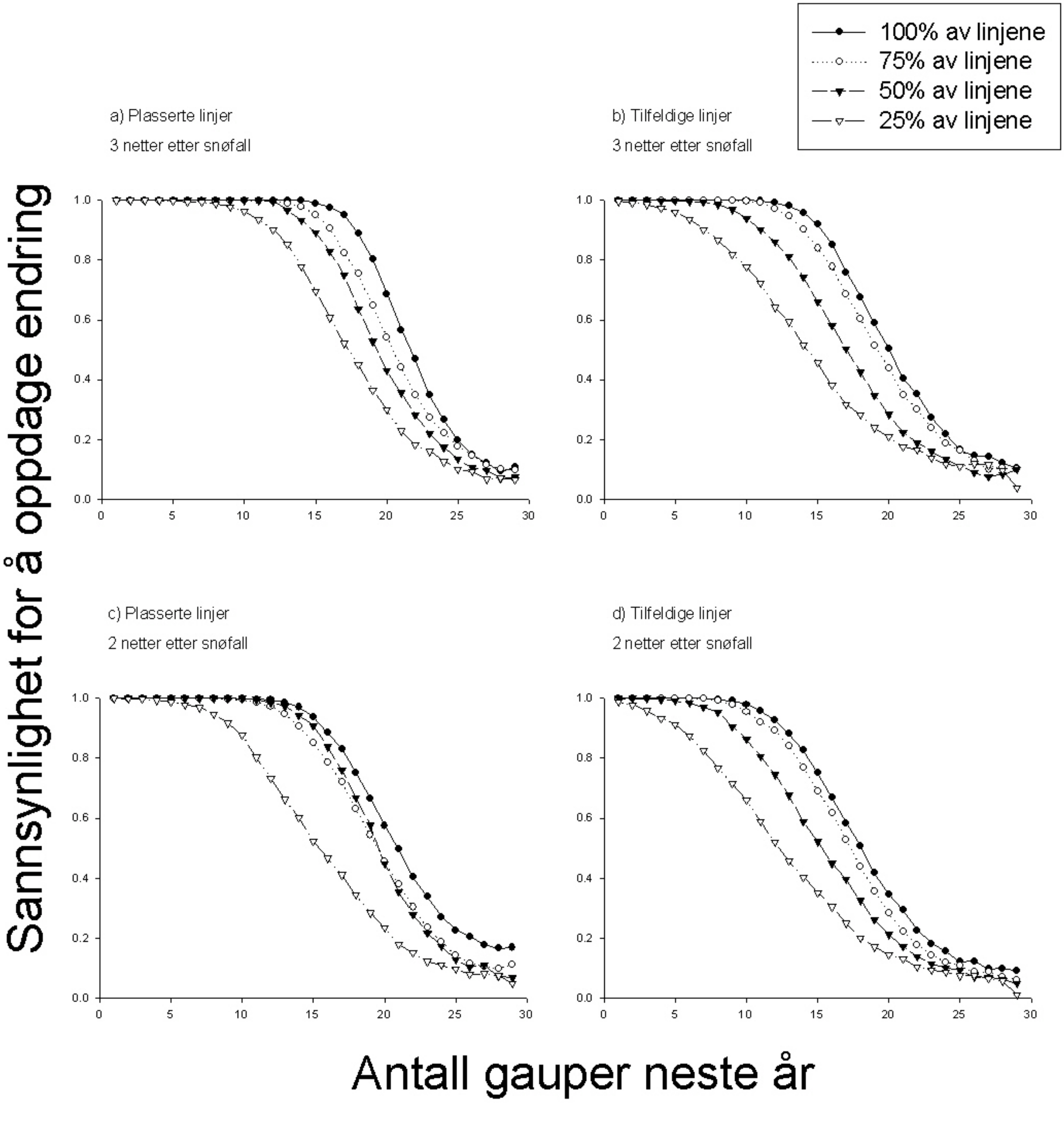
Resultater av simuleringene
Sannsynlighet for å oppdage gauper var betraktelig høyere med nettverket av plasserte linjer sammenlignet med de tilfeldige linjene. Sjansen for å oppdage gauper økte også med antall netter etter snøfall (figur 1), og minsket etter som antall linjer minsket. Resultatene viser at det vil være en 80 % sjanse for å oppdage en gaupe hvis man foretar registreringene på 3 netter gammel sporsnø og med en linjetetthet på 1 linje per 38 km^2.

Figur 1. Sannsynligheten for å oppdage gauper med plasserte linjer og tilfeldige linjer som en funksjon av dager etter snøfall. De ulike linjene i figuren representerer ulike tettheter av indekslinjer med 100 % lik 1 linje per 38 km^2.



Plasserte linjer oppdaget også nedgang i bestanden bedre enn tilfeldige linjer (figur 2). Sannsynligheten for å oppdage en bestandsnedgang mellom to år økte også med dager etter snøfall. Simuleringene viste at hvis alle de plasserte linjene (100%) er gått 3 dager etter snøfall, så vil man oppdagen en bestandsnedgang fra 30 til 19 individer fra et år til et annet i 8 av 10 tilfeller (figur 2a). Hvis linjene er gått 2 dager etter snøfall vil man oppdagen en bestandsnedgang fra 30 til 17 individer fra et år til et annet i 8 av 10 tilfeller (figur 2c). Vi så videre at sannsynligheten for å oppdage en bestandsnedgang minsket ettersom antall linjer minsket.

Figur 2. Estimert statistisk styrke til en chi-square test for å oppdage nedgang i en gaupebestand fra et år til et annet som en funksjon av bestandsstørrelsen for 2 og 3 dager etter snøfall. Bestanden første år ble satt til 30 individer. Den statistiske stryken er beregnet for plasserte og tilfeldige linjer og for 100 %, 75 %, 50 % og 25 % linjetettheter.



Konklusjon

Resultatet av simuleringene viser at det foreslåtte systemet med indekslinjer vil kunne være et godt mål på evt. større variasjoner i en gaupebestand mellom registreringsår. Systemet vil også kunne strukturere og øke antall registreringer av familiegrupper av gaupe i Norge.

Det synes helt klart at indekslinjer bør plasseres ut slik at de maksimerer sannsynligheten for å oppdage gaupespor, dvs de bør plasseres der man lokalt forventer at det er størst sjanse for å finne gaupespor. Simuleringene viser også at en optimal tetthet av linjer ligger på rundt 3 linjer per kvadratmil, og at en registrering optimalt sett bør skje på minst tre dager gammel snø hvis dette er mulig.

- 3 km lange linjer (3 km i luftlinje fra start- til sluttpunkt)
- 3 linjer per 100 km^2
- Linjene legges ut av personer med god lokalkunnskap, på en slik måte at de maksimaliserer sannsynligheten for kryssing av gaupespor.
- Optimalt takseres linjene etter 3 netter siden siste snøfall.
- De samme linjene takseres hvert år.

Appendiks:
An evaluation of structured snow-track surveys to monitor Eurasian lynx Lynx lynx populations

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Counts of animal tracks that passively accumulate on a suitable substrate are commonly used to derive indices of large carnivore abundance. In this study we evaluate the suitability of a similar survey using multiple 3-km long transect-lines to detect changes in population size for Eurasian lynx in central Norway. We used GIS to simulate the crossing of transect lines by lynx using real telemetry data from the study area. We compared the effect of transect-line placement (deliberate versus random), transect-line density, and the number of nights over which tracks can accumulate in the snow. For each scenario we have evaluated both the probability of detecting lynx that are present in the survey area, and the power of the index to detect changes between consecutive surveys. Deliberate lines performed significantly better than random lines, and as expected line density and the period of track accumulation improved the outcome. Using 3 nights of track accumulation and the highest density of deliberate lines (1 per 38 km^2) both the probability of detecting lynx within the survey area, and the power to detect a 33% change in population size between two surveys, were greater than 80%.

Introduction

Monitoring large carnivore populations is always a challenging task for researchers and managers, conflicts over population size and conservation status often arise (Blanco & Cortés 2002). Low densities and cryptic habits make direct enumeration or statistical estimates of population size logistically difficult, and economically prohibitive, to obtain from large areas on a regular basis. As a result many studies have moved away from direct sampling methods (where the carnivores are counted) to indirect sampling methods (where scats, tracks and other signs are counted) that are usually used to generate indices of carnivore activity or abundance (Thompson et al. 1998). While attractants are often used to generate density indices for medium and small carnivores (Zielinski & Stauffer 1996), surveys for larger carnivores are often based on searching networks of transects for tracks or other signs (Smallwood & Fitzhugh 1995; Beier & Cunningham 1996; Stander 1998; Edwards, de Preu, Shakeshaft & Crealy 2000; Wilson & Delahay 2001). Recent evaluations have revealed that these line-intercept indices are relatively useful as they correlate well with real density (Stander 1998), but few studies have calculated the power of the survey to detect population changes (e.g. Beier & Cunningham 1996). Furthermore, the applicability of a given method to a given species will likely depend on the density and movement patterns of the species in question as well as the habitat configuration of the study area. There is therefore a need to shape the sampling intensity and design to the specific circumstances.

Eurasian lynx *Lynx lynx* are a large carnivore species found throughout Eurasia that occupy an ecological niche similar to that of the puma *Puma concolor* or leopard *Panthera pardus* (in terms of large home ranges, low densities, and ungulate based diets). In Norway, lynx are heavily harvested, partly to limit depredation on livestock and partly to provide hunter opportunities (Pedersen, Linnell, Andersen, Andrén, Segerström & Lindén 1999, Odden, Linnell, Moa, Herfindal, Kvam & Andersen 2002). As there are no wilderness areas or other unhunted refuges left in Norway that could serve to buffer over-harvest (Linnell, Andersen, Kvam, T, Andrén, Liberg, Odden, Moa 2001), there is a need for high-quality data on population size and trend to set annual hunting quotas.

The main monitoring method for lynx in Norway is a minimum count of family groups (adult females with dependent kittens) based on separating observations of tracks in the snow from each other using a set of distance rules (Andrén et al. in press; Linnell et al. submitted). Although minimum counts may be acceptable for many purposes (Knight, Blanchard & Eberhardt 1995), it was considered desirable to supplement the monitoring with an independent index that might offer a better foundation for statistical tests of trend and be independent of reproduction. As track counts have been used for ecologically similar pumas and leopards (Smallwood & Fitzhugh 1995; Stander 1998) we wanted to evaluate the potential of using a network of transects along which lynx tracks (in the snow) are recorded.

Our general approach has been to use a GIS system to simulate the crossing of “virtual” transects lines (with different densities and placement) by the actual movements of lynx derived from telemetry data from lynx in the study area. More specifically we had the following objectives; (1) Determine how distribution of transects would affect power to detect changes between two surveys, (2) Determine how different densities of transects would affect power to detect changes between two surveys, (3) Calculate the probability of the design to detect the presence of lynx in the area and (4). Evaluate the power of the system to detect trends in population size over time based on annual surveys. As tracks accumulate with time, we repeated the simulations using several track accumulation periods (i.e. number of nights since last snowfall). Finally, we compared the simulated results with those obtained from large-scale one-day censuses conducted in the study area using similar methodology.

Study area

Movement data were collected in the central part of Hedmark county in south-central Norway ($61^{o}30'$ N) between 1995 and 2001. Lynx were captured for radio-collaring using a combination of snares placed at kills, walk-through box –traps, darting from helicopters, treeing using trained dogs and implanting in neonates (Nybakk, Kjørstad, Overskaug, Kvam, Linnell, Andersen & Berntsen 1996; Arnemo, Linnell, Wedul, Ranheim, Odden & Andersen 1999). The habitat has been described in detail elsewhere (Linnell et al. 2001), but basically consists of intensively exploited boreal forest habitat, with some few patches of agricultural land dispersed along valley bottoms. The topography consists of north-south orientated valleys separated from each other by hills. The altitude varied between 200 moh and 900 masl. Lynx have very large home ranges in the region (500 to 1500 km^2) probably because their main prey, roe deer *Capreolus capreolus*, occur at very low densities and are confined to valley bottoms and artifical feeding sites during winter. In this region snow is the only substrate likely to record tracks as the soil does not record tracks on roads and trails during the snow-free season.

Methods

Placement of “virtual” transects

The 10173 km^2 study area was defined by the outer limits of the composite home ranges of the radio-collared lynx plus a buffer of 5 km. This area represented a saturated mosaic of neighbouring territories, with all lynx radio-collared. Within this area we defined a network of virtual transects within a GIS system, placed in two different manners. Firstly, we used our own experience from working with lynx to place transects in a manner that maximises the probability of a lynx crossing the transect if it is passing through the area. In most cases these “deliberate” lines stretched from the valley bottom up the side of the valleys, as lynx generally travel along valleys, or where associated with steep terrain that lynx favour for day-lairs. We set the standard length to be 3 km as this stretches from the valley bottom to an altitude higher than that normally used by lynx during winter, and corresponds with the maximum length of transect which it is reasonable to expect volunteers to ski. A total of 264 lines were placed within the study area for a density of 1 per 38 per km^2. Secondly, we scattered 259 3-km transects (1 per 39 km^2) at random (random placement and orientation, but without overlap) throughout the same study area at the same density.

Lynx movement and transect intercepts

For the purposes of this analysis, only movement data from winter (November to March) were used as this corresponds to the season when snow is most likely to be on the ground. Data were collected from 31 individual lynx during the study period. Lynx were mainly located during day-time when they were inactive, i.e. in day-lairs. We created four different data sets, designed to reflect the effect of the number of nights since snow-fall during which tracks could accumulate. The one-night set contained all observations where lynx were located on consecutive days (1378 movements for 31 lynx). The sets of two, three and five-nights consisted of all sequences where lynx were located daily for three, four and six days respectively (951 movements for 29 lynx, 810 movements for 27 lynx and 598 movements for 24 lynx respectively). On nights where lynx did not move, we added a circle of 500m radius to simulate movement between a day-bed and a kill.

For each nights movement we have calculated how often each lynx crossed each virtual transect. By representing these movements as linear we will underestimate the actual distance travelled by lynx during their night-time travels. We have partly allowed for this by buffering all lynx movements with 100m. Furthermore, because of the very large home ranges and long movement distances of lynx in our study area, the difference between straight-line distance travelled and actual distance travelled is likely to be less than that found in other studies (Jedrzejewski, Schmidt, Okarma & Kowalczyk 2002). We have simply regarded each transect as being crossed or not in line with Beier & Cunningham (1996).

Computation of detection probabilities

To check how well the survey designs were able to detect the presence of lynx in the study area we computed the probability of a track crossing at least one census line if a lynx was present. In the computation each observation (the number of lines crossed by each lynx during the one, two, three or five night track accumulation periods) was given the value one if the lynx had crossed at least one line and the value zero if the lynx had crossed no lines. Detection probabilities was computed for both sampling strategies (random and deliberate), for different number of days since the last snowfall (one, two, three, and five), and for different densities of sampling lines (100%, 75%, 50%, and 25% of original density).

Because the number of observations varied greatly among individuals (from 1 to 129 one day periods, 0 to 45 two day periods, 0 to 28 three day periods, and 0 to 14 five day periods) the computation of detection probabilties could be biased by the behaviour of individuals with many observations, and thus not be representative of the lynx population in the study area as a whole. To avoid such bias we computed the detection probabilities as a two step process. First we computed the detection probability for each individual as the proportion of observations where it had crossed at least one line. Then we computed the mean of those proportions as an estimate of the detection probability in the population. An individual was included in these computations if at least five observations were available.

Detection probability increased with increasing number of days since last snowfall (see results). Practical considerations (snowfall distribution, availability of personnel) suggest that performing censuses two to three nights after snowfall is the most likely scenario. We therefore performed our simulations of different sampling strategies for two and three nights after snowfall only.

Detecting differences in track-count index between two periods

We assumed a starting population of 30 lynx in the study area (representing 0.3 individuals per km^2). Because this is close to a saturated lynx population in the study area, we only simulated potential reductions in the population. The index that we used was the number of lines crossed by at least one track during the period. We tested the change in population from year one to year two with a chi-square test of the number of lines crossed by at least one lynx track. The simulations was performed as follows:

1. From the available lynx we drew randomly with replacement n individuals, n representing the simulated population size (30 in year one, 1 to 29 in year two).
2. For each individual we drew one observation from the available observations of that individual and the number of lines the lynx had crossed was counted.
3. In each year the number of lines crossed by all lynx from the simulated population was summed.
4. The sums were tested with a chi-square test.
5. Steps 1-4 were repeated 1000 times and the number of significant test at $\alpha = 0.05$ was counted.
6. Power was computed as number of significant tests divided by 1000.

Trends (detection of a long term population decline)

If the censuses are performed across many years the results could be used to detect if there are any long term trends occurring in the lynx populations. Because we assume that populations at present are close to saturation in the study area, we concentrated on detecting declines in populations over time. In these simulations we make the assumption that population decline is linear without any year to year variation. This is an unrealistic assumption, and any violations of that assumption are likely to reduce the power of the test. However, this simplification makes the simulations more tractable and the results should give an illustration of the maximal power one could expect with the present design. This power simulation was only performed for two days after snowfall with 100% of the census lines. To simplify the interpretation of the power data we present them as decline from a starting population of 30 lynx that could be detected with a power of 0.8 at α of 0.05 for each time period from 7 to 20 years. The simulations were performed as follows:

1. The number of years of census period was set to 7
2. The number of lynx in the starting populations was set to 30
3. The number of lynx in the final population was set to 15 (half the original population)
4. For each of the years in the census period a population size was computed as a linear decline from 30 to 15 over the period. Population size was rounded to the nearest integer number (n).
5. From the available lynx we drew randomly with replacement n individuals, n representing the simulated population size in that year.
6. For each individual we drew one observation from the available observations of that individual and the number of lines the lynx had crossed was counted.
7. In each of the years from the start to the end of the census period the number of lines crossed by all lynx from the simulated population was summed.
8. The sums over the period were tested for a trend with linear regression.
9. Steps 1-8 were repeated 500 times and the number of significant test at α(two tailed) = 0.05 was counted.
10. Power was computed as the number of significant tests divided by 500.
11. If power was greater than 0.8 the final population size was increased, and if power was less than 0.8 the final population size was decreased and step 1-10 was repeated until power was 0.8.
12. The number of years of the census period was increased with one and step 2-11 was repeated until the length of the census period was 20.

Field trials

In January 1999 and January 2001 we organised two large field surveys that covered partly overlapping areas of Hedmark county, including our study area (Odden et al. 2000, 2001). These surveys were based around the deliberate line distribution, with each transect of 3 km in length. Each survey involved hundreds of volunteers. For each survey we calculated (1) the proportion of radio-collared lynx that were present within the sample area that were detected, (2) the proportion of index lines that contained lynx tracks, and (3) the ability of volunteers to correctly identify lynx tracks. In addition, to the 3 km transects, many of the volunteers continued further along unstructured routes and chance observations from the public on the same day were also recorded. Although this additional data could not be used in evaluating a track count index it could be used to increase the chance of detecting lynx presence.

Results

Detection probabilities

The probability of detecting a lynx that was present was significantly higher on a network of deliberate lines than for random lines for all track accumulation periods (Table 1). Detection probability increased with increasing length of accumulation period (Figure 1 and Figure 2), and decreased as the number of census lines were decreased (Figure 1 and Figure 2). Females with kittens and males appeared to have a higher detection probability than females without kittens (Figure 2), however, the difference among groups were difficult to test in a satisfactory manner. With deliberate lines and 100% of the census lines we estimate that we are able to detect the presence of lynx in 80% of the cases if the census is performed three nights after snowfall (Figure 1). If the number of census lines is reduced to 75% the presence of a lynx is estimated to be detected in 72% of the cases with census three nights after snowfall, and if the density of census lines is reduced to 25% we estimate that a lynx will be detected in only 38% of the cases (Figure 1).

Changes between two surveys

Lines chosen deliberately performed better at detecting population declines than lines chosen at random (Figure 3). The ranking of the sampling regimes was similar across the various accumulation periods. From our simulations it appears that power increases with days after snowfall. However, during a five day period it is increasingly likely that more snow will fall, and furthermore it is difficult to have personnel that can perform census after exactly five days after snowfall. Therefore the results for one, two and three night accumulation periods are probably most representative of conditions that will be met when performing lynx censuses in the field. The simulations indicate that if all lines (100%) are censused three nights after snowfall, we will detect a decline from 30 to 19 individuals from one year to the next in eight out of ten times (Figure 3a). While if the lines are censused two nights after snowfall a decline from 30 to 17 individuals will be detected eight out of ten times (Figure 3c). Deliberate lines gave higher power than random lines for both three (Figure 3a versus Figure 3b) and two night (Figure 3c versus Figure 3d) track accumulation periods. Power decreased as the census line density decreased (Figure 3). For example, a reduction from 30 to 20 individuals will be detected in 69% of the cases for three night periods with 100% of the lines, in 54% of the cases with 75% of the lines, in 43% of the cases with 50% of the lines, and in only 30% of the cases with 25% of the lines (Figure 3a). The apparently similar performance of 75% and 50% of the lines in Figure 3c is probably a result of the selection of lines (see methods), and should not be interpreted as if 50% and 75% of the lines are equally good for detecting population declines.

Trends (detection of a population decline)

The largest final population size that a decline could be detected for (i.e. the smallest detectable reduction) at a power of 0.8 increased from five individuals (a decline from 30 to 5) at seven years to 13 individuals (a decline from 30 to 13) at 20 years (Figure 4). These results are simulated under the assumptions that the decline is linear, and can therefore be tested with a linear regression, and that all deliberate lines are sampled two days after snowfall each year. These results means that over a period of 20 years a decline from 30 to 13 individuals will give a significant (at $\alpha = 0.05$) negative regression in 8 out of ten cases.

Field trials

Details of the two surveys are presented in Table 2. The data show that majority of volunteers were able to correctly identify lynx tracks, although there is room for improvement through education and training. The species which caused confusion where wolverine *Gulo gulo*, red fox *Vulpes vulpes*, mountain hare *Lepus timidus*, and domestic dog. In the 2001 survey, one more of the radio-lynx was detected by a member of the public who was only indirectly connected with the census, bringing the overall detectability to 2 of 2 for family groups and 3 of 4 overall.

Discussion

The results of both the simulations and the field trials demonstrate that the proposed system for monitoring lynx has good potential both in theory and in practice. For both 2 and 3 nights of track accumulation on the most successful design (i.e. deliberate lines) and with 75% or 100% of the transects there was a >80% power to detect a reduction of the population from 30 to 20, i.e. a 33% reduction from one survey to another in our simulations. This power is somewhat stronger than that estimated from similar studies on pumas (Beier & Cunningham 1996). The results, however, do agree with most similar evaluations of track count methodology in that only large scale changes in population size (25-50%) will be detectable (Kendall, Metzgar, Patterson & Steele 1992; Van Sickle & Lindzey 1992; Beier & Cunningham 1996). As expected from statistical first principles the power of the survey-design to detect changes between two surveys was far higher than its ability to detect trends over time. However, as lynx are hunted intensively (20-30% of population per year), and quotas are set annually it is unlikely that there will ever be a period of

>10 years over which a constant decline can be expected, making this scenario unlikely in Norway.

Secondary, but equally important products of these snow-track surveys are the collection of records of lynx family groups. While, the snow-track index may be a useful and statistically robust indicator of population trend, it is the minimum number of family groups recorded in a region that is used to set a realistic annual quota (Andrén et al. in press; Linnell et al. submitted). The use of both static and dynamic distance rules (Linnell et al. submitted) allows the inclusion of observations from the public and hunters that are recorded throughout an entire winter. However, in any monitoring system that depends on records from the public, there is the problem of being able to control for survey effort. Variable survey effort and reporting frequency will lead to uncontrolled variation in results (Mattson 1997). One effect that is common in large carnivore surveys is that the public are much more likely to report observations in the first years after lynx colonisation, but as observations become routine they are less likely to report them. It is therefore highly desirable to secure at least some minimum search effort as a constant, and the results of our simulations and field trials indicate that even a single structured snow-track survey has a very high probability of detecting family groups that are present. In order to control for sampling intensity it would be possible to differentiate between family group observations obtained from the structured survey (constant effort) and the total number of observations collected during an entire winter (variable effort).

The simulations of both power to detect trends and the detectability of individual lynx indicates that the reduction of survey intensity from 100% of the transect lines to 75% did not have dramatic effects on the results. This sample intensity corresponds to between 15 and 20 transect lines per family group home range. Reduction to 50% of the line density led to a clear reduction in survey effectiveness, implying that there is some cut off point that our scenario modelling did not identify. The better results obtained from the use of deliberate lines versus random lines lies in the lower occurrence of zero values in the deliberate lines as they are placed in areas where the chances of their being crossed by lynx are greater. Based on similar observations from bears, tigers and mountain lions (Smallwood & Fitzhugh; Clevenger & Purroy 1996; Carbone et al. 2001) it should be regarded as standard practice to selectively place transects to maximise encounters (Wilson & Delahay 2001).

In some other track surveys an attempt has been made to score the number of individuals responsible for making tracks on each transect. These efforts are fraught with difficulty (Edwards et al. 2000; Wilson & Delahay 2001) so like Beier & Cunningham (1996) we opted to operate on a presence / absence scoring. Snow is also a very labile medium such that track size and shape can vary through melting or differences in snow consistency making it hard to use measurements to separate between age classes and individuals (Smirnov & Miquelle 1996; Grigone, Burman, Bleich & Pierce 1999). In addition, there is very little age or sexual dimorphism in lynx tracks (Linnell unpublished data). Snow does compensate in that as long as it has full coverage and conditions have been stable there is a far greater chance (near 100%) of any lynx that cross the transect leaving tracks than for other media such as sand or dust (Smallwood & Fitzhugh 1995; Stander 1998; Edwards et al. 2000).

It is important to remember that these results have been obtained from a population that was basically a saturated mosaic of lynx territories. Application to a lower density population, or to one with more holes in the mosaic would require a higher sampling intensity to obtain similar power. Furthermore, if this methodology was applied to another population with smaller home ranges, and shorter nightly movement rates, there would need to be an increase in transect density such that the same ratio of transects to nightly movement distance was maintained. As the home ranges, and resultant movements in this study area are the largest ever documented for the species (Linnell, et al. 2001, Linnell et al. submitted) it is most likely that other study areas will contain lynx populations that have smaller home ranges and shorter movements (e.g. Jedrzejewski et al. 2002, Linnell et al. submitted). Finally, the difference between the deliberate and random lines is clearly a product of the topography of the study area. The high snow-fall in the region concentrated the lynx's main prey, roe deer, into the valley bottoms, thus shaping the movement patterns of lynx. In a flatter landscape, with a more uniform distribution of prey, the difference between the two designs would probably be far less (e.g. Stander 1998). Because of these inter-population differences in home range size, movement rate and movement pattern in the landscape any attempts to use indices to compare population density in different areas or extrapolate from index to absolute density (Danilov, Helle, Amekov, Belkin, Bljudnik, Helle, Kanshiev, Lindén & Makowsky 1996) must be approached with caution.

In terms of practical application of this methodology to large scale surveys it is vital to recruit volunteers if the process is to be cost-effective. In Fennoscandia, hunters are regularly incorporated into wildlife monitoring systems for ungulates (Solberg & Sæther 1999) and small game (Lindén, Helle, Helle & Wikman 1996) as well as large carnivores (Liberg & Glörsen 1995). Given the proper organisation, it should be possible, at least in Norway, to establish a tradition of hunter involvement in annual repeats of this structured survey as was done during the two field trials (Odden et al. 2000, 2001). Given that there is some misidentification of tracks, there is clearly a need for further education and field controls of reported tracks. Snow conditions are rarely identical over very large areas, so a greater degree of regional flexibility in timing will make implementation even more practical. In principle, there is no need for widespread regional synchrony in survey timing, although it would make sense if as large blocks as possible were surveyed at the same time.

The cost effectivity of this system could be further enhanced through the collection of data on other species. In our field trials, tracks from wolves and wolverines were detected. As both these species occur at very low density in our study site (Landa, Tufto, Franzén, Bø, Lindén & Swenson 1998; Wabakken, Sand, Liberg & Bjärvall 2001) any observations of their presence are vital in mapping distributional changes. The possibility of collecting data for other wildlife species also needs to be considered (Lindén et al. 1996).

In conclusion, the results of this simulation indicate that a structured snow-track survey should provide both an effective index to monitor changes in total population size and act as a minimum survey effort to detect tracks of family groups for annual minimum counts. As all single methods associated with monitoring large carnivores are generally associated with relatively poor precision and accuracy we consider that both mutually supportive methods should be used, and that data on trends in livestock depredation and age, sex structure of harvested lynx should also be considered when adjusting annual hunting quotas.

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Table 1. Detection probability computed for 100% of deliberate and random census lines for different track accumulation periods. The differences in detectability of individual lynx between the two census strategies was tested with a Wilcoxon pairwise test. A lynx was included in the computation of detectability, and in the test, if more than five observation sequences were available for the individual.

	Detectability				
Nights since snowfall	Deliberate lines	Random lines	Number of lynx	z (Wilcoxon)	p(Wilcoxon)
1	0.35	0.17	29	4.31	<0.001
2	0.57	0.30	21	3.92	<0.001
3	0.80	0.52	11	2.67	0.008
5	0.91	0.68	8	2.37	0.018

Table 2. Details of two field surveys conducted in Hedmark county in 1999 and 2001.

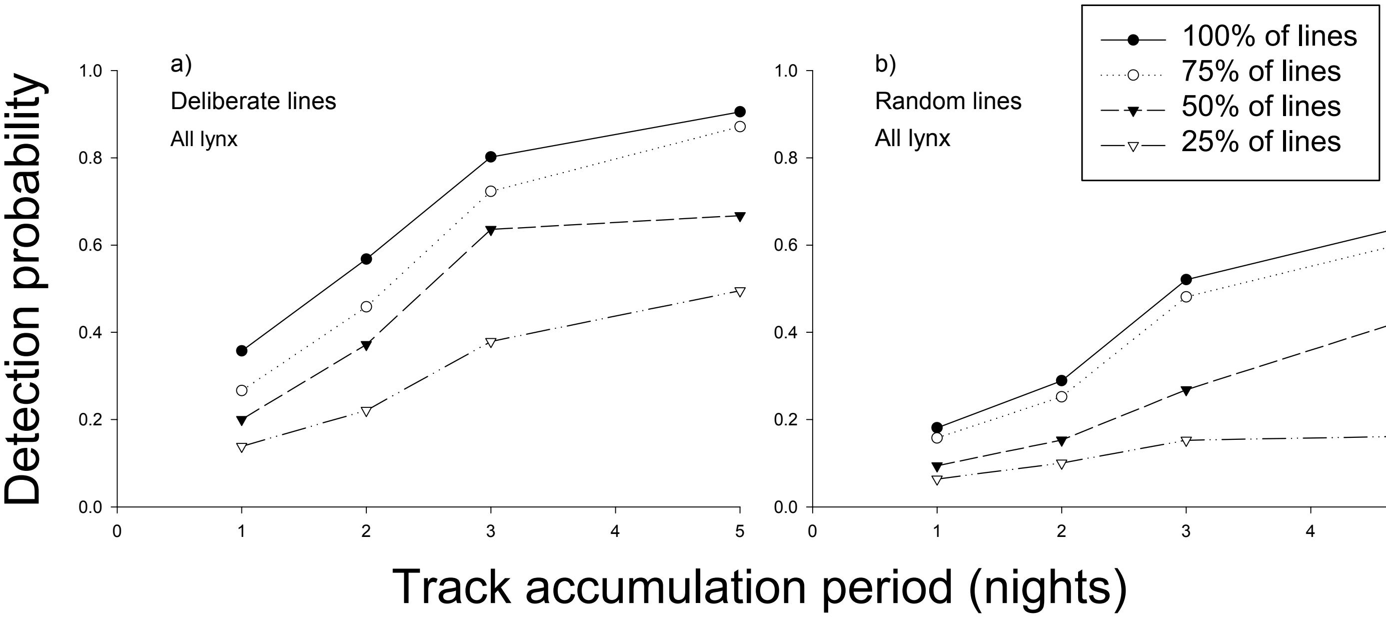
Parameter	1999	2001
Area covered (forest only)	12252 km^2	14099 km^2
Number of volunteers	692	500
Number transect lines	396	286
Transect density	1 per 31 km^2	1 per 49 km^2
Track accumulation period (nights)	3	1.5
% transects with lynx tracks	13	6
% of radio-lynx detected on transects	83 (10 of 12)	50 (2 of 4)
% of family groups detected on transects	100 (4 of 4)	50 (1 of 2)
Number of lines crossed per radio lynx	1.7 (0 – 4)	1
% of misidentifications	16	6

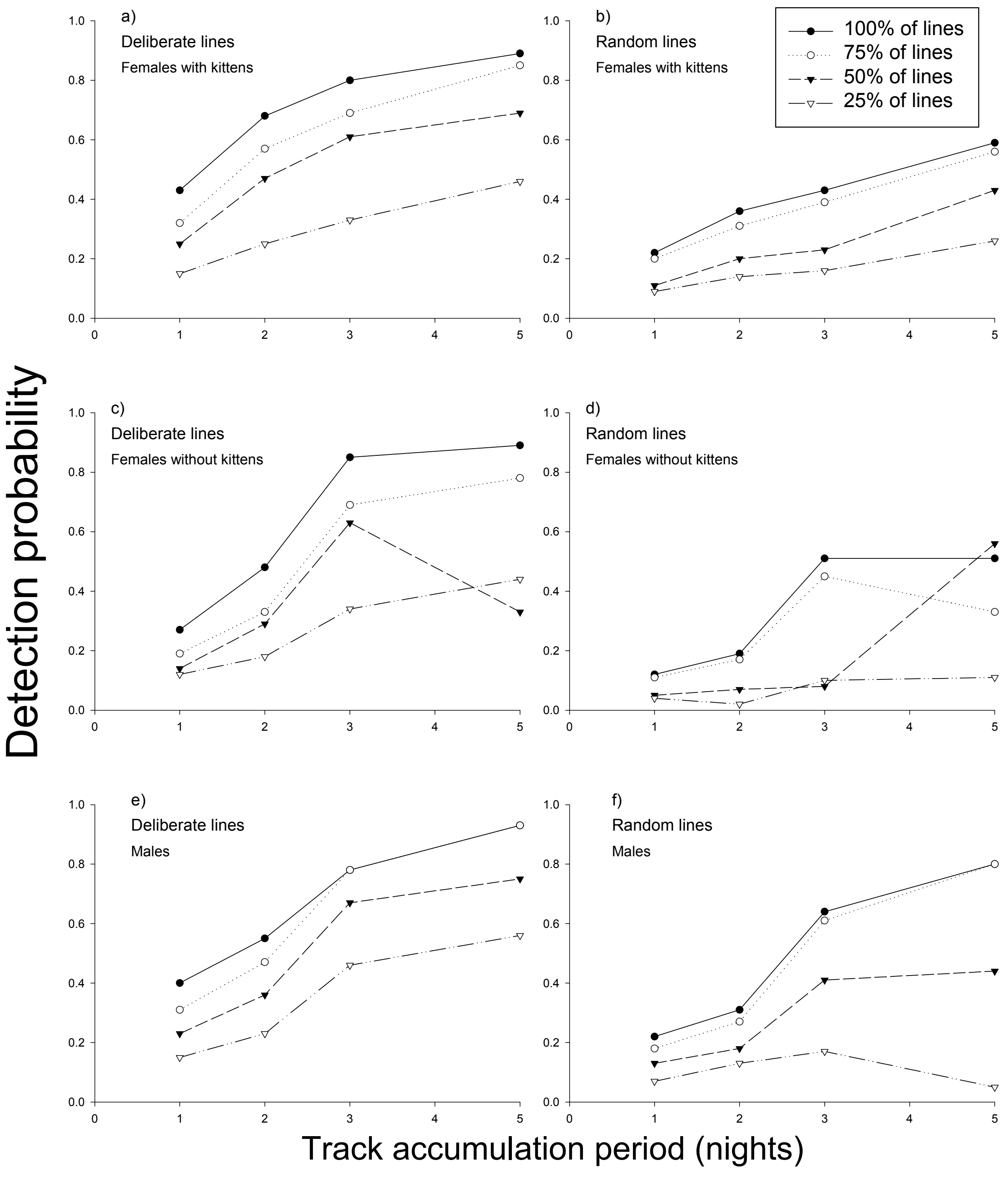
Figure 1. Estimates of the probability of detecting lynx for two different census strategies (deliberate and random lines) as a function of days after snowfall. Different lines in the figure represent different densities of census lines with 100% representing 1 line per 38 km^2. Detection probability is mean of the detection probability for individual lynx. For each day after snowfall lynx is included in the computation if we had data for five or more periods.

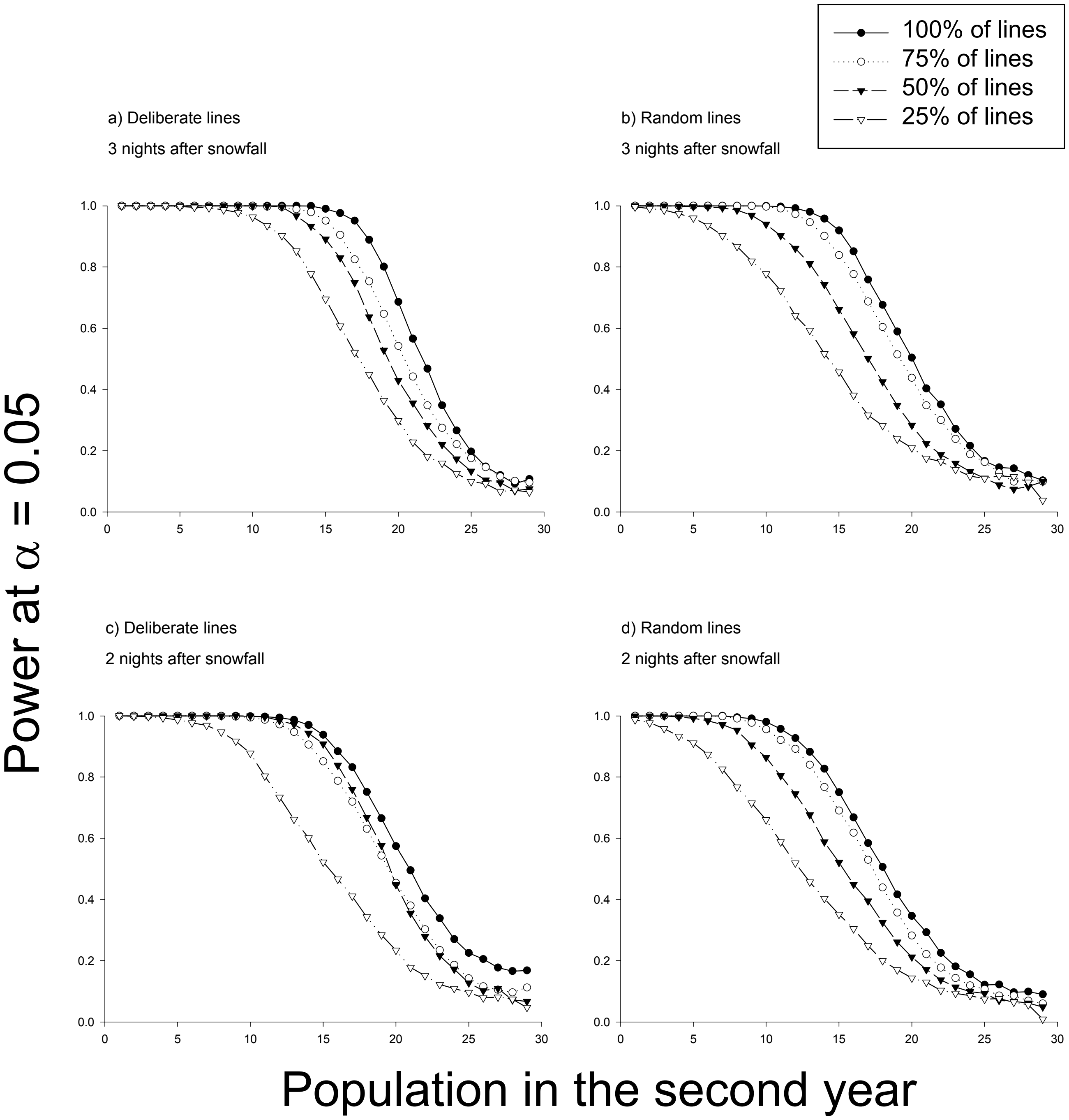
Figure 2. Estimates of the probability of detecting lynx for two different census strategies (deliberate and random lines) as a function of days after snowfall. Different lines in the figure represent different densities of census lines with 100% representing 1 line per 38 km^2. Detection probability is mean of the detection probability for individual lynx. For each day after snowfall lynx is included in the computation if we had data for five or more periods. The data are presented for male, females with kittens, and females without kittens.

Figure 3. Estimated power of a chi-square test to detect declines in the lynx population from one year to the next as a function of population size in the second year for two and tree days after snowfall. The population in the first year was held constant at 30 individuals. Power is presented for deliberate and random lines and for 100%, 75%, 50% and 25% line densities.

Figure 4. Ability to detect a linear decrease in population size with a power of 0.8. Expressed as the maximum population size (reflecting minimum change) to which an initial population of 30 must decrease in order to detect change for different time series lengths. The simulations are performed under the assumption that all deliberate lines are sampled two days after snowfall in each year of the survey.


Detection probability
Track accumulation period (nights)
a)
Deliberate lines
All lynx
b)
Random lines
All lynx
100% of lines
75% of lines
50% of lines
25% of lines
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5


Detection probability
Track accumulation period (nights)
100% of lines
75% of lines
50% of lines
25% of lines
a)
Deliberate lines
Females with kittens
b)
Random lines
Females with kittens
c)
Deliberate lines
Females without kittens
d)
Random lines
Females without kittens
e)
Deliberate lines
Males
f)
Random lines
Males
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5

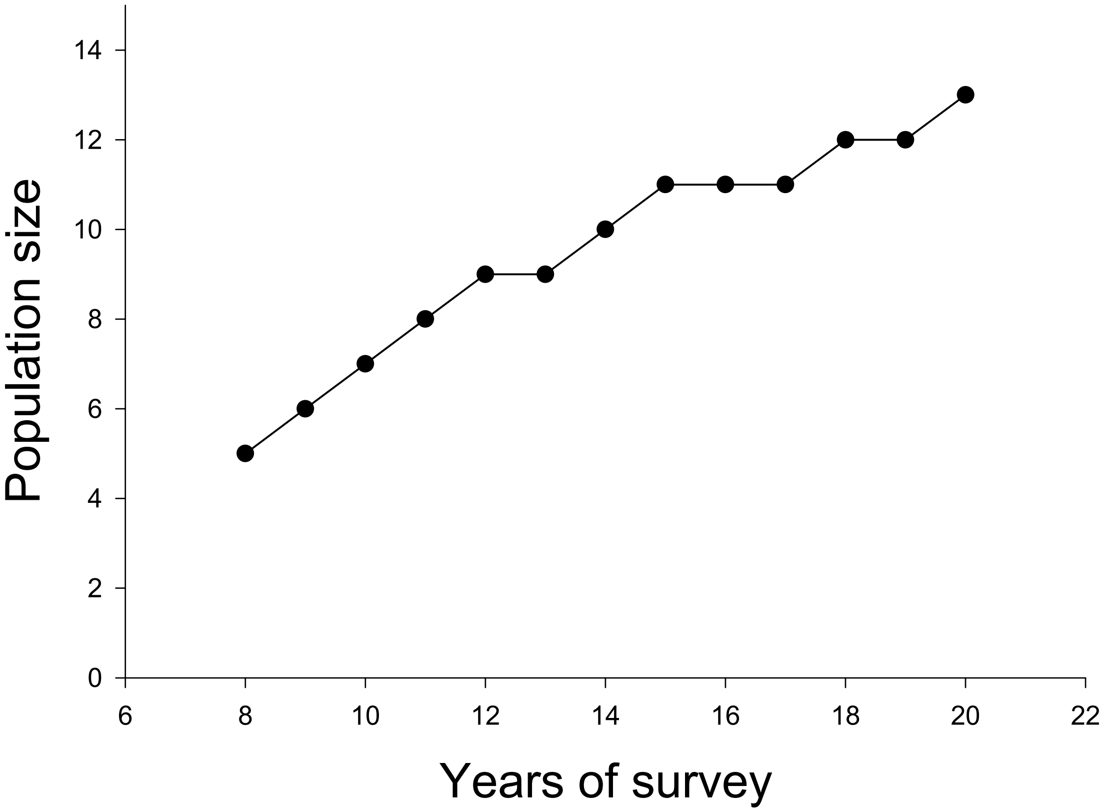


a) Deliberate lines
3 nights after snowfall

b) Random lines
3 nights after snowfall

c) Deliberate lines
2 nights after snowfall

d) Random lines
2 nights after snowfall


Population size
0
2
4
6
8
10
12
14
6
8
10
12
14
16
18
20
22
Years of survey