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Spatial variation in detectability of bears, wolverines and wolves during large-scale non-invasive genetic sampling in Norway and Sweden

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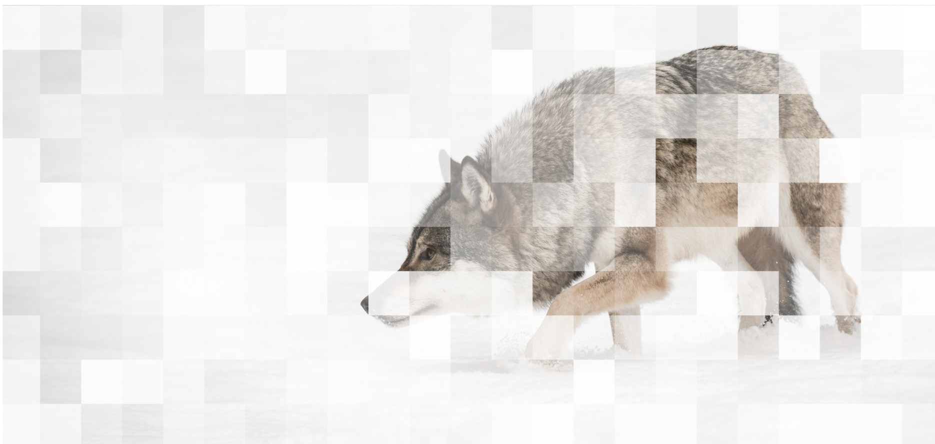

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COVER PICTURE

Imperfect detection of a wolf, stylized. Photo: Andrew Astbury/Shutterstock. Overlay: RovQuant

NØKKELORD

Brunbjørn (*Ursus arctos*), jerv (*Gulo gulo*), ulv (*Canis lupus*), deteksjonssannsynlighet, ikke-invaderende innsamling av genetisk materiale, åpen populasjon romlig fangst-gjenfangst, leteinnsats

KEY WORDS

Brown bear (*Ursus arctos*), wolverine (*Gulo gulo*), wolf (*Canis lupus*), detectability, non-invasive genetic sampling, open-population spatial capture-recapture, search effort

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Summary

Background Sweden and Norway monitor their populations of brown bears (*Ursus arctos*), wolverines (*Gulo gulo*) and wolves (*Canis lupus*) primarily by non-invasive genetic sampling (NGS). NGS is performed through 1) *structured* searches by the authorities with records of search-efforts for the wolverine and wolf, and 2) *unstructured* (opportunistic) searches conducted by both authorities and members of the public for all three species. Importantly, detection during NGS is imperfect and not all individuals present in the population are detected. Although population estimation methods used to analyze Scandinavian NGS data today account for imperfect detection, knowledge about how detectability varies across the landscape can help optimize the allocation of finite resources and ultimately the monitoring of large carnivores in Scandinavia.

Aim In this report, we present different metrics of detectability of bears, wolverines and wolves during NGS across their respective ranges in Norway and Sweden. Our goal was to assess *overall* and *spatially-explicit detectability*. *Overall detectability* represents the proportion of individuals present in the population that are detected during monitoring, while *spatially-explicit detectability* is the probability to detect an individual at least once, given its location within the study area.

Approach We derived both *overall detectability* and *spatially-explicit detectability* using parameters estimated from open-population spatial capture-recapture analyses for the three species (Dupont et al., 2024b; Milleret et al., 2024a,b). Predicted *spatially-explicit detectability* allowed us to map detectability across the main range of each species and sampling approach, for every monitoring season between 2015 and 2024.

Results Overall, we estimated that 68% of bears, 88% of wolverines and 83% of wolves were detected by NGS during the most recent monitoring season included in our analysis. This high *overall detectability* is also evident in maps of *spatially-explicit detectability* where both sampling approaches (i.e., *structured* and *unstructured sampling*) are combined. Nonetheless, we identified areas with comparatively low detectability, especially for bears and wolves. Future investigations should explore A) the extent to which predicted spatio-temporal patterns in detectability are caused by analytical constraints *vs.* true underlying patterns in the detection processes, and B) alternative sampling designs to boost the efficiency of the large carnivore monitoring programs.

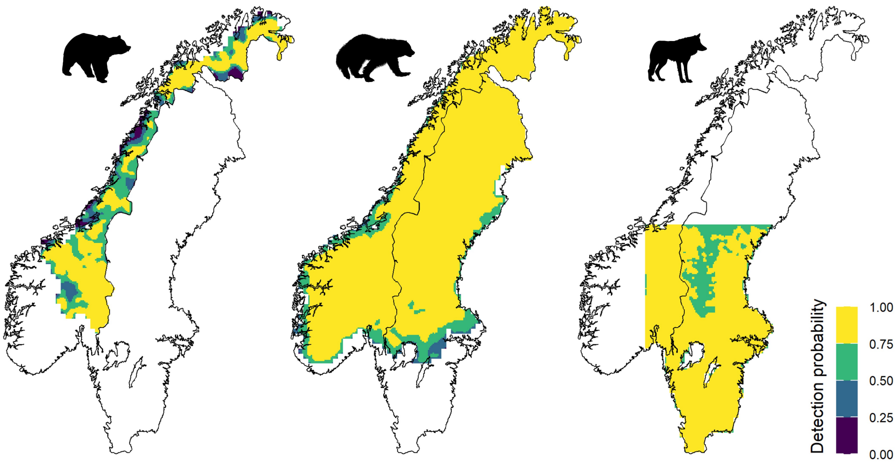


Figure 1: *Spatially-explicit detectability* of large carnivores through NGS during the most recent monitoring season in Norway and Sweden. From left to right, bear (year 2023; Norway only), wolverine (year 2024) and wolf (season 2023/2024). Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area.

Sammendrag

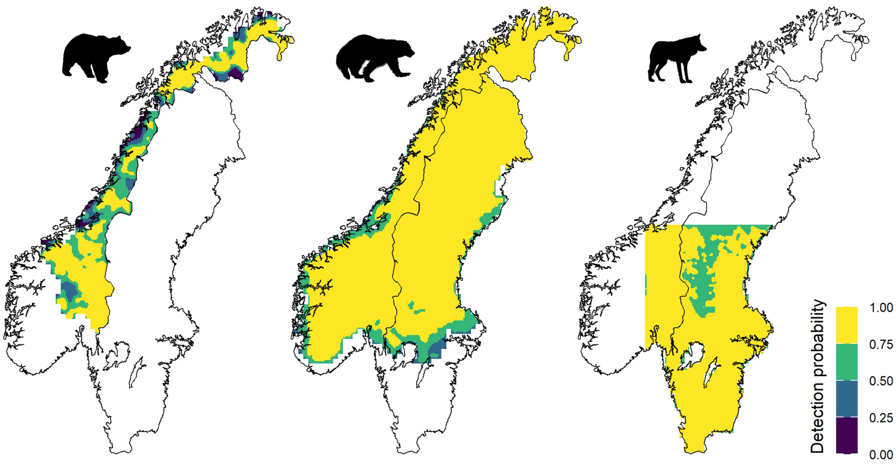
Bakgrunn Sverige og Norge overvåker sine bestander av brunbjørn (*Ursus arctos*), jerv (*Gulo gulo*) og ulv (*Canis lupus*) hovedsakelig ved hjelp av ikke-invasiv genetisk prøveinnsamling (NGS). NGS utføres ved 1) strukturert prøveinnsamling for jerv og ulv utført av myndigheter som også inkluderer registrering av leteinnsats og 2) ustrukturert (opportunistisk) prøveinnsamling for alle tre arter utført av både myndigheter og allmennheten. Deteksjon under NGS er ufullstendig, og ikke alle individer i populasjonen blir oppdaget. Selv om metoder for bestandsestimering brukt for å analysere NGS-data fra store rovdyr i Skandinavia i dag tar hensyn til ufullstendig deteksjon, kan kunnskap om variasjon i deteksjon i landskapet bidra til å optimalisere bruken av begrensede ressurser og forbedre overvåkningen av store rovdyr i Skandinavia.

Mål Vi har som mål å kartlegge deteksjonsgraden av brunbjørn, jerv og ulv i deres leveområder i Norge og Sverige.

Tilnærming Vi estimerte total og romlig deteksjonsgrad. Total deteksjonsgrad representerer andelen av individer i populasjonen som påvises ved overvåkning, mens romlig deteksjonsgrad er sannsynligheten for å påvise et individ minst én gang, avhengig av individets plassering i studieområdet. Vi avledet disse sannsynlighetene ved hjelp av parametre fra den nyeste åpen-populasjon-romlig-fangst-gjenfangst-analysen for de tre artene (Dupont et al., 2024b; Milleret et al., 2024a,b). Vi presenterer individuelle kart over deteksjonsgrad i hver arts hovedutbredelsesområde for hver prøveinnsamlingsmetode for hvert år mellom 2015 og 2024.

Resultater Vi laget årlige kart med tetthet av jerv fra 2015 til 2024, hvor bestandsstørrelsen både totalt og innenfor ulike administrative enheter kunne avledes. Basert på OPSCR modellen var den skandinaviske bestanden av jerv mellom 1012 og 1072 individer i 2024 (95% kredibelt intervall), med 642 til 690 individer i Sverige og 360 til 393 individer i Norge. I tillegg til årlige tettheter og områdespesifikke bestandsestimater, gir rapporten estimater på dødlighetsfaktorer, rekruttering og oppdagbarhet.

Resultater og diskusjon Vi estimerte at 68% av brunbjørn, 88% av jerv og 83% av ulv ble detektert ved hjelp av NGS under den siste overvåkningssesongen. Denne høye totale deteksjonsgraden er synlig i kart over romlig deteksjonsgrad, der begge prøveinnsamlingsmetoder (dvs. strukturert og ustrukturert prøveinnsamling) er kombinert. Vi fant likevel områder der deteksjonsgraden var påfallende lav, spesielt for brunbjørn og ulv. Videre undersøkelser kan avdekke A) i hvilken grad de observerte romlig-temporale mønstrene i deteksjon skyldes analytiske begrensninger vs. sanne underliggende mønstre i deteksjonsprosessene og B) alternative prøveinnsamlingsdesign for å forbedre ressursbruk i overvåkningsprogrammene for store rovdyr.



Den romlig-eksplisitte detekesjonsgraden av store rovdyr ved hjelp av NGS i den siste overvåkningssesongen i Norge og Sverige. Fra venstre til høyre, brunbjørn (2023; kun Norge), jerv (2024) og ulv (sesongen 2023/2024). Fargekodede pikselverdier indikerer sannsynligheten for at et individ med sitt aktivitetsområde i den pikselen blir oppdaget minst én gang i hele studieområdet.

Contents

1 Introduction

Large carnivore monitoring Sweden and Norway use non-invasive genetic sampling (NGS) and dead recoveries to monitor shared populations of brown bears (*Ursus arctos*), wolverines (*Gulo gulo*) and wolves (*Canis lupus*). NGS has been conducted in both countries for nearly two decades, resulting in one of the largest and most extensive large carnivore individual-based data sets in the world. This database, stored and publicly available in Rovbase (rovbase.se, rovbase.no), is used to assess the status of large carnivore populations in Scandinavia. Since 2017, project RovQuant (nmbu.no; Bischof et al. 2019) has been developing and applying statistical methods to assess the population status and dynamics of the three large carnivore species. Today, Bayesian open-population spatial capture-recapture (OPSCR) models (Bischof et al., 2020; Dupont et al., 2021) are used on a yearly basis by RovQuant to estimate and report annual estimates of population densities and vital rates of bears in Norway (Dupont et al., 2024b), and wolverines and wolves in both Norway and Sweden (Milleret et al., 2024a,b).

Imperfect detection During NGS, sources of DNA (e.g., scats, urine, hair) are collected following two main sampling approaches. *Structured sampling* is conducted by authorities for wolverines and wolves, while *unstructured sampling* (opportunistic) is conducted by both authorities and members of the public for bears, wolverines and wolves. The main difference between those two approaches is that a detailed search effort is recorded during *structured sampling*, while a direct measure of search effort is not available for *unstructured sampling*. The wildlife management authorities in charge of the large carnivore monitoring programs are the Norwegian Nature Inspectorate (SNO) in Norway and the County Administrative Boards (Länsstyrelserna) in Sweden. Regardless of the sampling method, detection is imperfect, meaning that not all individuals present in the population are detected each year. While OPSCR models estimate and thus account for imperfect detection when estimating population size, knowledge about the spatial and temporal variation in detectability is useful in itself. It could for example help identify important gaps in NGS coverage and, generally, make resource allocation more effective.

This analysis In this report, we derived *overall* and *spatially-explicit detectability* of bears, wolverines and wolves during annual NGS in Norway and Sweden using results from the RovQuant OPSCR analyses (Dupont et al., 2024b; Milleret et al., 2024b,a). We then mapped *spatially-explicit detectability* across each species' range for the nine most recent monitoring seasons and two sampling approaches (i.e., *structured* and *unstructured*). We conclude with a discussion of the implications of our findings for the monitoring of large carnivore in Scandinavia and suggestions for future research.

Box 1: Terms and acronyms used

AC: Activity center. Model-based equivalent of the center of an individual's home range during the monitoring season. "AC location" refers to the spatial coordinates of an individual AC in a given monitoring season.
Detectors: Potential detection locations in the open-population spatial capture-recapture framework. These can refer to fixed locations (e.g., camera-trap locations) or, in this report, to areas searched (e.g., habitat grid cells where searches for genetic samples were conducted or samples could have potentially been collected opportunistically).
Länsstyrelserna: Swedish County Administrative Boards, in charge of the monitoring of large carnivores at the county level.
NGS: Non-invasive genetic sampling.
OPSCR: Open-population spatial capture-recapture. OPSCR models use the spatial information contained in detections of individuals collected over multiple monitoring seasons to estimate population densities, vital rates, and probability of detection.
p_0: Baseline detection probability; probability of detecting an individual at a given detector, if the individual's AC is located exactly at the detector location.
σ : Scale parameter of the detection function; related to the size of the circular home-range.
Rovbase: Scadinavian large carnivore database (www.rovbase.se, www.rovbase.no).
RovQuant: Research project at the Norwegian University of Life Sciences (Ås, Norway) that develops and applies OPSCR models (www.nmbu.no).
SNO: Statens naturoppsyn (Norwegian Nature Inspectorate) is the operative field branch of the Norwegian Environment Directorate (Miljødirektoratet).
Overall detectability: The proportion of individuals in the population that are detected at least once during NGS.
Spatially-explicit detectability: The probability that an individual is detected at least once depending on its location within the study area. This *spatially-explicit* measure allows mapping spatial variation in detectability.
Structured sampling: Sampling approach conducted by authorities and for which detailed search effort (i.e., length of GPS search tracks) is available. *Structured sampling* is conducted for wolverines and wolves. In Norway, the wildlife management authority in charge of the large carnivore monitoring programs is SNO, and NGS collection is conducted by SNO field officers, wardens at Statskog Fjelltjenesten (www.statskog.no), wardens at Fjellstyrene (fjellstyrene.no). Rovdata (rovdata.no), a unit within the Norwegian Institute for Nature Research, has responsibility for the Norwegian large carnivore monitoring program. In Sweden, the collection of NGS is managed by Länsstyrelserna at the regional level and carried out by field officers from Länsstyrelserna.
Unstructured sampling: Sampling approach conducted by both authorities and members of the public such as local predator contacts, hunters and other members of the public. No record of search effort is available for *unstructured sampling* as NGS samples are collected in an opportunistic manner. *Unstructured sampling* is conducted for bears, wolverines and wolves.

2 Methods

We derived *overall* and *spatially-explicit detectability* by using the parameter estimates of the species-specific OPSCR models developed by RovQuant (Dupont et al., 2024b; Milleret et al., 2024a,b). We derived *overall detectability* for each species and monitoring season, and we mapped *spatially-explicit detectability* for each species, sampling approach, and monitoring season.

OPSCR models and detection probability OPSCR models are composed of three sub-models: 1) a model for population dynamics and population size (population dynamics and population size sub-model); 2) a model for density and movement (density and movement sub-model); and 3) a model for detections during DNA searches (detection sub-model). The two first sub-models represent the ecological process, i.e., how individuals in the population are distributed, move, survive, and reproduce, while the third sub-model represents the observational process, i.e., how individuals in the population are detected or not, depending on their location and status.
The detection sub-model considers the spatial and individual variation in detection probability by modeling individual detection probability across a grid of detectors (5 × 5 km cells for bears, and 10 × 10 km cells for wolverines and wolves). Individual detection probability at each detector is then modeled as a function of the distance between the detector and the individual's activity center (AC) location (estimated by the density sub-model). In our OPSCR models, a half-normal detection function is used to express the declining probability of detection with increasing distance between the AC and the detector:

$$p_{i,j,t} = p_{0_{i,j,t}} \cdot e^{-\frac{D^2_{i,j,t}}{2\sigma^2_t}} \quad (1)$$

where $p_{i,j,t}$ is the probability to detect individual i at detector j during monitoring season t, $p_{0_{i,j,t}}$ is the baseline detection probability, i.e., the probability to detect an individual at its AC location, $D_{i,j,t}$ is the Euclidean distance between the AC location of individual i and detector j in season t. The scale parameter σ describes how fast the detection probability decreases with distance from the AC. In addition to being allowed to vary among seasons, p_0 is modeled as a function of several spatial and individual covariates to account for additional sources of variation in detection probability. For each species, the following covariates were used (note that there was no *structured sampling* for bears):

Structured sampling:

- Spatio-temporal variation in effort using the length of GPS search tracks in each detector grid cell (**wolf and wolverine**).
- Spatio-temporal variation in snow cover (**wolverine and wolf**).
- Spatio-temporal variation in monitoring regimes between jurisdictions (groups of counties in Sweden, monitoring regions in Norway; **wolverine and wolf**).
- Individual and temporal variation linked with a detection during the previous monitoring season that could be expected to positively influence the probability of being detected during the current monitoring season (**wolverine and wolf**).
- Individual and temporal variation linked with the state of the individual, i.e., adult scent-marking individuals *vs.* other individuals (**wolf**).

Unstructured sampling:

- Spatio-temporal variation in carnivore observations/detections. For each detector grid cell and during each monitoring season of each species, we identified whether a) any carnivore sample had been registered in Rovbase and b) any observation of carnivores had been registered in Skandobs. Skandobs is a web application (skandobs.se, skandobs.no) that allows anyone to register observations (e.g., visual, tracks, faeces, etc.) of bears, wolverines, wolves and lynx (*Lynx lynx*) in Scandinavia. Roughly, this binary variable distinguishes areas with very low detection probability from those with a higher probability that carnivore DNA samples could have been detected and submitted for genetic analysis (**bear, wolverine, and wolf**).
- Spatial variation in accessibility measured as the average distance to the nearest road (**bear, wolverine, and wolf**).

- Spatio-temporal variation in snow cover (**wolverine and wolf**).
- Individual and temporal variation linked with a detection during the previous monitoring season that could be expected to positively influence the probability of being detected during the current monitoring season (**wolverine and wolf**).
- Individual and temporal variation linked with the state of the individual, i.e., adult scent-marking individuals *vs.* other individuals (**wolf**).

More details about the RovQuant OPSCR models and the data used to fit the models (including the detection covariates listed above) can be found in Dupont et al. 2024b; Milleret et al. 2024b and Milleret et al. 2024a.

2.1 Overall detectability

We calculated *overall detectability* (i.e., the proportion of individuals detected in the population) for each species and monitoring season. We did this by dividing the number of detected individuals with model-estimated AC locations inside the study area (i.e., the entire range of each species) by the total number of individuals (detected and undetected) estimated to have their ACs within the study area. OPSCR-based number of individuals estimated within the study area were obtained from the last RovQuant reports (Dupont et al., 2024b; Milleret et al., 2024a,b). We calculated uncertainty (i.e., 95% Bayesian Credible Intervals) associated with the *overall detectability* estimates from the posterior distribution of the number of ACs estimated by the OPSCR.

2.2 Spatially-explicit detectability

2.2.1 Calculating spatially-explicit detectability

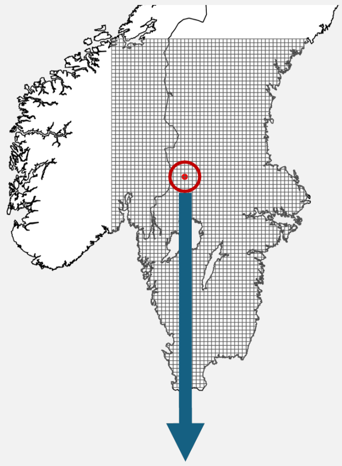
The p_0 parameter of OPSCR models quantifies the probability of detecting an individual right at its AC location. This parameter is challenging to interpret as it does not directly translate to the probability that the individual will be detected at all (or completely missed) during sampling. We therefore used the parameter estimates from the OPSCR that are related to detection probability (described above) to predict *spatially-explicit detectability*, i.e., the probability that an individual is detected at least once anywhere in the study area, conditional on the location of its activity center. Thus, detectability $\dot{p}_{s,t}$ for an individual with its AC location s during monitoring season t can be calculated as:

$$\dot{p}_{s,t} = 1 - \prod_{j=1}^{J} (1 - p_{s,j,t}) \tag{2}$$

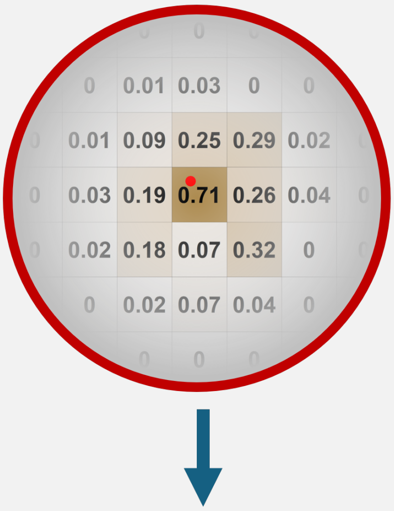
where $p_{s,j,t}$ is the detection probability at detector j and monitoring season t of a hypothetical individual whose AC is located at s. *Spatially-explicit detectability* as defined by equation 2 thus represents the probability of detecting an individual at least once given its AC location and configuration of detectors. In probabilistic terms, it is the complement of the probability of not detecting the individual in any of the detector grid cells. A schematic illustration of the process for calculating *spatially-explicit detectability* is provided in Box 2.

Because the different probabilities in detection at the different detectors are taken into account in the calculation, this measure of *spatially-explicit detectability* accounts for spatial variation in search effort and other factors influencing detectability that were considered in the OPSCR model (see covariates on detection sub-model above). We derived *spatially-explicit detectability* at a 5-km resolution to generate corresponding raster maps. This process was repeated for each species, sex, monitoring season, and when applicable, for different individual states (i.e., individual detected the previous monitoring season or scent-marking individual) and sampling approaches (i.e., *structured* and *unstructured sampling*).

Box 2: Calculation of spatially-explicit detectability



1. Activity center location of one example individual (red dot) and detector grid (wolf study area).



2. Detection probability for this individual is calculated at all detectors. Numbers show the detection probability of the individual at each detector j during monitoring season t. These values include potential covariate effects such as search effort, individual state, etc.

$$\dot{p}_{s,t} = 1 - \prod_{j=1}^{J} \left(1 - p_{s,j,t}\right)$$

3. Spatially-explicit detectability across the entire study area for this individual is calculated by considering the detection probabilities ($p_{s,j,t}$) at all J detectors.

$$\dot{p}_{s,t} = 0.97$$

4. The result is the probability of detecting that individual at least once across the entire study area. The process is repeated for all possible locations s.

2.2.2 Generating combined detectability maps

In order to obtain a single detectability map for each species and monitoring season, we combined the rasters corresponding to different categories (sex and individual states) and sampling approaches (*structured* and *unstructured*; see section above).

- For **bears**, we combined detectability maps of males and females during *unstructured sampling* only.
- For **wolverines**, we combined detectability maps of males and females, during *structured*- and

unstructured sampling, and for individuals which *had been* detected during the previous monitoring season and *had not been* detected during the previous monitoring season.

- For **wolves**, we combined detectability maps for males and females, during *structured*- and *unstructured sampling*, for individuals which *had been* detected during the previous monitoring season and *had not been* detected during the previous monitoring season, and for each state (i.e., *scent-marking* individuals and *not scent-marking* individuals).

Combined maps were produced by calculating a weighted average of the different maps using the estimated proportions of a) males and females, b) previously detected and not previously detected individuals, and c) scent-marking individuals and non-scent-marking individuals estimated from the RovQuant models (Dupont et al., 2024b; Milleret et al., 2024a,b).

We thus obtained one map per monitoring season for the brown bear, and two maps per season for the wolf and wolverine (one for *structured sampling* and one for *unstructured sampling*). For wolf and wolverine, we further combined the *structured* and *unstructured sampling* maps by considering that total detectability ($\dot{p}_{\text{total}}$) is a function of the detection probabilities during *structured sampling* ($\dot{p}_{\text{struc}}$) and during *unstructured sampling* ($\dot{p}_{\text{unstruc}}$):

$$\dot{p}_{\text{total}} = 1 - [(1 - \dot{p}_{\text{struc}})(1 - \dot{p}_{\text{unstruc}})] \tag{3}$$

3 Results

Overall detectability during the last monitoring season was high for all three species: 68% (95% Bayesian Credible Interval (BCI) = 61-75%) for bears, 88% (85%-90%) for wolverines and 83% (77-88%) for wolves (Table A.1). *Spatially-explicit* estimates of detectability revealed that the probability of detecting an individual within the main population range for each species was high (Figure 1). Additionally, our detectability maps indicated that for wolverines and wolves, the combination of *structured* and *unstructured sampling* resulted in a consistently high *spatially-explicit* across nearly the entire study area (Figure 3 and Figure 4).

3.1 Brown bear

Only *unstructured* NGS data is collected during bear monitoring and our analysis was restricted to Norway due to the patchy and staggered monitoring design in Sweden (Dupont et al., 2024a,b).
Overall detectability for the bear across the study area in 2023 was 0.68 (0.61-0.75). This means that between 61% and 75% of bears estimated to reside in the study area were detected through NGS conducted in Norway. During the study period, *overall detectability* of bears in Norway ranged from 0.60 (0.53-0.67) in 2015 to 0.77 (0.70-0.84) in 2020 and 2021 (Table A.1).

Spatially-explicit detectability in 2023 was relatively high across the study area, but there were some areas (18% of the cells within the study area) with a detectability < 0.50 (Figure 2). Detectability was relatively stable over time - albeit slightly lower during the 2018 monitoring season (Figure A.1) - and comparable spatial patterns were observed across seasons.

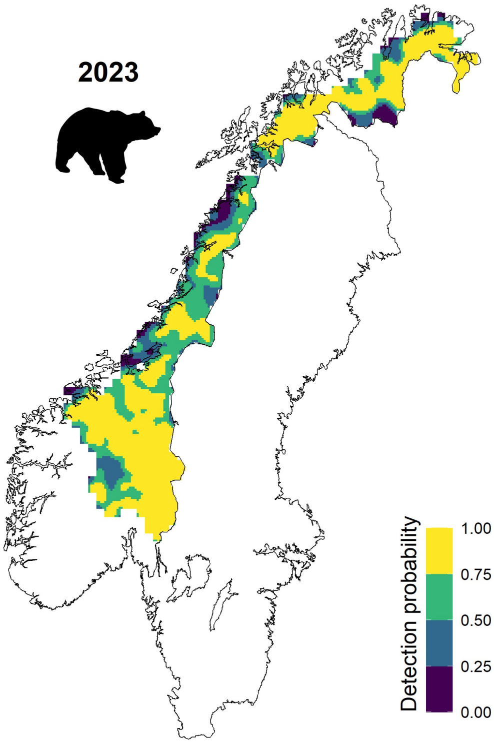


Figure 2: Brown bear *spatially-explicit detectability* in Norway in 2023. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area. Predictions are based on the estimated detection probability parameters obtained using the OPSCR model (Dupont et al., 2024b). Annual maps (2015-2023) are provided in Figure A.1

3.2 Wolverine

Overall detectability for the wolverine across the study area in 2024 was 0.88 (0.85-0.90). This means that 85% to 90% of wolverines estimated to likely live within the study area were detected during NGS. *Overall detectability* of wolverines varied substantially during the period covered in our analysis, ranging from 0.53 (0.49-0.57) in 2016 to 0.88 (0.85-0.90) in 2024 (Table A.1).

Spatially-explicit detectability during *structured sampling* in 2024 was highest in the North of the study area, especially in Northern Sweden (Norrbotten county), and in South-central Norway (Figure 3). For *unstructured sampling*, we estimated the highest detectability in the mountainous regions of Norway (Figure 3). The combination of both sampling approaches led to a high detectability across the entire study area (Figure 3). Spatial patterns in detectability during both *structured* and *unstructured sampling* varied notably over the 9-year study period (Figure A.2 and Figure A.3). Part of this variation was likely due to Norrbotten county not being sampled comprehensively every year. Note that in those years, detectability was set to 0 in Norrbotten county for both *structured* and *unstructured sampling* in the OPSCR analysis (Milleret et al., 2024a). Our maps also revealed that detectability was consistently higher in Norway than in Sweden during the study period.

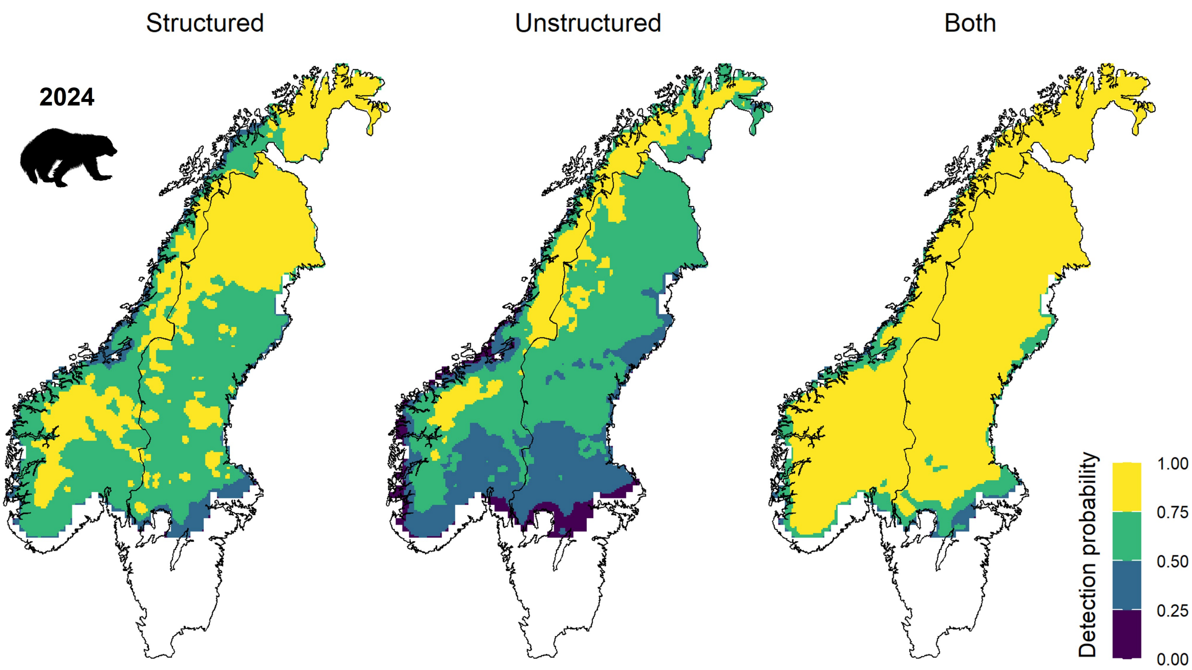


Figure 3: Wolverine *spatially-explicit detectability* in Scandinavia in 2024. Detectability is shown for *structured sampling*, *unstructured sampling*, and the combination of both. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area. Predictions are based on the estimated detection probability parameters obtained using the OPSCR model (Milleret et al., 2024b). Annual maps (2016-2024) are provided in Figure A.2, Figure A.3 and Figure A.4.

3.3 Wolf

Overall detectability for the wolf across the study area in 2023/2024 was 0.83 (0.77-0.88). This means that between 77% and 88% of all individuals estimated to reside within the study area were detected through NGS. During the study period, *overall detectability* of wolves ranged from 0.75 (0.71-0.79) in 2015/2016 to 0.94 (0.92-0.96) in 2019/2020 (Table A.1).

While *spatially-explicit detectability* during *structured sampling* in 2023/2024 was relatively homogeneous across the entire study area, detectability during *unstructured sampling* exhibited pronounced spatial patterns, with the lowest detectability estimated in the central part of Sweden, near the Norwegian border (Figure 4). This pattern in detectability was still visible, albeit tempered, when combining both sampling methods. Our time series of detectability maps showed that, during the 9-year study period, detectability during *structured sampling* was higher in Sweden than in Norway (Figure A.5). Detectability during *unstructured sampling* exhibited both pronounced spatial and temporal patterns, with generally higher detectability in Norway and the lowest detectability area consistently transecting the core wolf range in Sweden (Figure A.6).

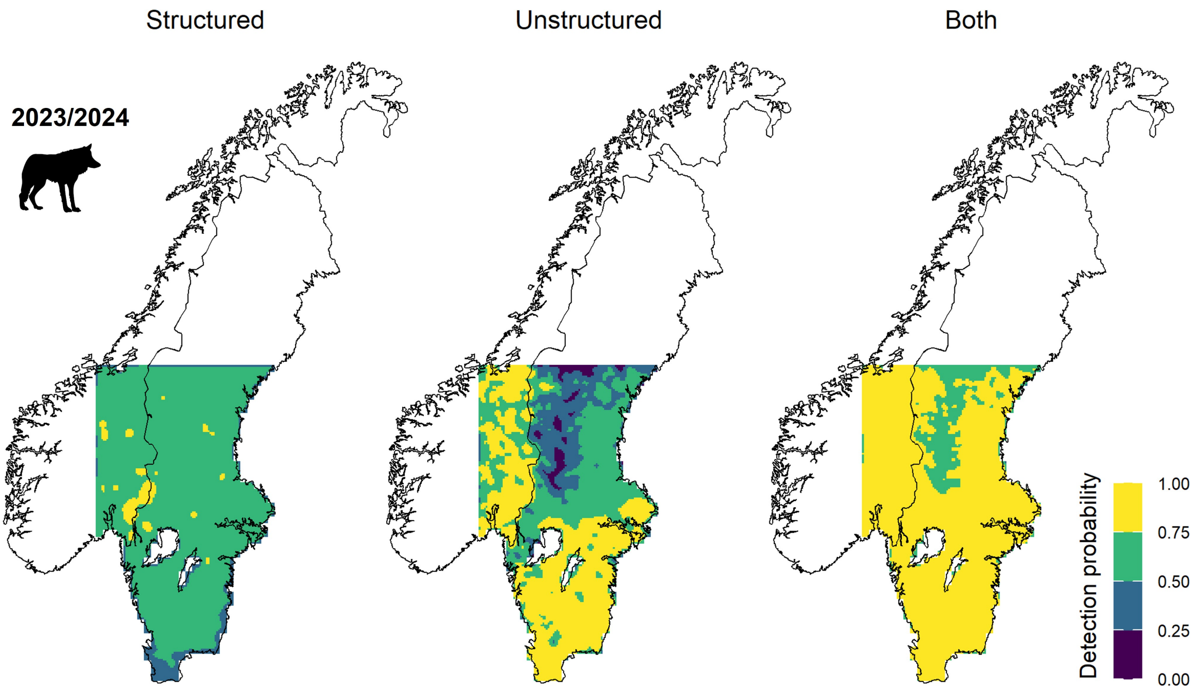


Figure 4: Wolf *spatially-explicit detectability* in Scandinavia during the 2023/2024 monitoring season. Detectability is shown for *structured sampling*, *unstructured sampling*, and the combination of both. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area. Predictions are based on the estimated detection probability parameters obtained using the OPSCR model (Milleret et al., 2024a). Annual maps (2015/16 - 2023/24) are provided in Figure A.5, Figure A.6 and Figure A.7.

4 Discussion

The main goal of this report was to investigate spatial and temporal patterns in detectability of the three large carnivore species monitored with NGS in Norway and Sweden. In summary, we found that:

1. *Overall detectability* for all species was high (68% for bears, 88% for wolverines and 83% for wolves during the last monitoring season available at the time of this report).
2. Maps of *spatially-explicit detectability* estimates for wolves and wolverines revealed that, due to the combined use of two sampling approaches (*structured* and *unstructured sampling*), the probability for an individual to be detected at least once was higher than 0.75 throughout most of the study area.
3. Our maps revealed that detectability was usually higher where species density was higher (see density maps in Dupont et al. 2024b; Milleret et al. 2024a and Milleret et al. 2024b) and tended to decrease with increasing distance from the core areas of the populations.
4. *Spatially-explicit detectability* of **bears** was low (<0.5) in 18% of the cells within the monitoring area. Low detectability in those areas can be explained by a combination of two factors: 1) lower accessibility to potential searchers (e.g., along the Norwegian-Russian border) and 2) longer distance of those areas from the core areas of the bear population in Norway and Sweden.
5. The apparent high *spatially-explicit detectability* of **wolverines** in mountainous areas throughout Scandinavia might be an artifact of the strong positive relationship between snow cover and baseline detection probability (p_0) estimated by the OPSCR models (Milleret et al., 2024b). The intensive sampling in Norrbotten during 2024 likely drove this strong correlation between snow cover and baseline detection probability, leading to high predicted detectability in other snow-covered regions throughout Scandinavia during that monitoring season.
6. Patterns in *spatially-explicit detectability* of **wolves** during *structured sampling* were mostly explained by spatial variation in search effort. Areas that were searched more intensively (i.e., higher density of GPS search tracks) had higher predicted detectability. On the other hand, differences in detectability across the study area during *unstructured sampling* mostly reflected spatial variation in carnivore observation reports (skandobs.se, skandobs.no), which was estimated to positively influence detectability by the OPSCR model. Areas with a higher number of carnivore observations were more likely to have been searched and thus detectability was estimated to be higher in those areas, highlighting the usefulness of this covariate as a proxy of search effort during *unstructured sampling.*

5 Suggestions for future improvements

In this report, we identified patterns in detectability across space and time during NGS-based monitoring of large carnivores in Scandinavia. These patterns were predicted by relying on the model-estimated association between detection probability and covariates used to quantify spatial, temporal, and individual variation in baseline detection probability in the OPSCR observation sub-model. While this approach aids in prediction, potentially important unmodeled sources of variation in detectability may be missed, including fine scale patterns driven by individual variation and local contexts. We therefore recommend further analyses to determine the extent to which current spatial covariates of detection probability capture true spatial patterns in detectability. This includes, for example, the implementation of goodness-of-fit test to formally check the performance of OPSCR models and testing alternative modelling approaches that explicitly account for spatial variation in detectability in the OPSCR framework (Dey et al., 2023; Choo et al., 2024). One such approach is the use of conditional autoregressive (CAR) models, which can account for spatial autocorrelation in detectability by assuming that the detection probability in a given cell is influenced by the detection probability in neighboring cells. This statistical approach could complement or even partially replace the use of spatial covariates in the OPSCR detection sub-model. Finally, regardless of the analytical approach chosen, we recommend exploring alternative ways of collecting NGS data by conducting simulation studies that yield a better understanding of the trade-off between monitoring intensity (over space and time) and reliability of density estimates.

6 Acknowledgements

This work was made possible by the large carnivore monitoring programs and the extensive monitoring and observation data collected by Swedish (Länstyrelsena) and Norwegian (SNO) wildlife management authorities, as well as the public in both countries. Our analysis relied on genetic analyses conducted by the laboratory personnel at the DNA laboratories at the Swedish University of Agricultural Sciences, the Swedish Museum of Natural History, the Norwegian Institute for Nature Research, and the Norwegian Bioeconomy Research Institute. We also thank Swedish and Norwegian wildlife managers for feedback provided during project RovQuant and the Research Council of Norway for partial funding (project WildMap NFR 286886, project PopFlow NFR 345279). The computations/simulations were performed on resources provided by NMBU's computing cluster "Orion", administered by the Centre for Integrative Genetics. J. Vermaat provided helpful comments on a draft of this report and N. R. Hansen helped with the Norwegian translation.

7 Data availability

Data, R code to reproduce the analysis, as well as figures, tables, and raster data underlying the detectability maps are available at https://github.com/richbi/RovQuantPublic.

References

Bischof, R., Milleret, C., Dupont, P., Chipperfield, J., Brøseth, H., and Kindberg, J. (2019). RovQuant: Estimating density, abundance and population dynamics of bears, wolverines and wolves in Scandinavia MINA fagrapport 63. Technical report, Norwegian University of Life Sciences, Ås, Norway.

Bischof, R., Milleret, C., Dupont, P., Chipperfield, J., Tourani, M., Ordiz, A., de Valpine, P., Turek, D., Royle, J. A., Gimenez, O., Flagstad, O., Åkesson, M., Svensson, L., Brøseth, H., and Kindberg, J. (2020). Estimating and forecasting spatial population dynamics of apex predators using transnational genetic monitoring. *Proceedings of the National Academy of Sciences*, 117(48):30531–30538.

Choo, Y. R., Sutherland, C., and Johnston, A. (2024). A monte carlo resampling framework for implementing goodness-of-fit tests in spatial capture-recapture models. *Methods in Ecology and Evolution*, 15(9):1653–1666.

Dey, S., Moqanaki, E., Milleret, C., Dupont, P., Tourani, M., and Bischof, R. (2023). Modelling spatially autocorrelated detection probabilities in spatial capture-recapture using random effects. *Ecological Modelling*, 479:110324.

Dupont, P., Milleret, C., Brøseth, H., Kindberg, J., and Bischof, R. (2024a). Challenges in estimating range-wide brown bear density and abundance in sweden (2012–2021). Report.

Dupont, P., Milleret, C., Brøseth, H., Kindberg, J., and Bischof, R. (2024b). Estimates of brown bear density, abundance, and population dynamics in norway 2014-2024. Report.

Dupont, P., Milleret, C., Tourani, M., Brøseth, H., and Bischof, R. (2021). Integrating dead recoveries in open-population spatial capture–recapture models. *Ecosphere*, 12(7):e03571.

Milleret, C., Dupont, P., Brøseth, H., Flagstad, O., Kindberg, J., Svensson, L., and Bischof, R. (2024a). Estimates of wolf density, abundance, and population dynamics in scandinavia, 2014–2024. Report.

Milleret, C., Dupont, P., Brøseth, H., Flagstad, O., Kleven, O., Königsson, H., Spong, G., Kindberg, J., and Bischof, R. (2024b). Estimates of wolverine density, abundance, and population dynamics in scandinavia, 2015–2024. Report.

Appendices

Table A.1: *Overall detectability* for each species and monitoring season. Bayesian credible intervals (95%) are shown in parentheses.

Bear	2015	2016	2017	2018	2019	2020	2021	2022	2023
	0.60 (0.53-0.67)	0.63 (0.56-0.70)	0.63 (0.56-0.70)	0.63 (0.56-0.71)	0.71 (0.65-0.78)	0.77 (0.70-0.84)	0.77 (0.70-0.83)	0.73 (0.66-0.79)	0.68 (0.61-0.75)
Wolverine	2016	2017	2018	2019	2020	2021	2022	2023	2024
	0.53 (0.49-0.57)	0.72 (0.70-0.75)	0.74 (0.71-0.76)	0.69 (0.66-0.71)	0.59 (0.57-0.62)	0.62 (0.59-0.64)	0.62 (0.60-0.65)	0.63 (0.61-0.65)	0.88 (0.85-0.90)
Wolf	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	2020/2021	2021/2022	2022/2023	2023/2024
	0.75 (0.71-0.79)	0.88 (0.86-0.91)	0.91 (0.89-0.93)	0.76 (0.72-0.80)	0.94 (0.92-0.96)	0.84 (0.81-0.87)	0.86 (0.83-0.89)	0.87 (0.84-0.90)	0.83 (0.77-0.88)

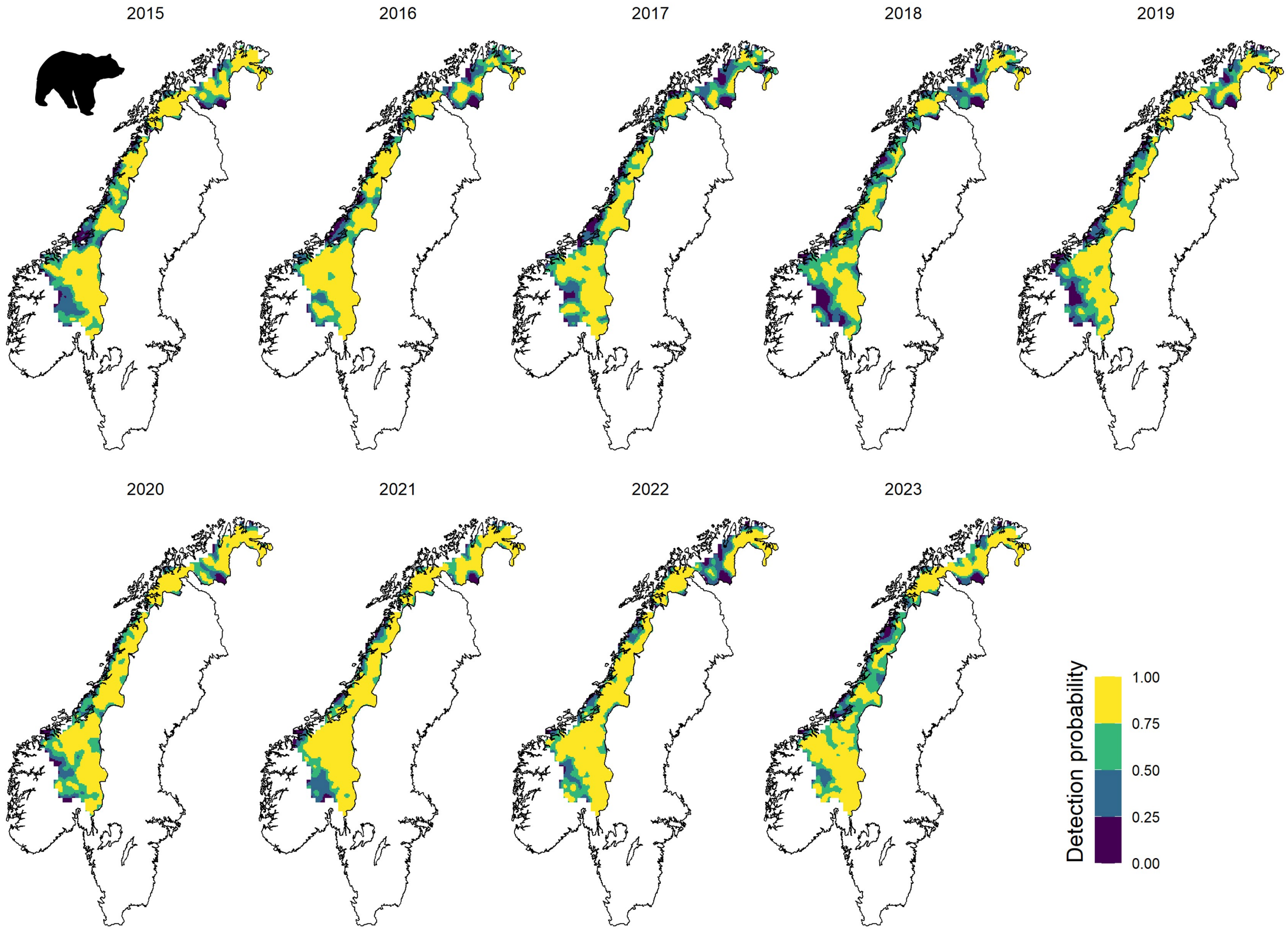


Figure A.1: Brown bear *spatially-explicit detectability* during *unstructured sampling* in Norway between 2015 and 2023. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area.

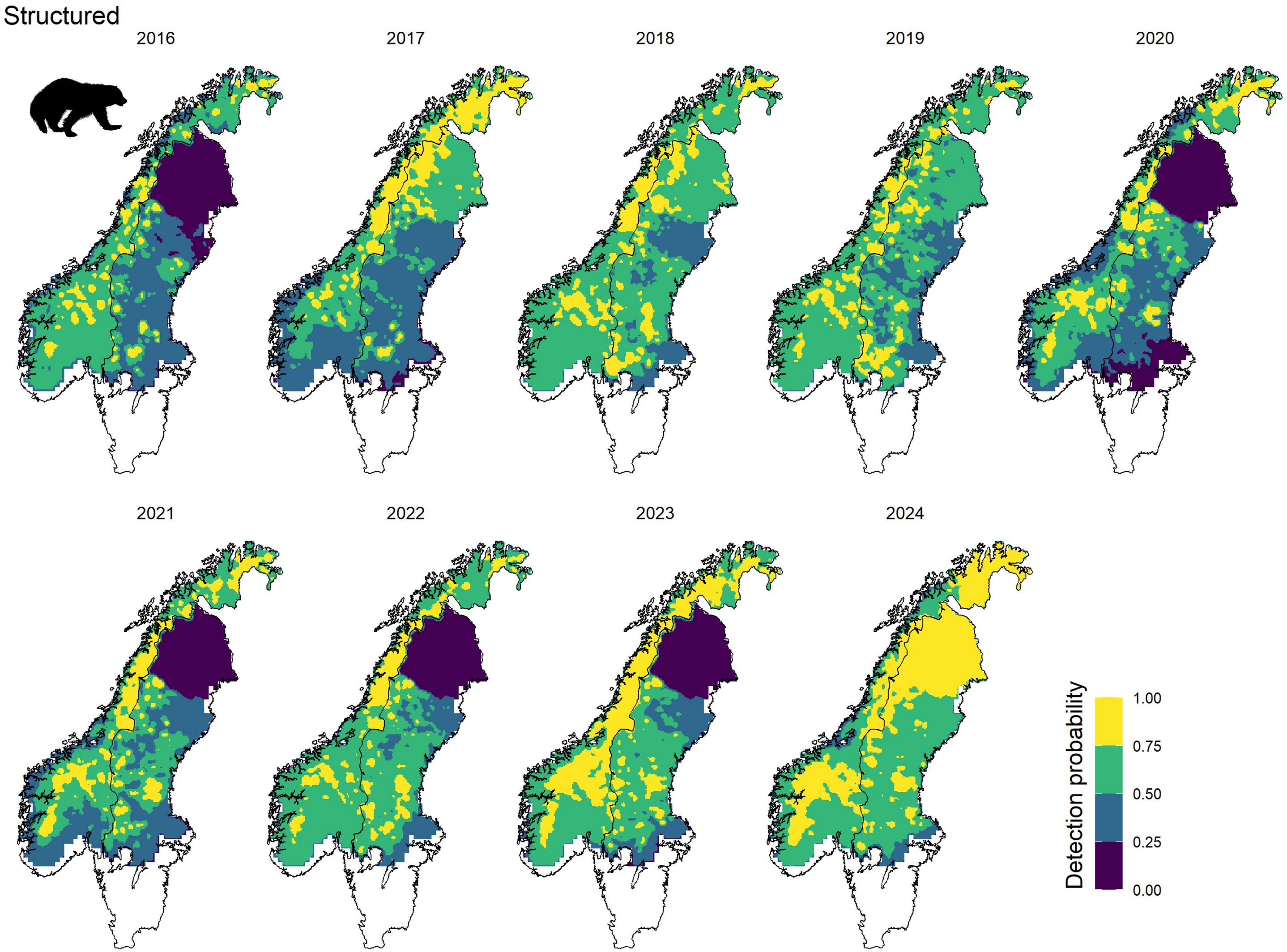


Figure A.2: Wolverine *spatially-explicit detectability* during *structured sampling* in Scandinavia between 2016 and 2024. Note that no comprehensive NGS was conducted in Norrbotten in 2016 and 2020-2023 and detectability was therefore assumed to be zero. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area.

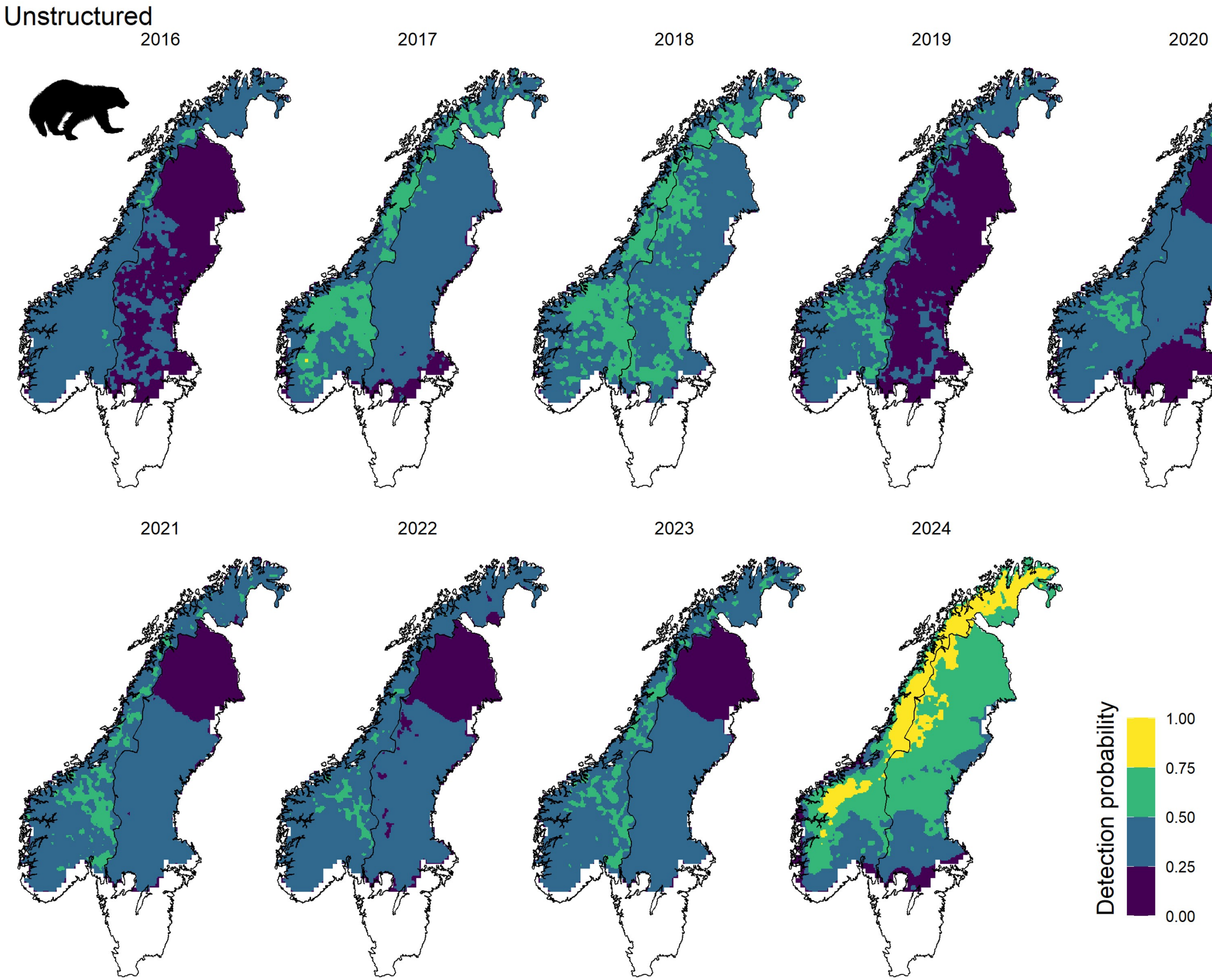


Figure A.3: Wolverine *spatially-explicit detectability* during *unstructured sampling* in Scandinavia between 2016 and 2024. Note that no comprehensive NGS was conducted in Norrbotten in 2016 and 2020-2023 and detectability was therefore assumed to be zero. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area.

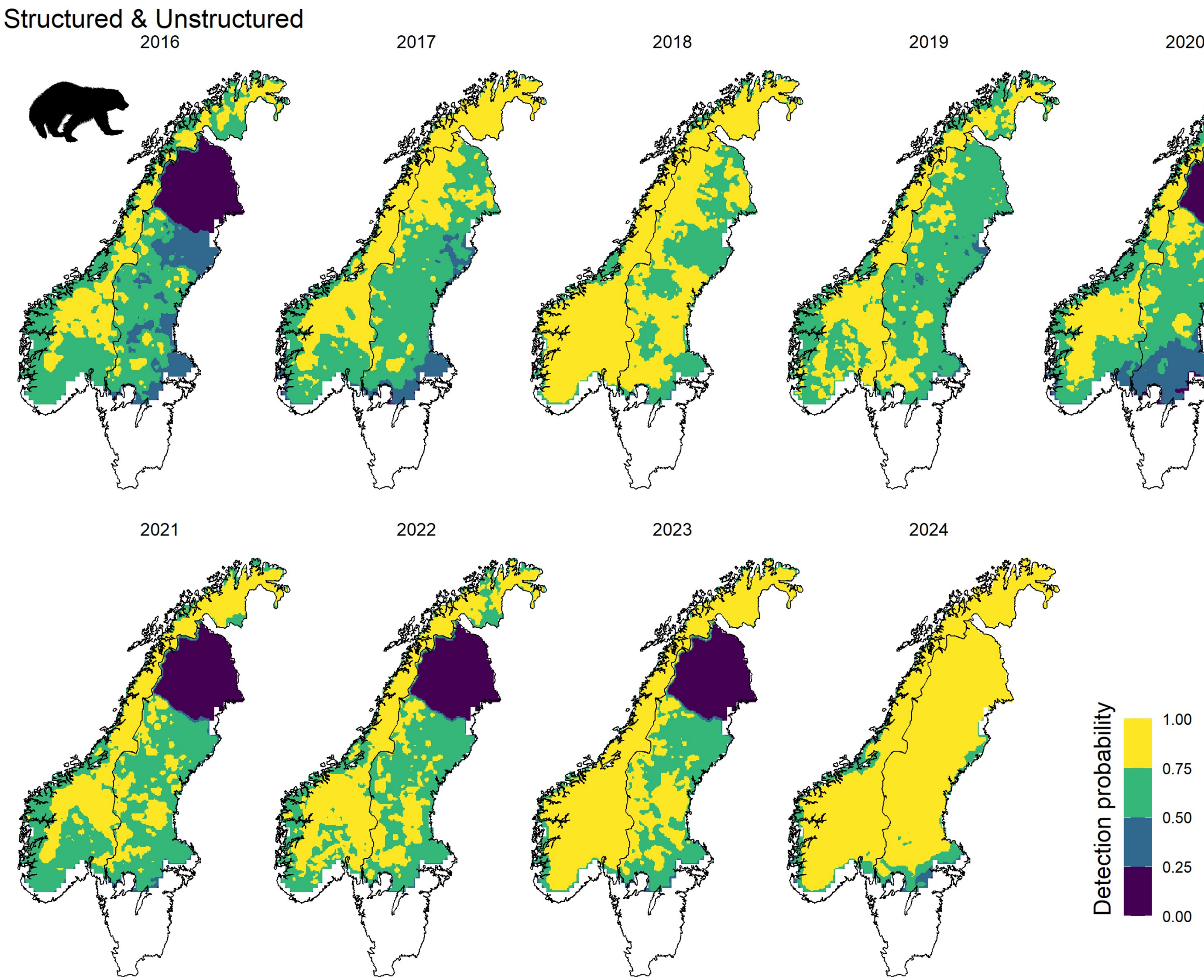


Figure A.4: Wolverine *spatially-explicit detectability* as a result of combining detectability during *structured* and *unstructured sampling* in Scandinavia between 2016 and 2024. Note that no comprehensive NGS was conducted in Norrbotten in 2016 and 2020-2023 and detectability was therefore assumed to be zero. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area.

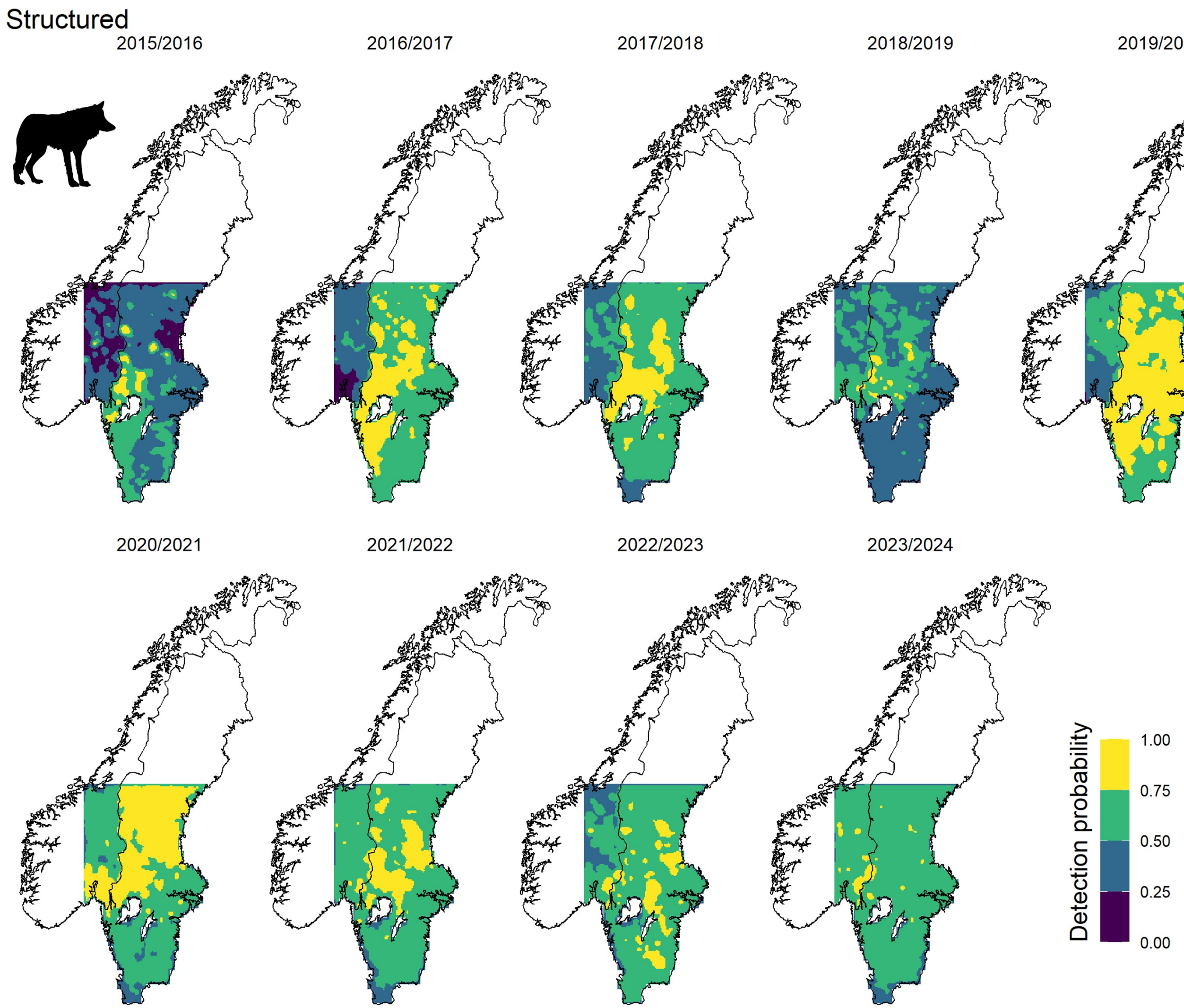


Figure A.5: Wolf *spatially-explicit detectability* during *structured sampling* in Scandinavia between 2015/2016 and 2023/2024. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area.

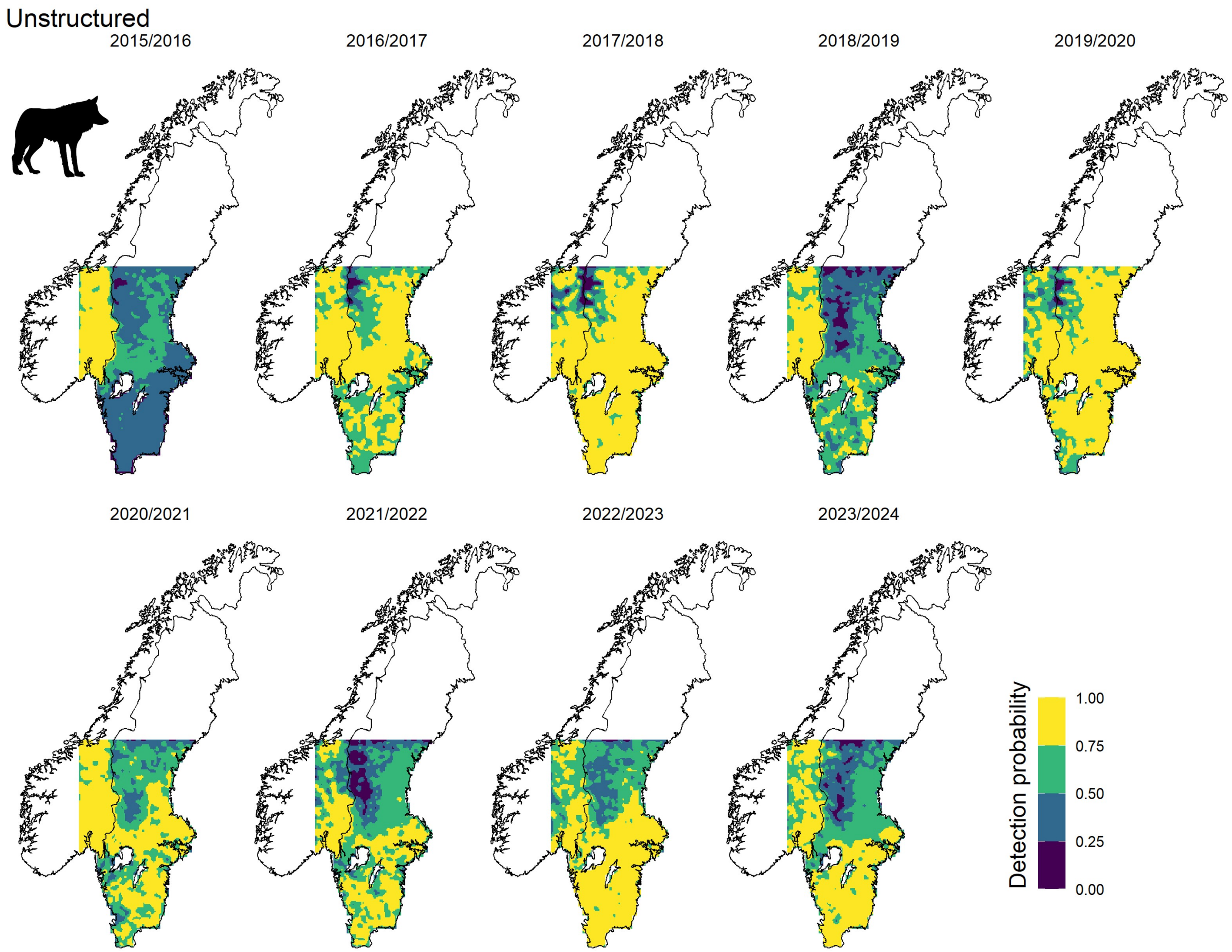


Figure A.6: Wolf *spatially-explicit detectability* during *unstructured sampling* in Scandinavia between 2015/2016 and 2023/2024. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area.

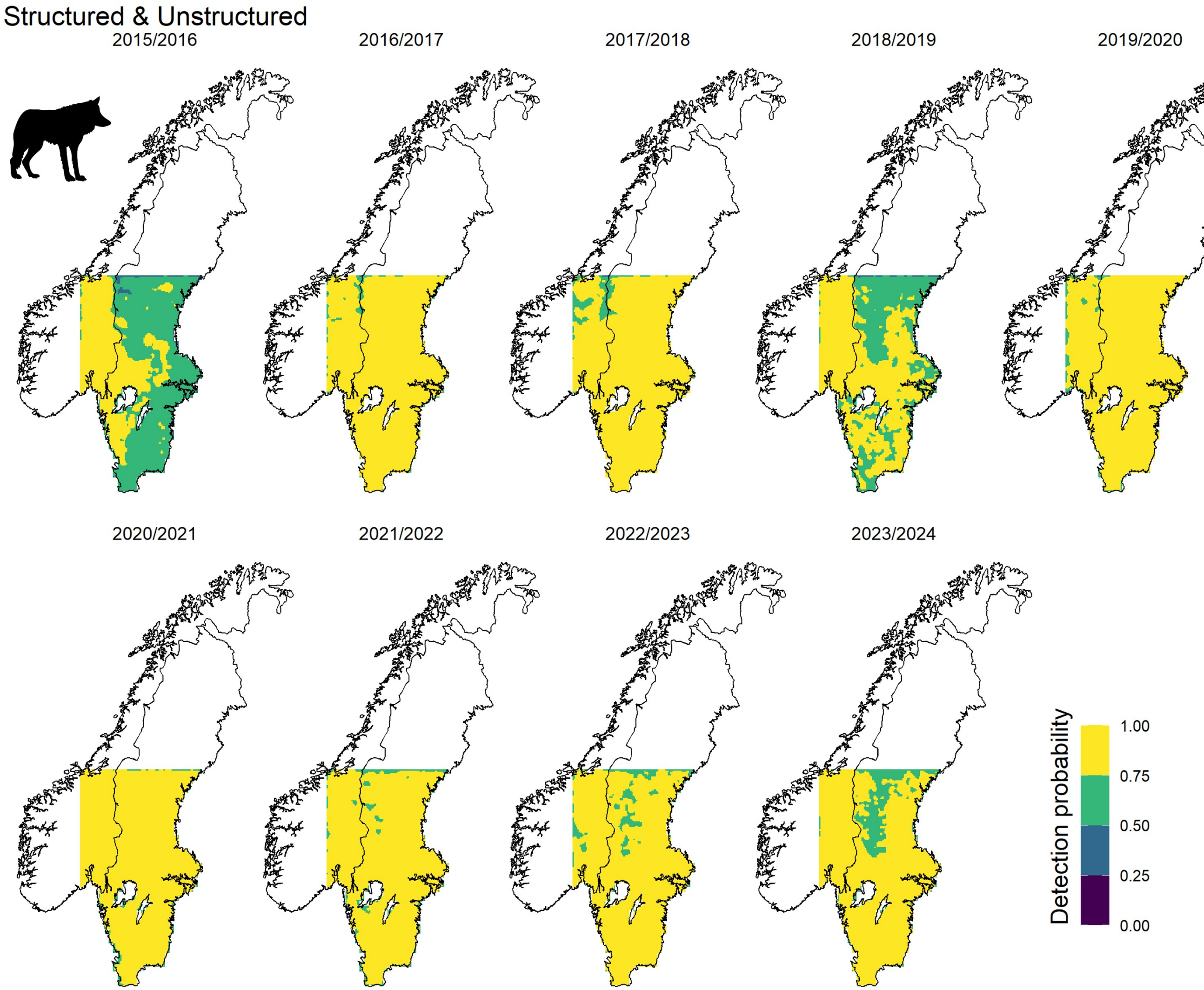


Figure A.7: Wolf *spatially-explicit detectability* as a result of combining detectability during *structured* and *unstructured sampling* in Scandinavia between 2015/2016 and 2023/2024. Color-coded pixel values indicate the probability that an individual with its activity center in that pixel is detected at least once in the entire study area.