Colorado Parks and Wildlife
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WILDLIFE RESEARCH REPORT

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ABSTRACT

In an effort to restore a viable population of Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999–2006. In 2010, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) determined that the reintroduction effort met all benchmarks of success, and that the population of Canada lynx in the state was apparently viable and self-sustaining. Here we evaluate options for monitoring the long-term success of the reintroduction effort using noninvasive techniques to assess species status and distribution. Ideally, this could be accomplished by estimating abundance of lynx in the state on a recurring basis. However, abundance estimation can be difficult for rare, wide-ranging carnivores because such efforts typically require multiple encounters with a number of individuals. Occupancy estimation may be a useful alternative as sampling under this framework requires only detection or non-detection information at the species level rather than multiple encounters with individuals. Models are fit to the detection data, collected over multiple visits to sampling units, to estimate the proportion of sample units used by the focal species within a study area. The monitoring objective may be to simply track this proportion (ψ) through time. However, ψ and abundance are clearly related; when abundance is zero, ψ is zero, and when the landscape is saturated with animals, $\psi = 1.0$. Thus, an alternative objective may be to use estimated ψ as a surrogate for abundance, and thus track abundance through time using occupancy estimation. We used a series of simulations based on pilot data to assess the effort required to detect declines (or increases) of interest in abundance and ψ of lynx in Colorado using occupancy estimation. We found that small changes could not be detected even with an enormous amount of effort. Even 50% declines or increases in abundance or ψ would require substantial effort and coordination to implement on a statewide basis. Tracking abundance through time using occupancy required relatively more effort than simply tracking a similar decline in ψ itself. Given these results, perhaps a scaled down approach is most practical. That is, CPW could implement a rigorous occupancy estimation program to track abundance, but only in a portion of the state. Elsewhere, rudimentary presence/absence surveys (i.e., surveys

conducted without repeat visits, and probably on a rotating basis so any given mountain range is only visited every ~5 years) could be conducted to ascertain the distribution of lynx among the major mountain ranges and this distribution would tracked through time as a secondary measure of population performance.

WILDLIFE RESEARCH REPORT

STATEWIDE MONITORING OF CANADA LYNX IN COLORADO: EVALUATION OF OPTIONS

JACOB S. IVAN

PROJECT NARRATIVE OBJECTIVE

Use simulation to assess occupancy estimation as a means of monitoring Canada lynx in Colorado.

SEGMENT OBJECTIVES

1. Complete simulations to assess the effort required to track various declines (or increases) in *abundance* of lynx using occupancy estimation.
2. Complete simulations to assess the effort required to track various declines (or increases) in *occupancy* of lynx using occupancy estimation.

INTRODUCTION

The Canada lynx (*Lynx canadensis*) occurs throughout the boreal forests of northern North America. While Canada and Alaska support healthy populations of the species, the lynx is currently listed as threatened under the Endangered Species Act (ESA) of 1973, as amended (16 U. S. C. 1531 et. seq.; U.S. Fish and Wildlife Service 2000) in the conterminous United States. Colorado represents the southern-most historical distribution of lynx, where the species occupied the higher elevation, montane forests in the state (U.S. Fish and Wildlife Service 2000). However, lynx were extirpated, or reduced to a few animals, in Colorado by the late 1970's, (U.S. Fish and Wildlife Service 2000) most likely due to multiple human-associated factors including predator control efforts such as poisoning and trapping (Meaney 2002). Given the isolation of and distance from Colorado to the nearest northern populations of lynx, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) considered reintroduction as the best option to reestablish the species in the state. Therefore, a reintroduction effort was begun in 1997, and 218 lynx were released into Colorado from 1999 – 2006 (Devineau et al. 2010). The goal of the Colorado lynx reintroduction program was to establish a self-sustaining population of lynx. Progress toward this goal was tracked via evaluation of criteria related to lynx survival, fidelity, and recruitment. Recently, CPW determined that the criteria had been met and an apparently viable Canada lynx population currently exists in Colorado (Shenk and Kahn 2010).

In order to track the persistence of this new population and thus determine the long-term success of the reintroduction, a minimally-invasive, statewide monitoring program is required. Ideally, this could be accomplished by estimating abundance of lynx in the state on a recurring basis. However, abundance estimation using traditional mark-recapture methods is difficult for rare, wide-ranging carnivores because such it typically requires multiple encounters with a number of individuals (Lukacs 2013). New advances in spatially explicit capture-recapture (Efford et al. 2009, Royle et al. 2009), use of multiple data sources (Sollmann et al. 2013a), and implementation of mark-resight approaches (Sollmann et al. 2013b) make the problem more tractable as these approaches generally require less intensive capture efforts than traditional mark-recapture. However, they still require some of this work, which can be both difficult and invasive.

Alternatively, occupancy estimation may be a useful approach for monitoring lynx (MacKenzie et al. 2006). Such an approach requires several visits to a set of sampling units, but the data collected for each visit is simply detection or non-detection of the focal species (MacKenzie et al. 2003). There is no need for marking or tallying individuals. The detection information is used to estimate the proportion (ψ) of sample units used by the focal species (i.e., "occupancy") which can then be monitored through time. The advantage in such an approach is that no individual identification is necessary and the information gathered during sampling is generally easier to obtain, especially for rare carnivores. The disadvantage is that information obtained about the population of interest is less resolute (i.e., knowing the proportion of the landscape used by a species is less informative than knowing the number of individuals within it).

Finally, monitoring might be accomplished by simply documenting distribution of lynx in the state. Under this approach, the metric of interest to be tracked through time would be the number of mountain ranges (of the 6–8 main ranges) with evidence of use by lynx. Currently lynx are known to be present in the San Juan, Sawatch, and Elk Mountains where the reintroduction and/or associated research occurred. Expansion into other ranges over the long-term could be considered evidence of a successful reintroduction; recession into only 1 range, or none would indicate failure. Monitoring distribution is the least costly approach considered here, but also the least informative and least rigorous.

We assume that estimation of abundance is not a viable option due to cost, although this assumption should be formally tested, especially as new statistical techniques arise. We further assume that documenting distribution is the least costly option and is thus logistically feasible. However, there is no power analysis or other statistical considerations associated with this option. Thus, from here forward, we focus on using simulation to assess the feasibility of using occupancy for monitoring lynx in Colorado.

Under an occupancy framework, the monitoring objective may be to declare ψ as the metric of interest and simply track it through time as a means of monitoring the lynx population in a coarse sense. However, ψ is clearly related to abundance; when abundance is zero, $\psi = 0$, and when the landscape is saturated with animals, $\psi = 1$. Thus, an alternative objective may be to use estimated ψ as a surrogate for abundance, and thus attempt to track abundance through time using occupancy estimation. This may be a preferable approach because abundance is ultimately the quantity of interest. The utility of this idea relies on the strength of the relationship between ψ and abundance, which is partially dependent on sampling effort and partially dependent on the characteristics of the system under study. That is, if home range size and territorial tendencies of the focal species result in an average of 1 individual per sample unit, then ψ can be expected to mirror abundance quite well. However, if the interaction of these characteristics leads to multiple individuals using a sample unit (on average), then ψ and abundance will be relatively decoupled. Abundance could decline fairly significantly before precipitating any change in ψ.

We conducted a series of simulations to assess the effort required for using occupancy estimation to detect declines (or increases) of interest in abundance or ψ of lynx in Colorado. Our simulations were calibrated to reflect estimates of ψ and detection probability (p) collected from pilot work in the state. We compare the various alternatives available for monitoring lynx in Colorado and discuss trade-offs associated with each.

METHODS

Pilot Work

CPW initiated work to evaluate methods for detecting lynx during winter 2009–2010 (Shenk 2009, Ivan and Shenk 2010). Similar to Squires et al. (2012), the pilot study area was divided into 75-km^2 sample units (roughly the size of a female home range) and 3 methods of detecting lynx were tested in 6 sample units where lynx were known to occur: snow tracking surveys, remote camera surveillance, and hair snags. The daily probability of detecting a lynx given their presence in the unit was 0.70, 0.09, and 0.00 for snow tracking, remote cameras, and hair snares, respectively (Ivan 2011). During winter 2010–2011, pilot work was expanded to include 30 wilderness sample units surveyed via remote camera and 30 accessible units surveyed via snow-tracking. The status of lynx (present or not) in these randomly selected units was unknown. We fit single-season occupancy models to data from each stratum and found $\psi = 0.33$ and $p = 0.40$ for wilderness units (Ivan 2012; camera data were collapsed by month into 5 occasions, $p = 0.40$ for each occasion), and $\psi = 0.65$ and $p = 0.37–0.43$ for accessible units (Ivan 2011; based on 3 occasions of snow-tracking surveys). Thus, overall, $\psi \approx 0.50$ and $p \approx 0.40$ for the pilot study area.

Assessment of using occupancy estimation to track changes in ψ

To assess the effort required to detect declines or increases of interest in ψ using an occupancy estimation framework, we conducted a series of analyses using the simulation function in Program MARK (White and Burnham 1999). Within the "robust design occupancy" data type (i.e., multi-season occupancy, MacKenzie et al. 2006), we set up a simulation model in which $\psi = 0.5$ for year 1 and $p = 0.4$, thus matching estimates derived from pilot work. We then specified linear declines in ψ to 0.45 (10% decline), 0.40 (20% decline), or 0.25 (50% decline) over a 10-year period. We also specified an increase in ψ to 0.75 (50% increase) over a 10-year period. We generated data from each simulation model for 2, 3, 4, or 5 occasions and $N = 25$, 50, 75, 100, 125, and 150 units sampled. We also considered that sampling may occur annually or only in alternate years. Thus, there were 192 possible combinations of parameters specifying the simulation model (4 levels of change in ψ, 4 levels of occasions, 6 levels of sample size, 2 levels specifying the survey interval), and we generated 1000 simulated datasets for each of the 192 combinations.

To each of the 192,000 data sets, we fit 2 estimation models. The first fixed ψ to be constant across the 10 years represented in each data set. The second specified a linear trend in estimated ψ. The true, data-generating model always included a trend of some type. Thus we defined "power" as the proportion of simulations in which Akaike's Information Criterion (adjusted for small sample size; AICc) selected the correct (second) model by at least 2 AICc units (Burnham and Anderson 2002). In general, given sparse data (such as that generated from only a few occasions and/or for a small number of sample units) AICc will select the constant model as the one that fits the data best because there is not enough information to support anything but the simplest model. As the data become richer (i.e., more occasions and/or larger sample size), AICc will begin to pick the correct model more often. We adopted the conventional benchmark of 0.8 as a cutoff for adequately identifying declines or increases of interest. That is, combinations of sample size and occasions that resulted in power = 0.80 were deemed adequate to confidently detect declines or increases under consideration.

Assessment of using occupancy estimation to track changes in abundance

To assess the effort required to detect declines or increases in abundance using an occupancy estimation framework, we conducted a series of analysis using the R (R Development Team 2013) package SPACE (Ellis et al. 2013). Specifically, we provided the package with spatially referenced data representing predicted lynx habitat in Colorado (Ivan et al. 2011). The package then randomly assigned home range centers for 125 males and 125 females on this landscape. Home range centers were only allowed to occur in cells that had reasonable probability of being lynx habitat. To mimic territoriality, males were not allowed to have a home range center within 6 km of another male; females could not be assigned a home range center within 5 km of another female. Males and females could be any distance from each other. Once home range centers were assigned for all 250 lynx, each individual was temporarily assigned a bivariate normal utilization distribution (i.e., the probability of occurrence for each individual was highest at its home range center and dissipated equally in all directions) appropriately sized for each sex. This simplistic utilization distribution was then weighted by the underlying map of predicted lynx habitat to produce an irregular, realistic utilization distribution that was unique to each individual. Thus, following this first step, a realistic number of virtual lynx were distributed across the state and assigned reasonable utilization distributions that governed their movement across the landscape. We then specified declines (50%, 20%, 10%), and increases (50%) in abundance over a decade by randomly removing or adding the appropriate number of individuals at each of 10 time steps.

Next, simulated landscapes were overlaid with a sampling grid consisting of 75-km^2 sample units. This was done for each of the 10 time steps. Based on utilization distributions assigned to each individual, SPACE computed the probability of at least 1 animal being present in each unit during each time step (i.e., sampling occasion). It then applied the detection probability specified for the simulation to generate detection/non-detection data for each unit. We generated data sets for a variable number of occasions and sample sizes similar to that described above. As before, each simulated dataset was fitted with 2 competing models, one in which the estimated ψ was fixed to be constant throughout the 10-year period, and second in which it followed a linear trend. We again defined power as the proportion of simulations in which AICc selected the correct model. We also considered the impact of sampling every other year by removing data from even years. On average, estimates of ψ and p for the first year of each simulation were 0.50 and 0.34 respectively, which is close to the values observed from the pilot work. Thus, the model was well calibrated to the field.

Sampling Details

For each of the monitoring metrics, ψ and abundance, we identified the most plausible scenario that could be implemented in the field by CPW personnel, and further detailed the effort required to complete a survey by selecting a mock sample. To accomplish this, we first defined the population of sample units of interest by overlaying a grid of 75-km^2 cells on the predicted lynx habitat layer for Colorado (Ivan et al. 2011). We identified cells as potential sample units if at least 50% of the lynx habitat pixels within them had probability values ≥0.60 (See Ivan et al. 2011 for detailed discussion of these probability values). This resulted in a population of 475 cells from which to draw a sample (Fig. 3). Next, we used the R (R Development Team 2013) package 'spsurvey' (Kincaid 2013) to enumerate each sample unit in a spatially balanced random fashion such that a valid sample of any size could be selected by simply ordering the cells by their randomly assigned number and selecting the 1st N cells. For each scenario of interest, we selected an appropriate sample, then summarized the effort required to complete the sample by CPW Area. We assumed 6 person-days would be required to sample each non-wilderness unit and 10 person-days would be required to sample each wilderness unit. These estimates were based on pilot work and assume that for snow-tracking surveys (non-wilderness units), personnel would work in pairs and complete 3 visits per sample unit. For wilderness units, we assumed personnel would work in pairs over 2.5 days to set 4 cameras in each selected unit, then work another 2.5 days per unit to retrieve the cameras after sampling. These represent minimum estimates of cost as any survey effort would also require personnel time to maintain snowmobiles and cameras, enter data, and complete analyses and reports.

RESULTS

Regardless of whether the objective was to use occupancy estimation to detect declines in ψ or abundance, power was low (≤ 0.40) for all but the most drastic changes in the lynx population, even with significant survey effort (e.g., *N* = 125–150; Fig. 1, 2). Fifty percent declines or increases in ψ over a decade could be adequately detected (power = 0.80) with 3 visits to each of 75 sample units if sampling occurred on an annual basis (Fig. 1). Reducing sampling effort to every other year did not impart dramatic changes to the sample size needed to maintain power. In contrast, annual surveys comprising 3 visits to 125 sample units were required to adequately detect 50% declines or increases in abundance over the same time span (Fig. 2). Also, in the case of abundance, reducing survey effort to every other year required ~250 units in order to maintain power.

Power curves in the panels representing results for 20% and 10% declines in abundance (Fig. 2) were relatively high at very small sample sizes, then declined with increasing sample size before increasing again at large sample sizes. These counterintuitive results are likely artifacts of fitting models to sparse data. When data are sparse, parameters may not be estimated well and the model may return values at a boundary (i.e., ψ will be estimated as either 0 or 1). If the estimates of ψ near the beginning and/or end of the time series are returned as 0 or 1, then a trend may be detected. In an actual analysis with a single data set, such a phenomenon is easy to diagnose and alternatives are available to tweak the model and prevent this from happening. However, when thousands of datasets and model fits are involved, such tweaking is impossible. Thus, these high initial values and subsequent declines should be ignored. Power to detect trends across this range of sample sizes is likely very low.

The most plausible scenarios for monitoring either ψ or abundance were those aimed at detecting a 50% change in either metric. Selection of an actual sample revealed that in both cases, the number of person-hours involved to carry out the sampling was substantial (Fig. 4, 5). For example, the scenario intended to provide an 80% chance of detecting a 50% decline in abundance over 10 years would require making 3 visits to each of 125 sample units on an annual basis. Assuming 2 Biologists, 2 District Wildlife Managers and 2 USFS Biologists were willing the carry out the work in each area, monitoring lynx under this scheme would require on average about 10 days worth of work per person per Area (Fig. 4; on average 64 person-days would be required per area; 64 person-days/6 people ≈10 days). Some Areas would require nearly 3 times that effort (Fig. 4; maximum estimated effort was 184 person-days; 184 person-days/6 people ≈ 30 days of work per person). The scenario intended to provide an 80% chance of detecting a 50% decline in ψ over 10 years was projected to require an average of 38 person-hours to complete per Area, or ~6 days per person if the same set of biologists and managers participated. Again, effort in some Areas would be nearly 3 times higher.

DISCUSSION

We rigorously tested the power to detect various changes in population status of Canada lynx in Colorado using occupancy estimation. Small changes (10% or 20% declines) could not be detected with any reasonable amount of effort. Detection of large changes (50% declines or increases in either abundance or ψ) may be possible but would require considerable investment and coordination among management entities. This was especially true for the scenarios aimed at detecting changes in abundance, which is the more preferable approach as it would be most informative. Detecting large changes in ψ over a 10-year period required just more than half of the effort required to detect the same change in abundance, thus making it more feasible. However, this level of effort would still be costly and the information gained would be of low resolution. That is, by the time ψ declines by 50%, a significant number of individuals would be lost from the landscape, and it may be too late for any action to counter the decline. Monitoring distribution rather than abundance or occupancy would likely be the most affordable option but it is also least informative and least rigorous. In fact, it was not evaluated in this report because it is completely absent of any statistical underpinnings. Furthermore, the distribution approach provides little opportunity to learn why changes are happening. The multi-season occupancy models employed here to track abundance or ψ include extinction and colonization parameters (which we have largely ignored for the purposes of simulation). Modeling these parameters may provide an opportunity to associate changes on the landscape (e.g., bark beetle outbreaks, wildfire, timber harvest) with changes in ψ, thus providing an opportunity to learn why changes are occurring.

Clearly trade-offs exist between containing costs and implementing a program that is meaningful, rigorous, and provides opportunities for continued learning. Perhaps the most practical way forward is a hybrid approach in which CPW implements a rigorous occupancy estimation program to track abundance, but only in a portion of the state, while simultaneously implementing the relatively less rigorous distributional approach statewide. Such an approach would provide detailed information about a (hopefully) representative subpopulation of lynx, but would be easier to implement as it would take less effort it would only be implemented in a portion of the state. Additionally, CPW would still obtain useful information regarding the statewide distribution of animals. If CPW were to adopt such a strategy, we suggest that the rigorous portion of the effort focus on the San Juan Range in the southwest as it provides the bulk of the lynx habitat and has long been considered a core stronghold for the species. Thus, it could be considered a "sentinel" area such that increases in the lynx population there probably bode well for the rest of the state, and declines there probably bode poorly.

ACKNOWLEDGMENTS

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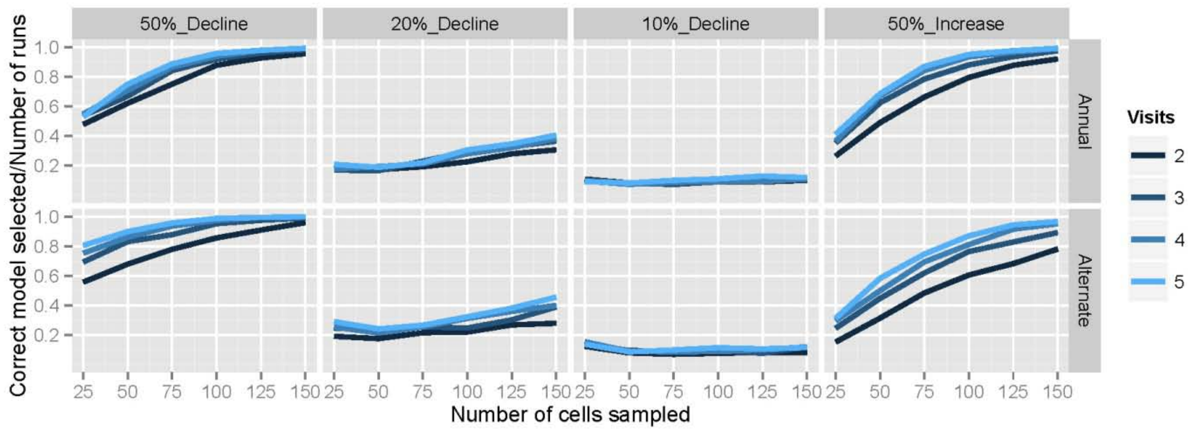


Figure 1. Power to detect various changes in the proportion (ψ) of sample sites used by lynx in Colorado using occupancy estimation. Changes were assumed to occur over a 10-year period. Power is shown for scenarios in which sample units were sampled annually (top panels) and when sampling occurred only in alternate years (bottom panels). "Visits" corresponds to the number of times selected units would be searched to collect detection/non-detection data. Visits could represent days for units surveyed via snow tracking, or they may represent blocks of time into which continuously collected camera data could be binned (e.g., 1 visit = 1 month of camera sampling).

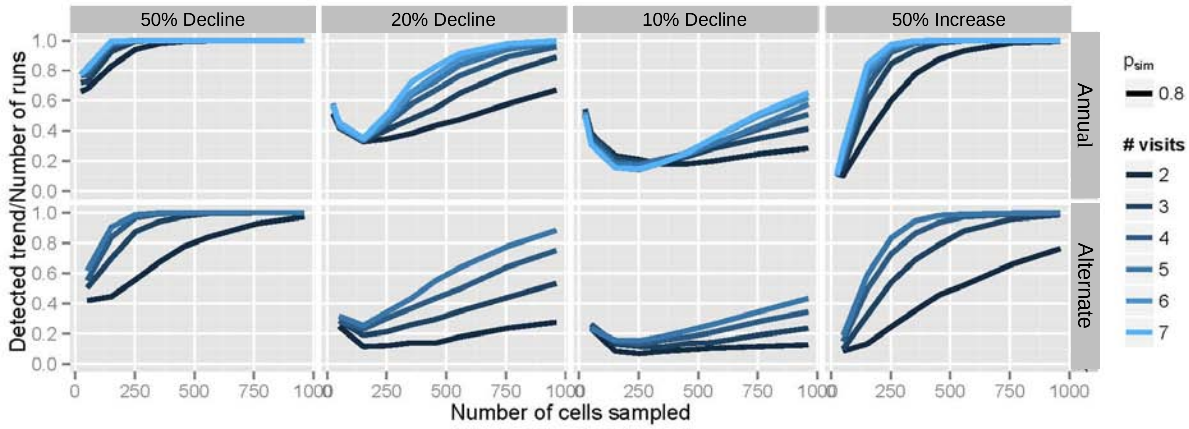


Figure 2. Power to detect various changes in abundance of lynx in Colorado using occupancy estimation. Changes were assumed to occur over a 10-year period. Power is shown for scenarios in which cells are sampled annually (top panels) and when sampling occurs only in alternate years (lower panels). “Visits” corresponds to the number of times selected units would be searched to collect detection/non-detection data. Visits could represent days for units surveyed via snow tracking, or they may represent blocks of time into which continuously collected camera data could be binned (e.g., 1 visit = 1 month of camera sampling).

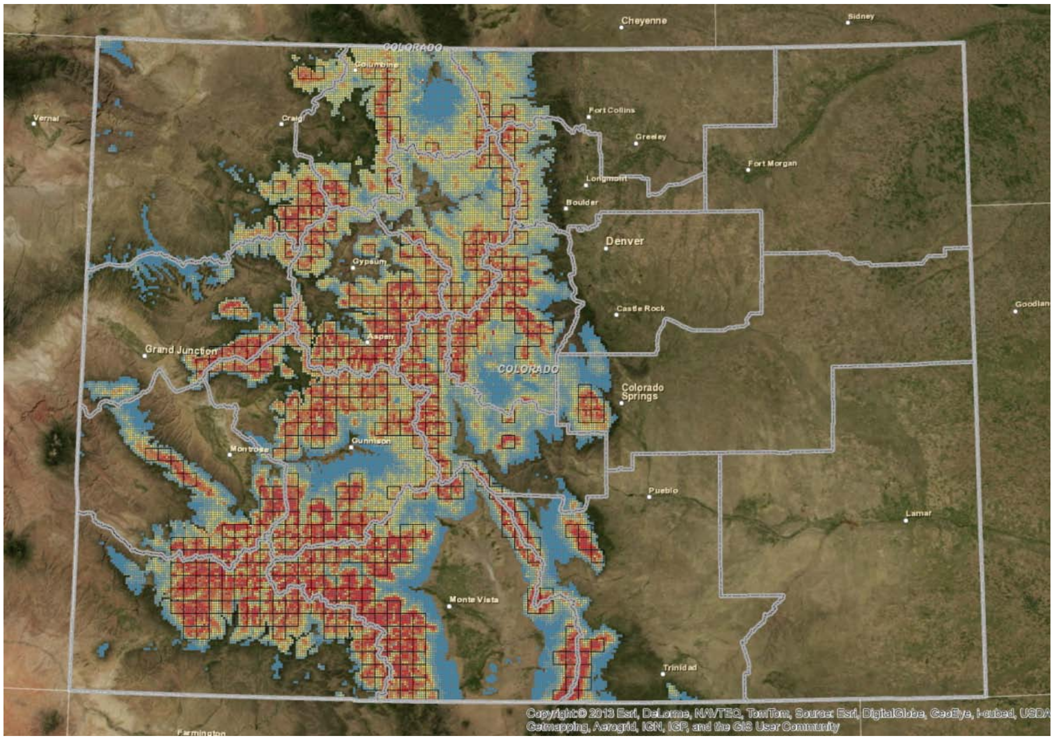
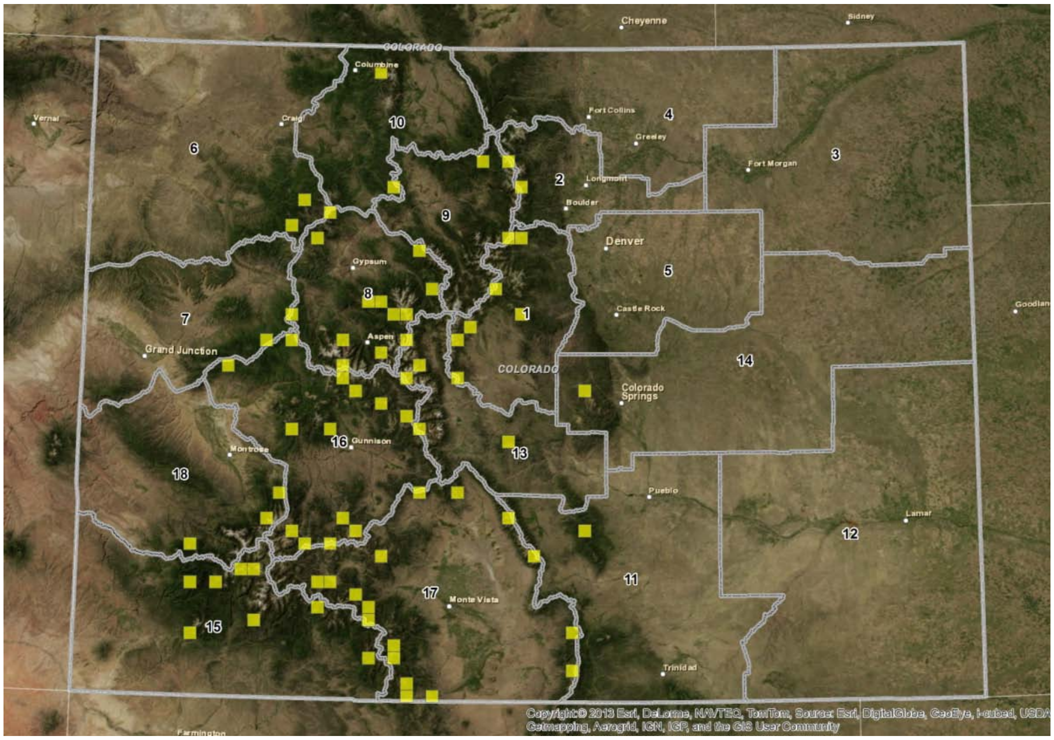
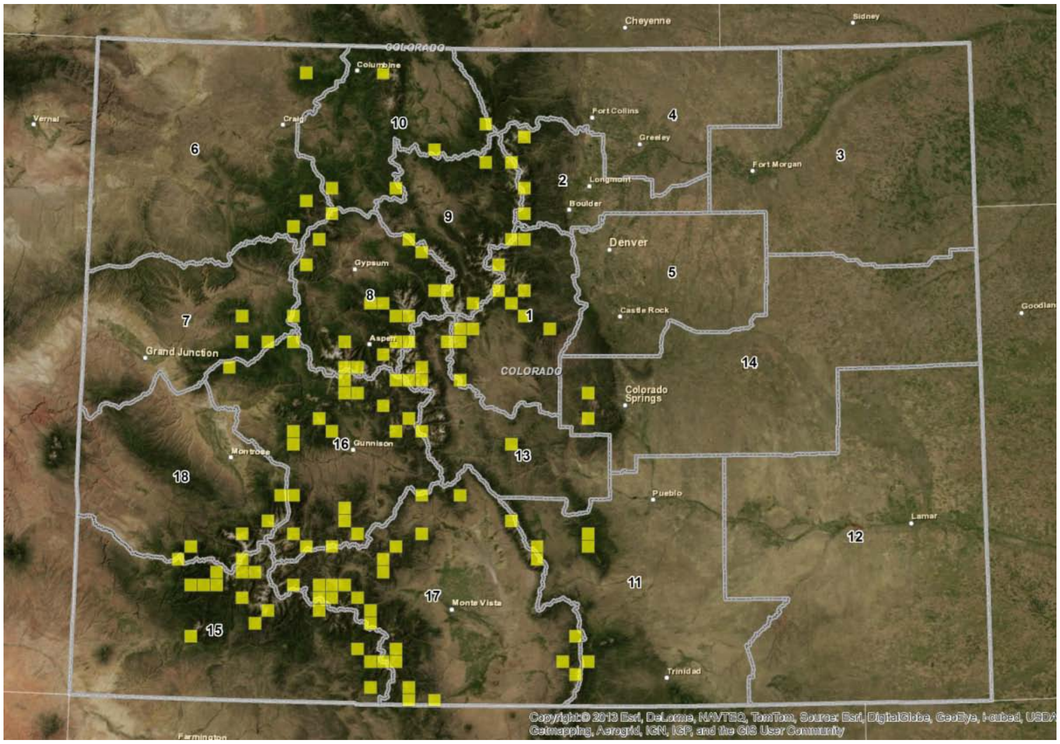


Figure 3. Predicted lynx habitat (red pixels = good, blue pixels = poor) in Colorado overlaid with 75-km^2 sample units (black squares, N = 475) from which to select a sample for monitoring declines or increases of interest in ψ or abundance. Only units where at least half of the lynx habitat pixels within them had probability values ≥0.60 were included in the population to sample from. See Ivan et al. (2011) for details regarding construction of the predicted lynx habitat map and interpretation of pixels that comprise it.



Region	**Area**	**#Sample Units**	**Effort (person-days)**
Northeast	1	6	44
	2	1	10
Northwest	6	2	16
	7	1	6
	8	13	102
	9	3	18
	10	2	12
Southeast	11	1	6
	13	4	28
	14	1	6
Southwest	15	8	52
	16	12	76
	17	18	128
	18	3	22
Total		**75**	**526**

Figure 4. Map and tabular summary of a spatially balanced random sample of $N = 75$ cells selected for monitoring a 50% decline or increase in ψ over a 10-year period in Colorado, USA using a combination of snow-track surveys and remote camera surveys. Estimated effort accounts for the differential time required to sample wilderness (cameras) and non-wilderness (snow-tracking) units.



Region	Area	#Sample Units	Effort (person-days)
Northeast	1	11	82
	2	3	26
Northwest	6	3	22
	7	3	18
	8	17	134
	9	5	30
	10	5	34
Southeast	11	4	24
	13	6	44
	14	2	12
Southwest	15	17	122
	16	19	130
	17	26	184
	18	4	28
Total		**125**	**890**

Figure 5. Map and tabular summary of a spatially balanced random sample of N = 125 cells selected for monitoring a 50% decline or increase in abundance of lynx over a 10-year period in Colorado, USA using a combination of snow-track surveys and remote camera surveys. Estimated effort accounts for the differential time required to sample wilderness (cameras) and non-wilderness (snow-tracking) units.