Abundance Estimation of Snow Lepards in Eastern Afganistan

Samuel Read

Department of Mathematical Sciences
Montana State University

May 1, 2016

A writing project submitted in partial fulfillment
of the requirements for the degree

Master of Science in Statistics

APPROVAL

of a writing project submitted by

Samuel Read

This writing project has been read by the writing project advisor and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the Statistics Faculty.

5/5/2016	Steve Cherry
Date	Steve Cherry Writing Project Advisor
5/05/2016	John Winnie
Date	John Winnie Project Ecology Advisor
May 5, 2016	Jay Rotella
Date	Jay Rotella Project Ecology Advisor
5/5/2016	Mark Greenwood
Date	Mark Greenwood Writing Projects Coordinator

1 Abstract

The secretive nature of snow leopards makes estimating populations of this endangered species a challenging task. This paper analyzes the use of camera trap data collected from the Wakhan corridor in Afghanistan to make an approximation of the snow leopard population in that region. Estimation was done through capture-recapture models assessing heterogeneity, behavior, and temporal variation. Results show it is improbable that the study area population is much larger than the 36 snow leopards that were photographed.

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2 Introduction

Snow leopards (*Panthera uncia*) are large carnivorous cats that inhabit the high mountains of Central Asia. Weighing up to 120 pounds and growing to between 4 and 5 feet long, the snow leopard is of closer relation to tigers than to leopards. Favoring steep, rough, alpine terrain, snow leopards rarely stray far from where they settled; keeping their distance from humans. Snow leopards are the apex predator in regions where they are found and the decline in numbers has many negative ecological implications (Jackson et al, 2008).

Snow Leopards were classified as an endangered species by the IUCN in 1972 and recent population estimates indicate a decrease in population since that time (Jackson et al, 2008). To better protect this unique species, efforts are being made to better understand its distribution and population dynamics. However, due to the elusive nature of the snow leopards, and the remote and often rugged terrain in which they are found, much of their natural history is poorly understood. Abundance estimation has been especially difficult with this animal, yet recent efforts have been made to obtain a more accurate estimation of the endangered animal's population (McCarthy et al, 2008).

Figure 2.1 Khani, one of the photographed snow leopards in this study, seen walking through the snow New Year's Eve 2012.

2.1 Project Goals

The ultimate objective of this project is to provide an estimate of abundance of snow leopards in the Wakhan Corridor by analyzing data gathered through the use of camera trapping. To achieve this, this project will construct encounter histories from continuous camera trap data to be used from capture-recapture analysis. Additionally, any information on capture probabilities, home ranges, density estimates, or other behaviors of snow leopards that can be discovered from the analysis is valuable information.

3 Background

The global population of the snow leopard is estimated between 4,080 and 6,590 (Jackson et al, 2008). The ambiguity in this estimate is due to regions where snow leopards are believed to inhabit but little surveillance work or in depth analysis has been done to get a proper estimate. Until recently, one of these regions was Afghanistan. It is believed that there are 100 to 200 snow leopards in the country, but this estimate is not based on hard data (Jackson et al, 2008).

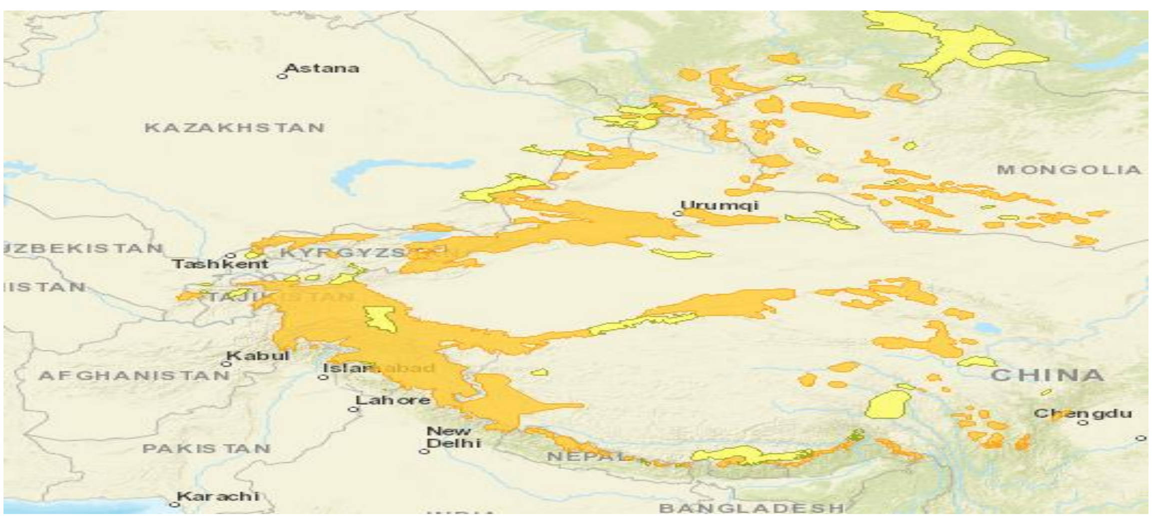

Figure 3.1 Range map of the snow leopard that displays the regions where snow leopards are known to be present, darker color, and regions snow leopards are likely to

3.1 Study Area

The region of interest for this study is the Wakhan Corridor, a remote, sparsely populated mountainous area, separating Tajikistan and Pakistan. This strip of land is part of the Wakhan district in the Badakhshan province of northeastern Afghanistan. The Hindu Kush mountain range provides a natural border to the south and the Pamir River a border to the north. The Hindu Kush provide habitat for snow leopards and while the quantity of snow leopards in this region is unknown, it is believed that a large portion of the snow leopard population of Afghanistan resides here.

3.2 Data Collection

A total of 43 cameras were set up along an approximate 100 kilometer stretch of the Wakhan Corridor, and any conclusions will be limited to within this area. Cameras were placed along the Hindu Kush Range, south of the valley. The placement was designed by the researchers to obtain a high capture rate of snow leopards; however, the challenging terrain and time constraints limited the placement of the cameras within a day hike from the valley. This resulted in most cameras being at most 12 kilometers away from the valley along the 100 kilometer stretch. Additionally, multiple cameras were placed along the different canyons or trails leading into the mountains with little disparity between them, creating more of a line rather than an area of study. A map of the camera locations can be seen below in Figure 3.2.

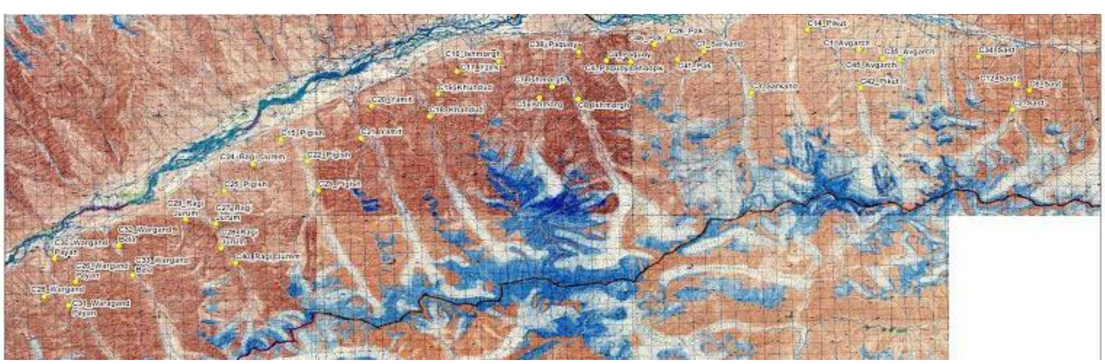

Figure 3.2 Map of the camera placement in the Wakhan corridor in Afghanistan. Cameras are represented by dots.

Cameras were set starting October 12, 2012 and recorded until November 30, 2013. However, not all cameras functioned throughout the entire time period. Some cameras were set up as late as June 4, 2013 and others were taken down as early as May 12, 2013. Although there is an inconsistency in camera dates, the geographic redundancy of the cameras and the behavior of snow leopards will counter so the capture rate will not be greatly affected. Figure 3.3 shows a nearly constant frequency of snow leopards seen over time, such that any discrepancy can be modeled in a varying capture rate. This constant frequency starts at October 30, 2012 and goes until October 29, 2013 and suggests the cameras, as a whole, had an equal capture probability over time and will be the time period evaluated.

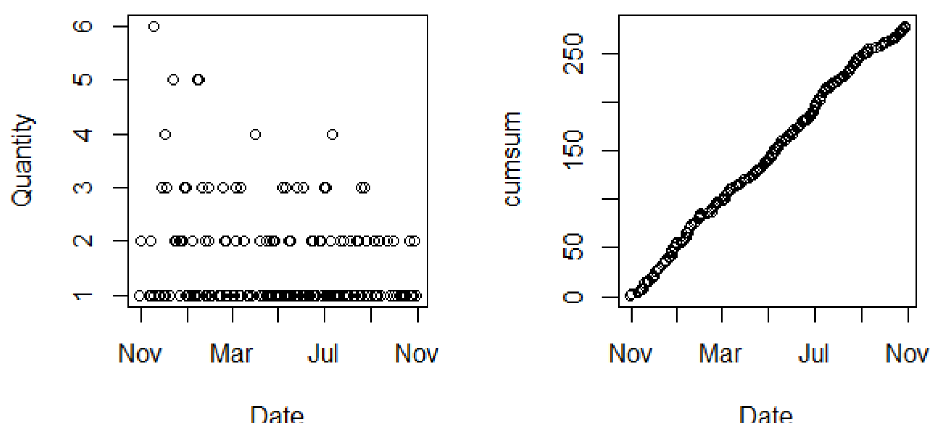

Figure 3.3 The graphic to the left depicts how many snow leopards were captured on each day throughout the year. A cumulative count of pictures throughout the year is seen by the right graphic.

3.3 Available Data

From the 43 cameras, a total of 5336 pictures were recorded. These were sifted through to reveal 393 pictures containing a snow leopard. From the images containing a snow leopard, a distinct identification was attempted in order to discover how many unique snow leopards were captured. Name and certainty levels were given to each picture. The certainty level was recorded as either unknown or a numerical level ranging from 1-3. Unknown indicated the researcher could not identify the cat in the photo. A certainty level 3 was a step up from unknown and meant the researcher was able to make a guess but was not confident with the accuracy of their guess. A certainty level 1 meant the researcher was confident they knew whicht individual was in the photo. Level 2 was added for the intermediate step between 1 and 3 but was mainly used as "fairly confident" yet not 100%. Due to the uncertainty behind the identifications and the risk of overestimating an endangered species, only pictures with certainty levels 1 and 2 were used in the analysis (Jackson et al, 2006). After eliminating ambiguous photographs, there were 279 pictures of 36 unique individuals seen over the year-long period. These individuals are seen in Figure 3.4

Figure 3.4 A frequency count of how many days each cat was photographed over a year can be seen

Cat	freq	Cat	freq
Ace	20	Bat	8
BKtail	4	Brute	1
Chloe	9	Cole	28
Drake	1	Glance	1
Isabel	3	Jerry	8
Khani	48	Kix	2
Kyle	6	Malika	23
Mask	1	Pace	1
Pahlawan	21	Pam	1
Pari	9	Possy	4
Prancer	7	Raz	1
Riley	11	Sam	3
Smoosh	8	Star	1
Strike	2	Sunset	2
Swan	2	Sym	4
Tats	15	Tine	1
Triplel	3	Trix	5
Val	14	Xion	1

4 Abundance Estimation

To find the total number of animals, N, in a closed population a census could be done by surveying the entire area of interest and finding every individual. However, this task is very difficult with snow leopards due to the secretive nature of the cat (McCarthy et al, 2008). Therefore, abundance estimation must be done.

Abundance estimation uses information on the unique number of animals encountered and the capture (encounter) probability to estimate a population (Williams, Nichols, & Conroy, 2002). The researcher samples during a specific amount of time, an occasion, and records if an animal is seen. Multiple occasions of sampling create individual encounter histories that consist of 1s and 0s; where a 1 means the individual animal was seen during that occasion, and 0 means that they were not seen. A Lincoln-Petersen estimator only uses two occasions evaluating how many of the recaptured animals in the second occasion were just seen for the first time. The process can be also done with multiple occasions using a maximum likelihood estimator to calculate the capture probability and estimate how many animals in the region were never seen (Williams, Nichols, & Conroy, 2002).

A critical assumption when doing abundance estimation is that the population is closed, meaning there are no births, deaths, immigration, or emigration during the study time period (Williams, Nichols, & Conroy, 2002). This means if an animal was not seen during an occasion it was still present in the study region. This allows an estimate to be made of the animals never seen based on how often the others were seen. It also must be assumed that marks are not lost, overlooked, or misread. If these assumptions hold, when surveying a closed population over multiple occasions, a decrease in the number of new individuals encountered in each occasion is expected. This trend is used to estimate the capture probability and population size (Cooch & White, 2009).

5 Method

An abundance estimate of snow leopards in the Wakhan Corridor was done by analyzing competing models for the capture-recapture data. To obtain abundance estimates using the capture-recapture design, there must be at least two sampling occasions(Cooch & White, 2009). However, the cameras ran continuously over a year, and discrete occasions must be defined before an estimate can be found.

5.1 Determining Occasions

In most studies, occasions are determined from the biology of the animal being studied. For example, if an animal usually returns to their home once a week, then it would make sense to set camera traps around the home and use one week as an occasion. Occasions can also be decided by the sampling design; say if sampling only occurred during weekends, each weekend could be considered an occasion. Yet, as mentioned before, the habits of snow leopards are not well known and sampling was continuous, providing no outline for occasions. Because of this the opportunity to define occasions in the analysis arose.

For Lincoln-Peterson estimation, two occasions need to be defined. There are two ways that make sense: Split the time in half or split the data in half. Because the capture rate is similar for the entire year, either way produces similar occasions. Splitting our data in half resulted in the first occasion ranging from October 29th, 2012 to April 27th 2013, with 139 snow leopards photographs recorded. Likewise, splitting the time in half resulted in the first occasion concluding on April 29th 2013, and had 141 photographs of snow leopards recorded. Although there is a two picture difference between the two methods, the estimate will not change because the number of unique leopards that were seen in the first and second occasions of the either splitting method is the same number as those seen in the other; consequently, the Lincoln-Peterson gives the same estimate.

Alternatively, capture-recapture estimation works with two or more occasions. Because there were no predetermined occasions, the yearlong data were divided multiple ways. The data were split into short windows of bi-weekly

(26) and monthly (12), as well as longer windows of 2 through 7 occasions. For every occasion length used, the snow leopard encounter histories corresponding to the number of occasions were then created and evaluated.

5.2 Creating Encounter Histories

The dataset included each sighting by all cameras, with the individual cat and date recorded. To get an encounter history for each snow leopard, the data for each cat must be consolidated. After pivoting the data to get each cat as an individual row, the number of times a cat was seen was added for every date in the year. Applying a max of 1, for the few occasions that an individual was seen more than once in day, results in 365 columns of 1s and 0s conditional on if the specific snow leopard was captured that day.

The dataset was then read into R (R Core Team, 2015). A manually created function that can be seen in R code, section 11, was created. This function allows for a user-defined number of occasions, number of days in the occasion, and start date (Wickham, 2011). The function concatenates the 365 days into a series of 1s and 0s, with the length representing the specified number of occasions. In total, 8 different encounter histories were created for each snow leopard by varying the number of occasions. The number of days in the occasion was specified to maximize the year's worth of data without going over the total 365 days. The remaining days were not used in the analysis.

5.3 Competing Models

For each set of encounter histories, varied by the number of occasions, a collection of models was used to analyze the data and estimate abundance. The models address 3 sources of capture variation: temporal, behavioral, and heterogeneity (Williams, Nichols, & Conroy, 2002). The first model, M(0), assumes no variation from any of the mentioned sources. This model has 2 parameters to be estimated: the capture rate, p, and the population, N. The likelihood model for t occasions and set of encounter histories, Xω, is:

$$L(N, p \mid \underline{X}) = \frac{N!}{[\prod_{\omega} X_{\omega}!] \cdot (N - M_{t+1})!} \cdot p^{n.} \cdot (1-p)^{t \cdot N - n.}$$

The second model, M(t), assumes variation in capture rates over time (capture rate varies from occasion to occasion). This model has t+1 occasions; where t is the number of occasions. Adding this variation changes the likelihood model to the following:

$$L\left(N, p_j \mid \underline{X}\right) = \frac{N!}{[\prod_{\omega} X_{\omega}!] \cdot (N - M_{t+1})!} \cdot \prod_{j=1}^{t} p_j^{n_j} \cdot (1-p_j)^{N-n_j}$$

The third model, M(b), assumes variation in behavior and that once a snow leopard is captured, the recapture rate for that individual differs. This assumes that the capture rate is equal across occasions but introduces a third parameter: the recapture rate, c. A behavior variation model changes the likelihood function to:

$$L(N, p, c \mid \underline{X}) = \frac{N!}{[\prod_{\omega} X_{\omega}!] \cdot (N - M_{t+1})!} \cdot p^{M_{t+1}} \cdot (1-p)^{t \cdot N - M_{t+1} - M.} \cdot c^{m.} \cdot (1-c)^{M. - m.}$$

The fourth model, M(h), assumes capture heterogeneity between snow leopards. This would mean there is a group of snow leopards that is more easily captured than another group of different snow leopards that stay hidden. For this model, an assumption is being made that if a snow leopard is part a more easily-captured group, they will be seen in the first occasion. To properly model this, five parameters are needed. Like before the capture rate is included in the model but is split between two groups: the easy-to-catch group, which will be the capture rate for the first occasion, and the capture rate for the hard-to-catch group, which will be the capture rate for the remaining occasions. The recapture rate in the second occasion will be equal to the capture rate of the easy-to-catch group. For all other occasions, a third parameter will estimate a recapture rate for both groups together. The final parameter is the population, N. This model's log likelihood function is:

$$L(N, p_1, p_2, c \mid \underline{X}) = \frac{N!}{[\prod_\omega X_\omega!] \cdot (N - M_{t+1})!} \cdot p_1^{n_1+m_2}(1-p_1)^{N-n_1} \cdot p_2^{M_{t+1}-n_1}(1-p_2)^{t \cdot N - M_{t+1} - M. - n_1 + m_2} \cdot c^{m. - m_2} \cdot (1-c)^{M. - m. - m_2}$$

These 4 models were run in MARK through RMark (Laake, 2013). The resulting AICc table compares the models for the possible sources of variation. A maximum likelihood estimate for the capture rate and the number of snow leopards are estimated simultaneously and can be retrieved for each model. For simplicity, no combination of these 3 sources of variation was modeled, but results can indicate whether or not the exploration of combination would be of interest.

6 Results

The 393 pictures collected show 36 distinctive snow leopards were seen over the year. From these photos, the number of snow leopards that were present in the study region but never seen can be estimated to obtain an abundance estimation.

6.1 Lincoln-Petersen Estimation

After splitting the data in half, both by time and quantity, the same number of snow leopards were recorded in both occasions. There were 25 unique snow leopards captured in the first half of study and 30 in the second half. Of the 30 caught in the second half, 19 were marked from the first half. The Lincoln-Petersen estimate then determines the population total as $\widehat{N}$ = 25*30/19 = 39.47.

The Chapman estimate, an adjustment for having a small sample size, gives an estimated population total of $\widehat{N}$ = ((25+1)*(30+1)/(19+1)) - 1 = 39.30 (SE = 2.52) (Willams, Nichols, & Conroy, 2002). Both estimates approximate that 3 snow leopards went uncaptured by the cameras for an entire year. An approximate 95% confidence interval indicates the true population of the study area to be between 34 and 45 snow leopards. The interval can be reduced to between 36 and 45 because 36 snow leopards were seen.

6.2 Capture-Recapture

After running the four models for the 8 different occasion lengths, Rmark returns the estimated parameters of capture probability, recapture probability, and a total abundance. The capture probability and the corresponding 95% confidence interval for each occasion length for model M(0) can be seen in Figure 6.1. The model M(0) assumes capture probability does not have temporal, behavioral, or heterogeneity variation, so the capture probability seen is the capture probability for all occasions as well as the recapture probability.

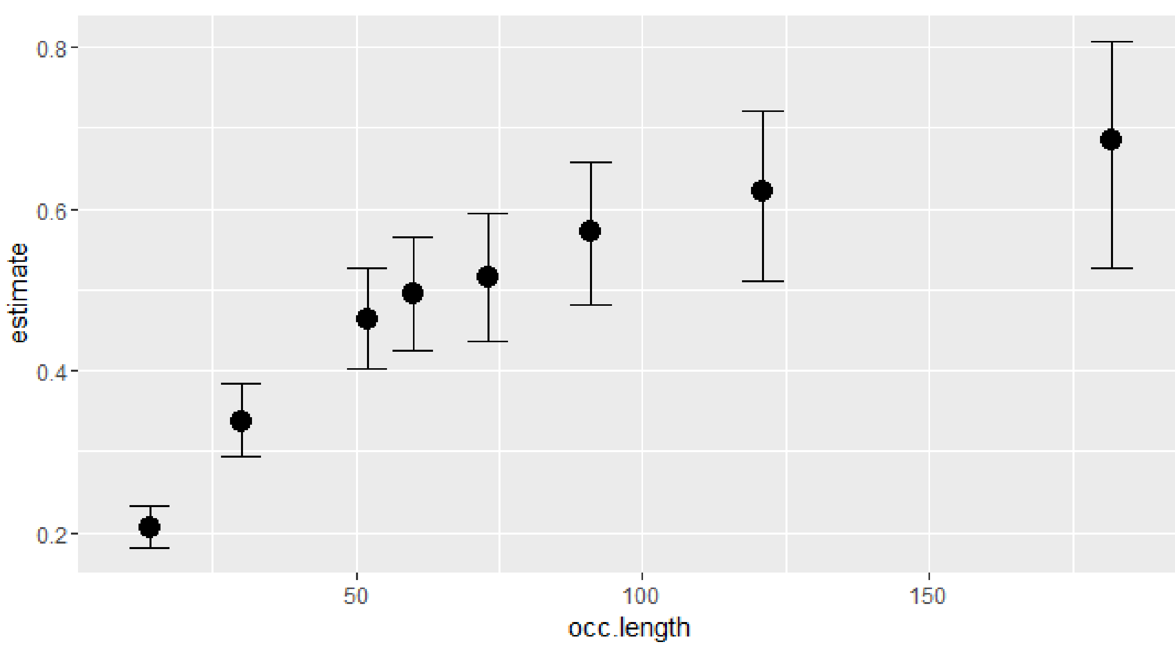

Figure 6.1 Predicted capture rates and the 95% confidence intervals for model M(0) at 24, 12, and 7-2 occasions

Figure 6.1 shows that as occasion periods are lengthened the capture probability increases. It also illustrates how there is more variability in the estimate as periods are lengthened. For example, the two occasion capture rate has a high estimate, X, but also has the largest variation. An ideal Capture-Recapture capture probability would have a relatively high estimate with a relatively low variation for that estimate. The middle group: four, five, and six occasions, have a capture probability above .5 and relatively small variation, showing support for using a 2-3 month occasion length.

However, the above estimates do not account for any possible variation of capture probability. To account for this, a comparison within each occasion length was done to show how the different sources of variation apply to estimating capture probability and abundance.

model	Npar	AICc	DeltaAICc	weight	Deviance
M(0)	2	7.839974	0	0.381047	39.08708
M(b)	4	8.066594	0.22662	0.340227	37.22738
M(h)	3	9.208701	1.368726	0.192204	38.36948
M(t)	5	10.80503	2.965053	0.086522	35.70246

Figure 6.2 AICc table comparing the different models for 4 occasions, quarter year occasion length

The quarter year AICc table, figure 6.2, shows the no variation model is the most supported by the data. Though this is not much more support than the behavioral model. It is also important to note the heterogeneity and temporal model are still both within 4 AICc units of the no variation model, and still have some support of being the best model for quarter year occasions.

Similar evaluations were done for all occasion lengths, and the AICc table for those results can be seen in the index. The other evaluations show similar trends in a comparison of the four models. The behavioral model and no variation model show the most support, while the temporal model is the least supported. The support for the heterogeneity model is inconclusive, with the support usually varying based on number of occasions but still less support than the top two models and more than the temporal model. Larger discrepancies between models are seen for the analysis of more occasions.

An abundance estimate and the corresponding 95% confidence interval were found using maximum likelihood techniques for each of the models within the different occasion lengths. These estimates can be seen for the quarter year occasion length models in Figure 6.3 below.

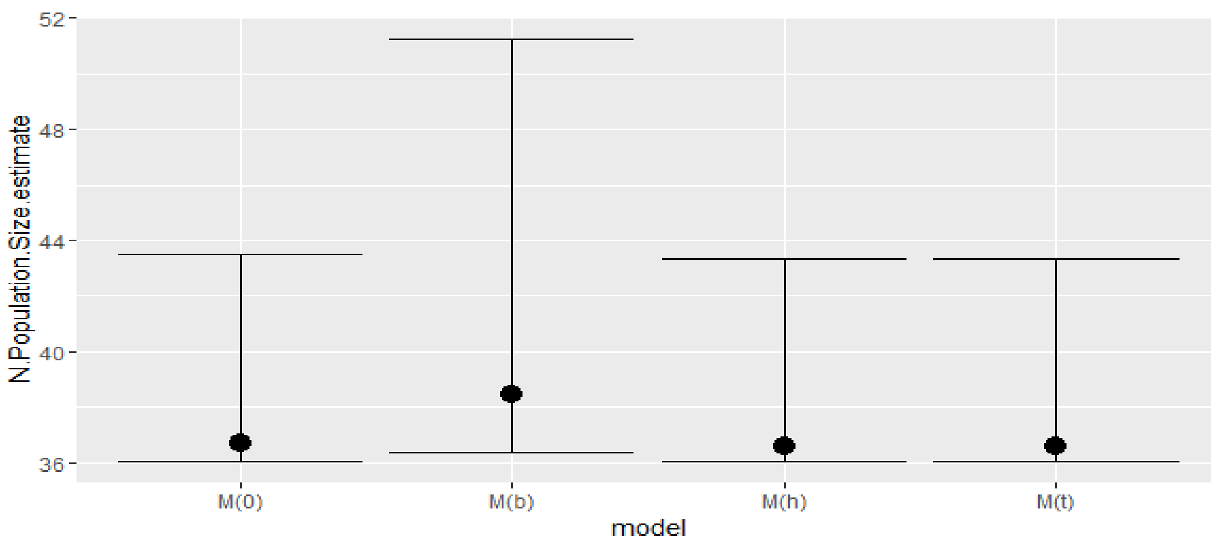

Figure 6.3 Predicted population and corresponding 95% confidence interval for the 4 models using quarter year occasions

The most supported models, M(0) and M(b), give estimates of 36.718 and 38.441 snow leopards in the study region for quarter year analysis, respectively. The M(b) model shows a larger variation in the estimate with a large 95% upper bound, 51.265. However, the point estimate and lower bound for all models are similar.

The estimates and corresponding 95% confidence intervals for all 32 combinations of models and occasion lengths can be seen in the index. Likewise, a graph of estimates specific to occasion length, such as that in Figure 6.3, can be seen in the index. These estimates are similar to what is seen in the quarter year occasion length, but occasions with a longer length have more variation in the estimate. Likewise, occasions with shorter length have less variation. The bi-weekly, monthly, and seven occasion estimates show no variation because of the low capture rate over multiple occasions.

7 Discussion

7.1 Models

After examining results from all occasion lengths, the behavioral model, M(b), showed the most support from the data. This parallels the knowledge of a snow leopard sticking to the same area. If these hard-to-catch snow leopards were captured by a camera once, it is likely they will be captured again by the same, or nearby cameras. This is consistent with the results for the behavior models that return an estimated recapture rate that is higher than the original capture rate. Although, the no variation model, M(0), did have some support as well and could provide evidence that the capture and recapture rate were not different. This support is more likely due to an exhaustive camera layout within the study region providing a high original capture probability.

The other two models, M(t) and M(h), did not receive much support from the data. This suggests that snow leopards are not moving a great deal more during one part of the year than another; therefore, the capture rate is similar among different occasions. These results also suggest that there is not another group of harder-to-catch snow leopards hiding within the study region. With the high coverage rate of cameras throughout the region it makes sense that there would not be a large group that is not spotted throughout a whole year.

7.2 Estimation

Based on model estimates and the corresponding support for the models, it appears that there are estimated to be between 36 and 40 snow leopards with a possible, but not likely, larger upper-bound estimate. However, due to snow leopards being an endangered species, overestimating a population could be detrimental to the species.   For this reason, a suitable estimate would be the lower-bound of the 95% confidence interval.

As seen in the results, most lower-bound estimates were approximately 36. Because 36 snow leopards were seen in the photographs, a population estimate of 36 would suggest that all snow leopards in the study region were seen. As discussed before, the M(h) model was not well supported and it is likely that there is not a group of snow leopards hiding within the data set that have not been seen through the whole year. Likewise, it is possible that every snow leopard was seen at least once during the year.

7.3 Possible Violation Assumption

36 could be an overestimate of the true population because some of the captured snow leopards could have been from just outside the study region, and just happened to wander through on their way to settle elsewhere. This would violate the closure assumption. On the other hand, it is possible that new snow leopards may have settled into the region counterbalancing those that left. Nonetheless, it does not seem likely there are many snow leopards coming and going since two borders of the study region are natural. The high mountain peaks

and an exposed canyon valley would deter most from leaving. The snow leopards living just outside the boarders are still of interest and it is likely that the study region should include a wider area than the camera trap edges. Overall, it is conceivable that the study region is not closed, but it is also doubtful that this violation is heavily influencing the estimate. Assuming marks were not misread, overlooked, or lost seems to be reasonable assumption as much time and care was put into collecting this data.

7.4 Scope of Interest

Any conclusions made from this project are limited to this area and areas that this area is representative of. A case can be made to extrapolate population estimates to the neighboring stretch in the Wakhan Corridor, but other variables could be contributing to the study area population that has not been accounted for that may differ elsewhere, such as local villages that could provide another potential food source. Likewise, conclusions about snow leopards behaviors and capture rates can only be inferred to the study region population. It is possible further analysis may show the study area to be larger.

7.5 Conclusion

Findings from this project indicate approximately 36 snow leopards in our study area. While there could be some cats that went undetected, it is unlikely that there is a large group hiding within the study region. These results imply that the camera set up captured close to, if not all of the snow leopards in the study area. Further analysis can help determine the validity of the assumptions made in analyzing this data but it is doubtful that estimates will drastically change given the strong concurrence across multiple models, each with different explicit assumptions.

Figure 7.1 Chole, one of the 36 snow leopards photographed in the study area.

8 Future Work

To address the possibility of the closure violation in this study, a seasonal Ad Hoc model could be run. This will allow for emigration and immigration in the times between the seasons. An abundance estimation could then be obtained for each season and allow for a better indication on how the snow leopard population is fluctuating throughout the year and if a simplified closed abundance estimate could still be relevant. However, due to the low shorter occasion capture rates that would have to be used in a seasonal analysis and the smaller population of snow leopards, it may not possible to obtain reasonable estimates for each season.

The current study is limited to conclusions to the region where cameras are set up. Finding the snow leopards average movement within the region would help determine how far outside of the camera boarder line snow leopards were traveling. This could provide an extrapolation of the results to a slightly larger region. The area of this region would also be needed to calculate a more accurate density estimate (Alexander et al, 2015).

There are many possibilities with other spatial and temporal analysis of this data. One possibility is using the snow leopards that were encountered more often and following where that individual was going over time to create a home range for an individual. It could be possible that there are patterns among individual snow leopards that could give insight on how to divide encounter histories based on their behavior and achieve higher capture rates for future studies.

9 Acknowledgments

This project would not have been possible without the advice and assistance from John Winnie and Jay Rotella. They were able to help a statistician work in the unfamiliar world of ecology.   Another big thank you goes to Steve Cherry for his support, supervision, and statistical advice. The data was collected by the Wildlife Conservation Society. Amber Gill did the identification of the snow leopards; creating the data set used for analysis. Eric Loftsgaarden provided coding assistance in creating a function that processed the data into encounter histories in reasonable time.

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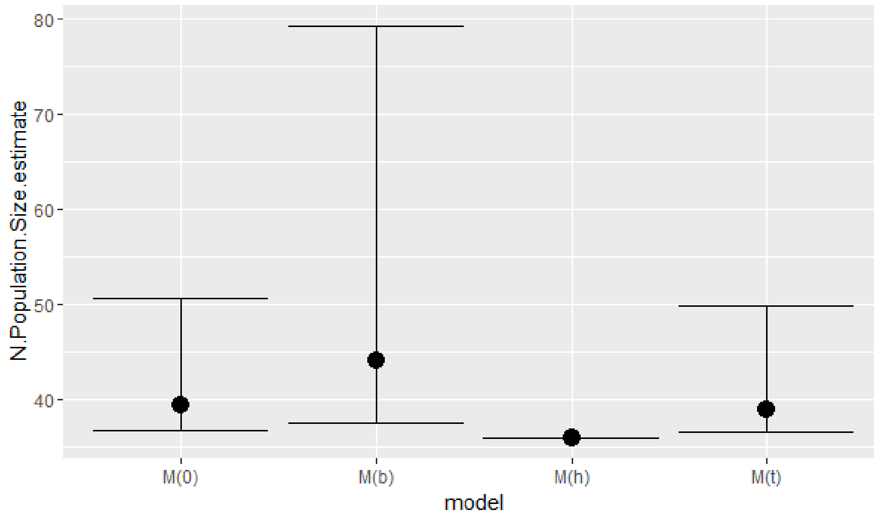
11 Code

```
require(plyr)
require(ggplot2)
require(RMark)

#Read in Data
dat <- read.delim("Data")
#View(dat)

occasion.length <- X #number of days in each period
occasions <- X  #total number of period aggregating data to
cats <- X #specifying unique number of cats

start.col = 2   # first column that has data
end.col = start.col + (occasion.length - 1)
occasion.df <- data.frame(cats=dat$Cat) # set first column of final output DF

for (j in 1:occasions){
  tmp=rep(0,cats)
  for (i in start.col:end.col) {
    #tmp<-tmp+dat[[i]]    # cumulate counts used  for debugging
    tmp<-pmin(tmp+dat[[i]],1)  # 1 or 0. actual execution
  }

  colname = paste("Occasion",j) # set name of new column to add
  occasion.df[[colname]]<-tmp  # add new period column to data frame

  start.col = end.col+1  # set new start column number for next loop
  end.col = start.col + (occasion.length - 1) #set new end col number for next loop
}

#head(occasion.df)
ch <- c()
for (k in 2:ncol(occasion.df)){
  ch <- paste(ch,occasion.df[,k],sep='')
}

final.df <- data.frame(cats=dat$Cat)
final.df$ch <- ch
final.df$freq <- 1
final.df <- final.df[-1]
#head(final.df)
```

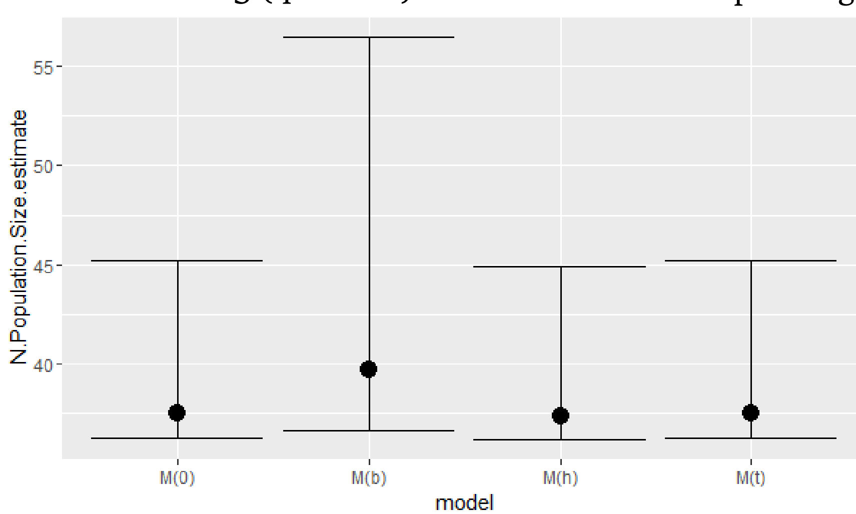
```
final.pr = process.data(final.df, begin.time = 1, model = "Closed")
# Create default design data Create 'age' variable for Phi and p For Phi,
final.ddl = make.design.data(final.pr)

# add columns to ddl data for p for M(b) model
# 1. add 2 categories of time (1st occ.[0] or later[1])
final.ddl$p$t2=0
final.ddl$p$t2=ifelse(final.ddl$p$Time==0,0,1)

# add columns to ddl data for c for M(b) models
# 1. add 2 categories of time (1st occ.[0] or later[1])
final.ddl$c$t2=0
final.ddl$c$t2=ifelse(final.ddl$c$Time==0,0,2)

# function for running set of models for phi and for p
run.final = function() {

  # Define parameters for p and c Note: 'share=TRUE' indicates that 'p' & 'c'
  # share the same columns in the design matrix
  p.dot = list(formula = ~1, share = TRUE)
  p.time = list(formula = ~time, share = TRUE)
  p.h.2p=list(formula=~t2,share=TRUE)
  p.dot.c.dot = list(formula = ~1, share = FALSE)

  # Create competing models based on strcutures for 'p' & 'c'
  final.model.list = create.model.list("Closed")

  # NOTE: if you do not want to see the output for each model, add the text ',
  # output=FALSE' after 'ddl=final.ddl' below.
  final.results = mark.wrapper(final.model.list, data = final.pr, ddl = final.ddl,
output = F)

  # Return model table and list of models
  return(final.results)
}
```

Population Estimates for 2 (half year) occasions and corresponding AICc table



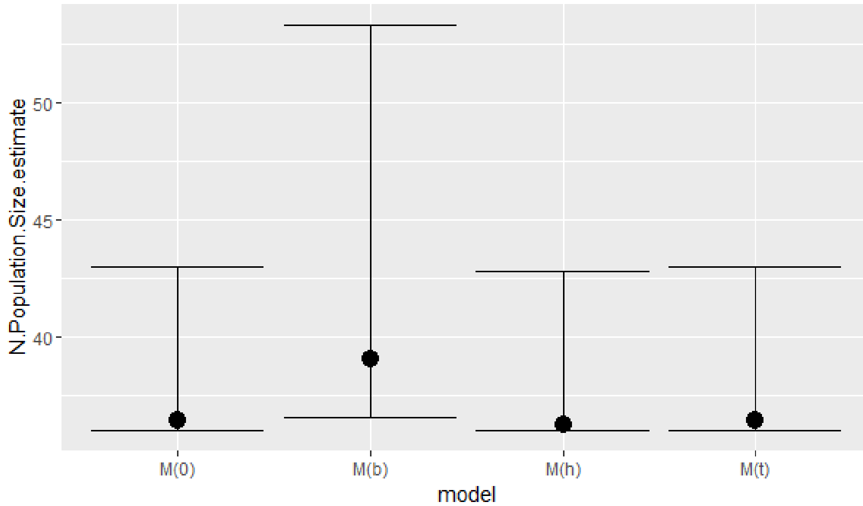
model	npar	AICc	DeltaAICc	weight	Deviance
M(h)	4	-111.7827	0	0.494778	0.482609
M(0)	2	-109.2461	2.536642	0.139183	5.198287
M(t)	3	-109.2214	2.56129	0.137478	3.043902
M(b)	3	-108.3602	3.42248	0.089378	3.905094

Population Estimates for 3 (4 month) occasions and corresponding AICc table



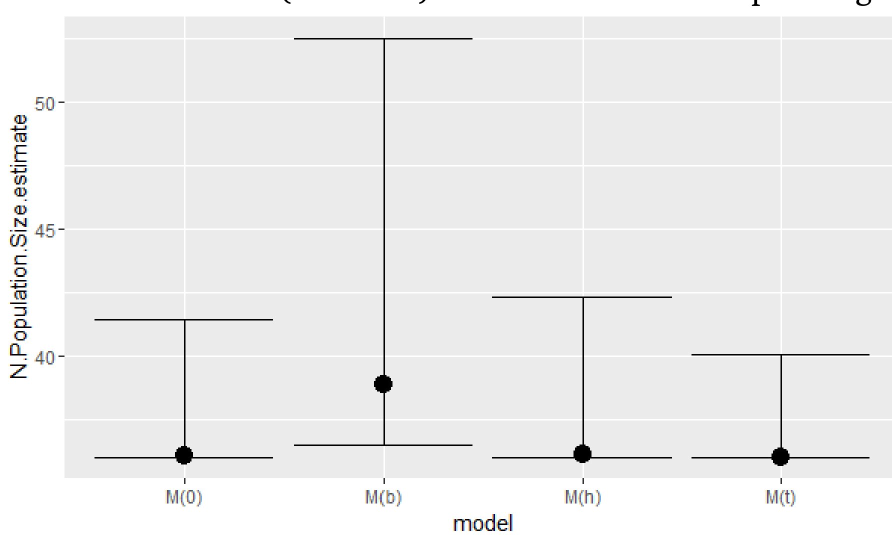
model	npar	AICc	DeltaAICc	weight	Deviance
M(h)	4	-48.78216	3.613634	0.116348	19.01928
M(0)	2	-48.44189	3.953903	0.098146	21.47603
M(b)	3	-47.61151	4.784284	0.064797	20.18993
M(t)	4	-44.24357	8.152224	0.012029	21.40029

Population Estimates for 5 occasions and corresponding AICc table



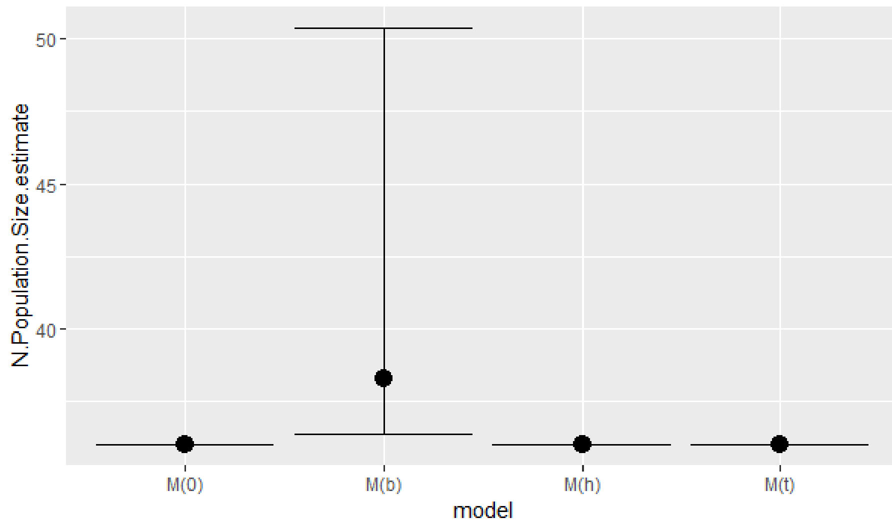
model	npar	AICc	DeltaAICc	weight	Deviance
M(b)	3	59.35039	0	0.544387	72.6125
M(0)	2	61.6131	2.262714	0.175617	76.94378
M(h)	4	62.291	2.940614	0.12513	75.55311
M(t)	6	68.40056	9.050167	0.005898	75.31348

Population Estimates for 6 (2 month) occasions and corresponding AICc table



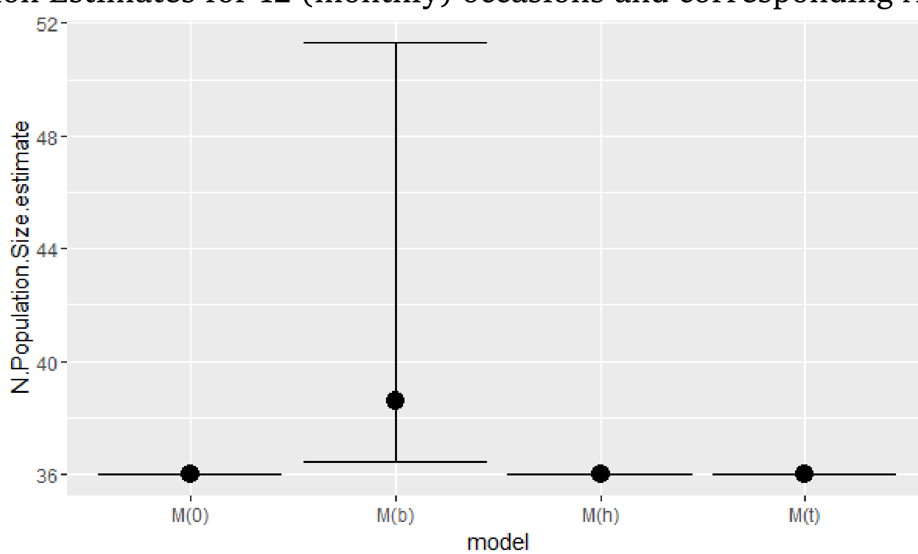
model	npar	AICc	DeltaAICc	weight	Deviance
M(b)	3	106.5544	0	0.895327	98.50904
M(0)	2	112.0344	5.48001	0.057811	106.0459
M(h)	4	113.9427	7.38825	0.022266	105.8973
M(t)	7	119.0732	12.51871	0.001712	102.6025

Population Estimates for 7 occasions and corresponding AICc table



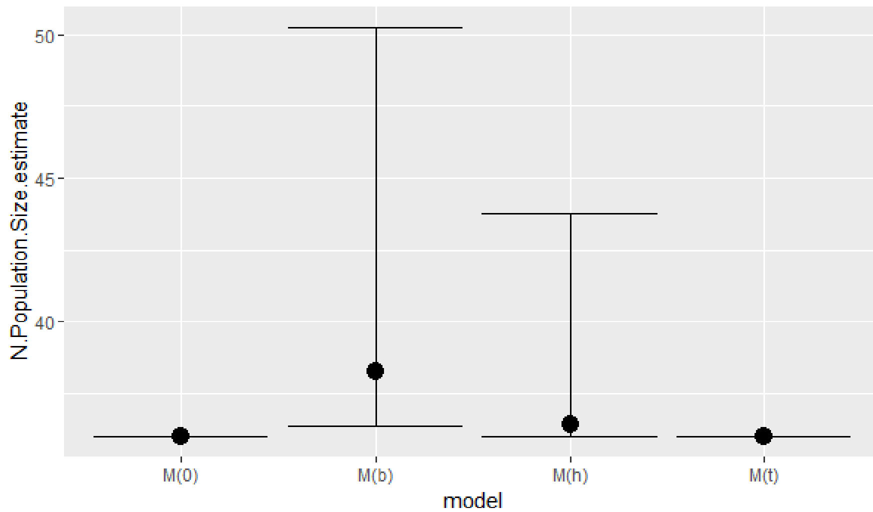
model	npar	AICc	DeltaAICc	weight	Deviance
M(b)	3	154.5384	0	0.908425	129.507
M(0)	2	160.6682	6.129729	0.042387	137.6854
M(h)	4	162.6576	8.11914	0.015676	137.6262
M(t)	8	167.8682	13.32974	0.001158	132.341

Population Estimates for 12 (monthly) occasions and corresponding AICc table



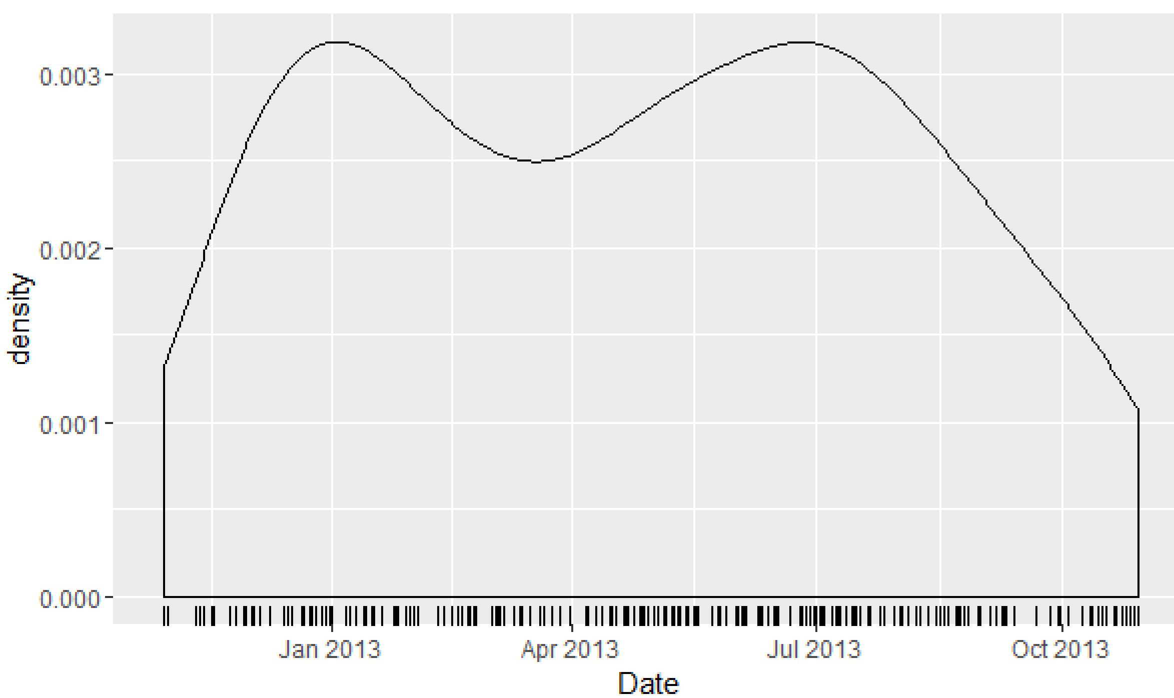
model	npar	AICc	DeltaAICc	weight	Deviance
M(b)	3	351.6252	0	9.98E-01	293.9046
M(0)	2	365.2678	13.64268	1.09E-03	309.5753
M(h)	4	365.7221	14.09696	8.67E-04	308.0015
M(t)	13	374.9682	23.343	8.51E-06	296.4328

Population Estimates for 26 (biweekly) occasions and corresponding AICc table

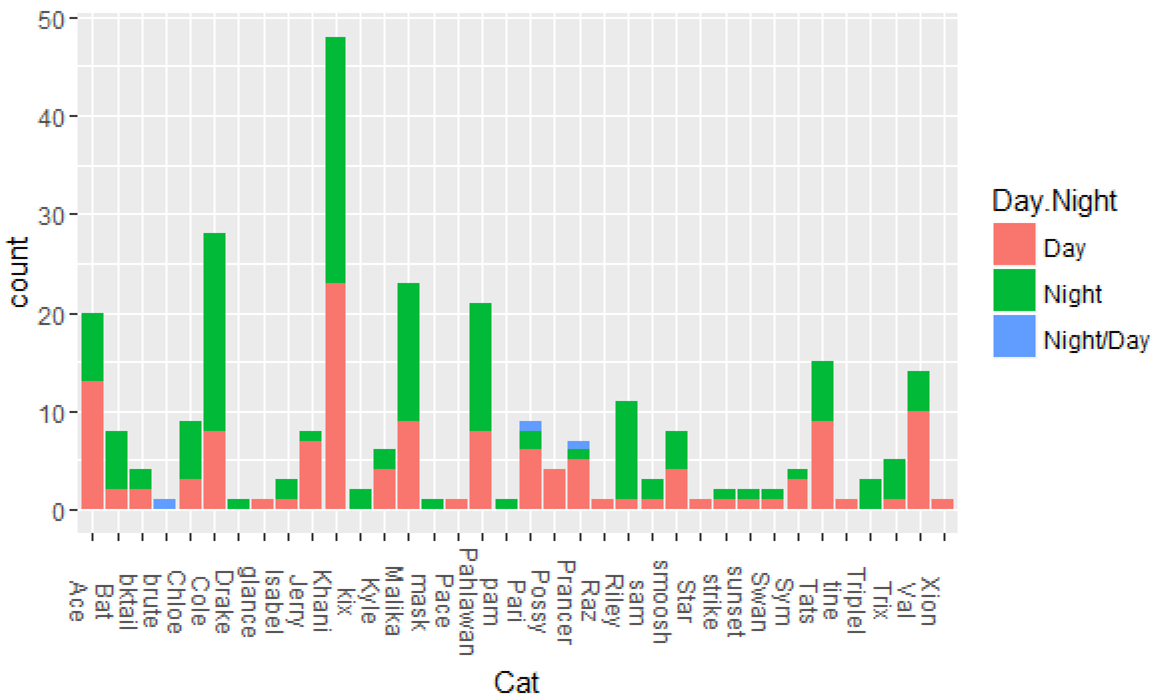


model	npar	AICc	DeltaAICc	weight	Deviance
M(b)	3	739.2226	0	9.77E-01	673.2146
M(h)	4	746.7678	7.54518	2.25E-02	680.7598
M(0)	2	765.1849	25.96227	2.25E-06	701.1898
M(t)	27	789.8955	50.67286	9.70E-12	674.248

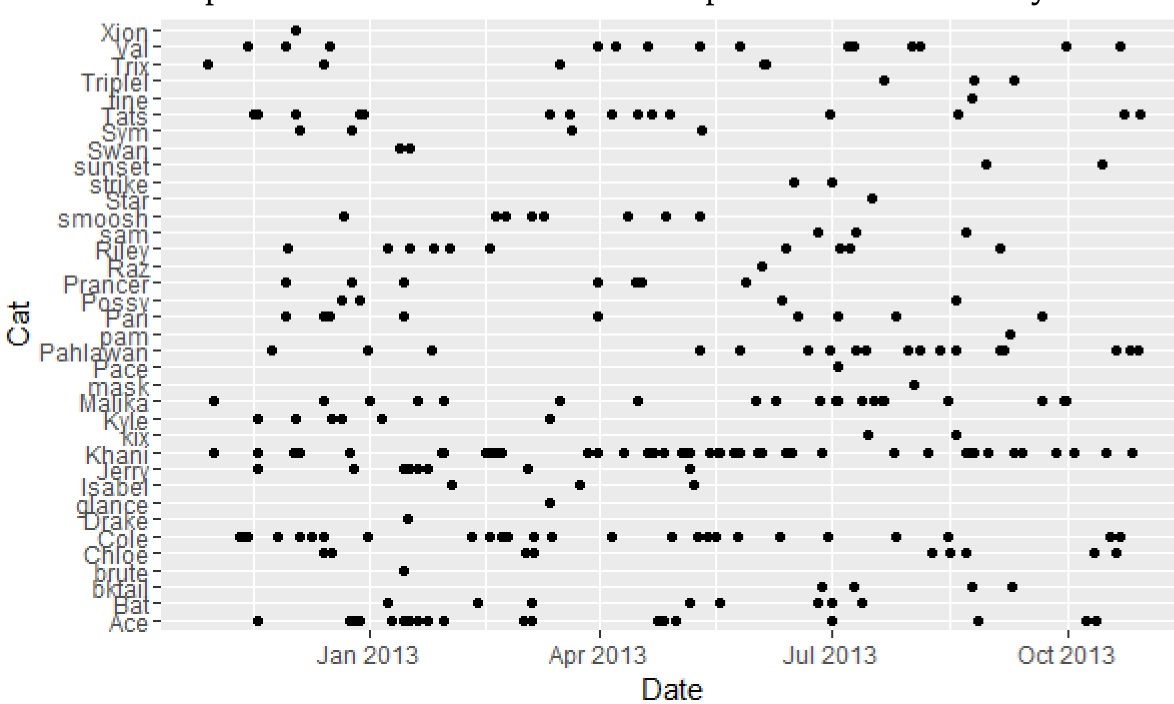
Zoomed in graph of photograph Density that illustrates camera set up and take down



Graphic illustrating time of day snow leopards were seen



A temporal look at when each snow leopard was seen over a year



A complete table of Abundance Estimates and the matching 95% confidence bounds based off number of occasions and the model

N.Population.Size.estimate	N.Population.Size.se	N.Population.Size.lcl	N.Population.Size.ucl	num.occasions	model
36.0000	0.0003	36.0000	36.0003	26	M(0)
36.0000	0.0000	36.0000	36.0000	12	M(0)
36.0000	0.0002	36.0000	36.0001	7	M(0)
36.0509	0.8638	36.0005	41.4061	6	M(0)
36.4437	1.1107	36.0281	43.0123	5	M(0)
36.7184	1.2805	36.0690	43.4841	4	M(0)
37.5431	1.7598	36.2579	45.2338	3	M(0)
39.4903	2.9509	36.8275	50.7221	2	M(0)
38.2860	2.6975	36.3665	50.2593	26	M(b)
38.5807	2.9245	36.4346	51.3239	12	M(b)
38.2852	2.7178	36.3629	50.3916	7	M(b)
38.8685	3.1686	36.4982	52.5145	6	M(b)
39.0649	3.3361	36.5419	53.3349	5	M(b)
38.4406	2.8864	36.3902	51.2653	4	M(b)
39.7017	3.9577	36.6687	56.4913	3	M(b)
44.1048	8.4018	37.5190	79.2432	2	M(b)
36.0000	0.0002	36.0000	36.0001	26	M(t)
36.0000	0.0003	36.0000	36.0003	12	M(t)
36.0000	0.0001	36.0000	36.0000	7	M(t)
36.0170	0.8426	36.0001	40.0659	6	M(t)
36.4152	1.0948	36.0247	42.9824	5	M(t)
36.6157	1.2264	36.0515	43.3634	4	M(t)
37.5379	1.7575	36.2564	45.2254	3	M(t)
38.9876	2.7440	36.6450	49.8382	2	M(t)
36.4313	1.2018	36.0240	43.7426	26	M(h)
36.0000	0.0000	36.0000	36.0000	12	M(h)
36.0000	0.0006	36.0000	36.0004	7	M(h)
36.1120	0.9178	36.0020	42.2834	6	M(h)
36.2295	0.9965	36.0078	42.7964	5	M(h)
36.5763	1.2111	36.0451	43.3628	4	M(h)
37.3674	1.6774	36.2090	44.9447	3	M(h)
36.0000	0.0000	36.0000	36.0000	2	M(h)

A compiled graph of all 32 estimates with 95% confidence intervals