Estimating Frog Density from Acoustic Surveys: A Comparison of Spatial Capture-Recapture Methods

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A brief statement on how scholarship has furthered career development:

This summer scholarship has given me a chance of putting statistical knowledge into solving real-life research problems and improving my coding skills by practicing statistical programming. I had a great time exploring new knowledge needed for the project, solving problems step by step with applying both my programming skills and analytical methods. It was a great opportunity for leading my career development to statistical research and data analysis.

A summary of research and its significance, suitable for a general readership:

This research project is mainly about comparing two existing methods which are for estimating how many frogs are in a certain area. As this kind of cryptic frogs are small and hard to catch, we use microphones for detecting their calls so that we get to know information about how often they call, and how close they are to the microphone detectors; we then estimate the amount by applying statistical knowledge.

My responsibility is to generate reasonable data for the survey, which you can think as data having a similar pattern as those collected from real life. Then code up functions to fit these two methods in with our generated data, and we are good to compare these methods from the results of running our functions. The standard of our comparison will be mainly on how accurate the methods are on estimating or how close our results are to our original data caught from microphone detectors. It is an essential part of the big picture of the method development, as we want to put the cost, and the result accuracy both into consideration.

With successful management of this project, we will be able to provide a better method for helping other scientists exploring the size of amphibian populations while spending less time and resources.

An abstract of the research with not more than 250 words:

With the interest in working out how many creatures inhabit a space when they are elusive, small and have lots of places to hide, Acoustic surveys are used so that we collect the animal call rates and the time of call arrival from our detectors rather than trying to catch them from the field. This research project is mainly about comparing the performance of two existing spatial capture-recapture (SCR) methods which provide estimations of animal population density.

We compare the methods first by simulating data based on the original data from an acoustic survey of South Africa’s Cape Peninsula moss frog, then we write up functions to fit these two methods with simulated data. The results gotten by running the functions thousands of times are compared by interpreting both a set of boxplots of percentage bias and a statistical coefficients table generated.

The rest of the report should cover aims, methods and results/discussions:

Spatial capture-recapture method is often used for studies of animal populations with including a spatial point process model for individuals' locations and allow capture probabilities to depend on locations (Borchers and Efford, 2008). It allows us to reach a more realistic and efficient estimation by putting animal habitat preference, movement patterns, and demographic parameters all into considerations on spatial variables (Borchers and Fewster, 2016). How acoustic survey makes a distinction in the research is that calls or sounds rather than animals or natural marks from animal bodies are captured for future estimation when the research targets are small and good at hiding around but have clear calls; the target will be one kind of cryptic moss frogs in our case. "It can be an efficient, cheap, and non-invasive alternative to physical trapping of individuals", as described by Stevenson et al (2015).

In this project we will compare two recently developed SCR methods for estimating animal density from acoustic surveys. The first, which we call ASCR, was proposed by Stevenson et al (2015), while the second, which we call SCR, was proposed by Young (2018). The ASCR assumes that it is hard to distinguish the origin of calls, or we cannot say which call is from which frog as the differences are very subtle. Locations of vocalizations don't come from a homogenous Poisson process, which is because multiple calls from the same frog will come from the same location if frogs do not move during the survey. Calls are not independent when they are from the same frog. For having the estimation unbiased, we pretend that the call density is under Poisson distribution, and we collect the call-rate data separately by recording from a small amount of frog sample found in the field. Animal density will be the rate of call density and call rate. However, this can be a very time-consuming task because individual frogs are difficult to find due to their size. The ASCR can be used for both moving and stationary animals as we have an extra call-rate variable.

On the other hand, The SCR does not need call rate data as it assumes that we can distinguish which frog the calls are from. ID can be assigned to each call detected, and we estimate the animal density by calculating the max likelihood (Young, 2018). The SCR method in this project is only possible for using on stationary animals, so we also assume that the frogs make multiple calls from the same place, but this is a reasonable assumption for this particular species (Stevenson et al, 2015).

The process can be achieved by first running the methods once on each time with real-life data collected as input to get a set of parameters. We treat this set as our start parameters. Data simulations are run based on these parameters. Then by refitting the method with new simulated data, parameter estimates are generated. With a thousand times repeated, we can calculate the percentage bias between the estimated parameters and the true parameters (the start parameters) and create percentage bias boxplots to see how close our estimations are to the true parameters.

Now, even without having the estimation results on hand, it is easy to find out that ASCR is more realistic as more information is processed, while it is difficult to catch sample for collecting call rate data. SCR needs less information but is asking for distinguishable calls which are also difficult to manage.

With the development of survey detectors, we can get extra data such as estimated distances, estimated bearings, received signal strengths, and received signal times of arrival. We can have a more efficient way of simulating data for running both methods. We can reduce our simulated survey region by knowing the max detectable distance; capture histories can be simulated by calculating detection probabilities with knowing the estimated distances between call center locations and detector locations. We can also simulate time of arrivals with knowing the distance and sound speed (Measey, Stevenson, Scott, Altwegg, and Borchers, 2017).

One of the tricky parts in simulating capture history is that we need to first determine the distributions of animal locations, call density, the timing of calls, and the number of animals. They are determined as uniform distribution, Poisson distribution, and Poisson distribution separately. The process then starts with simulating the number of animals based on the animal density input and survey region size. frog locations can be simulated by knowing how many animals are there, following with simulating call center locations by basically duplicating frog locations based on a Poisson distributed number of calls. After calculating the distances between each location and detector, it is good to go ahead for each probability calculation of getting detected, then generate a capture history filling with binaries depending on probabilities. We eliminated all the no detection histories for data cleaning purpose, and we generated a time of arrivals table by having a sum of the simulated start of calls for each available detection and the time took for spreading the sound to detectors. We also added random error to the times to acknowledge that microphones do not perfectly measure times on the scale of milliseconds.

The standards of method evaluation are accuracy and efficiency. Firstly, we must assume that we can distinguish animal calls in SCR method to make it possible to run. We need to balance the result between how accurate the method is in estimating the animal density and how different the accuracy is between two methods; we also need to consider both the difficulty of getting samples for call rate data and what the minimum of the maximum amount of sample is for achieving relatively better accuracy.

A good way to interpret the results is to have a comparison table (Figure 2) and a set of percentage bias boxplots between two methods (Figure 1). According to the boxplot (Figure1) of both estimates from ASCR with the number of samples for call rate as 5 and from SCR. We found that the range of animal density percentage bias from ASCR had a less range (-80 to 90) comparing with the one from SCR (-80 to 120), and less outliers. What is more, the boxplot from ASCR looks more symmetrical with the median being very close to the true value, while the one from SCR is right skewed as a greater number of estimates in total are less than the true value. However, the difference is not huge, and we also found that the interquartile ranges between two methods are very similar (-30 to 30). A comparison table (Figure 2) is made for a more detailed interpretation.

Three statistical values (percentage bias, percentage coefficient of variation, and percentage root mean square error) are calculated for animal density from ASCR with the number of samples for call-rate being 2, 5, and 10 separately, and for that from SCR method. We have every value standardized as percentage because we want them to be related to the true density so that we will not be confused by the absolute numbers themselves. By going through these values one by one, firstly, bias describes how far away our estimates are on average from the true value. A great improvement is made by increasing the sample amount from 2 to 5 according to the change of %bias (from 5 to 2) while the improvement gets less dramatic from 5 to 10 (from 2 to 1). What should also be mentioned is that SCR has gotten 4.7 which is close to ASCR 2-monitored's. Therefore, 5 is considered as a better number for call-rate sample in terms of bias.

Coefficient of Variation (CV) shows how various the estimates are in terms of the true value. SCR has the greatest CV value (56), and by changing the sample amount from 2 to 5 in ASCR method, CV decreases from 34.6 to 32.7. No great improvement is found by changing the sample amount from 5 to 10.

Root Mean Square Error (RMSE) is the root of a combination of bias squared and variance, which measures the average of the squares of the errors. The smaller it is, the better we consider estimations are. It is found that the values are similar to CV. With SCR having the greatest value (56.5) and ASCR 2-monitored has the second greatest (41). ASCR with call-rate sample amount as 5 (35) and 10 (32.7) have smaller RMSE values.

Overall, ASCR with call-rate sample amount as 5 gives a great accuracy in terms of estimating parameters under the circumstances that we set, which beats SCR method according to both boxplots and three different statistical coefficients, and the call rate sample amount is not considered too big. It is concluded as a relatively more effective and accuracy mothed for estimating stationary animal density for our research.

Figure 1:

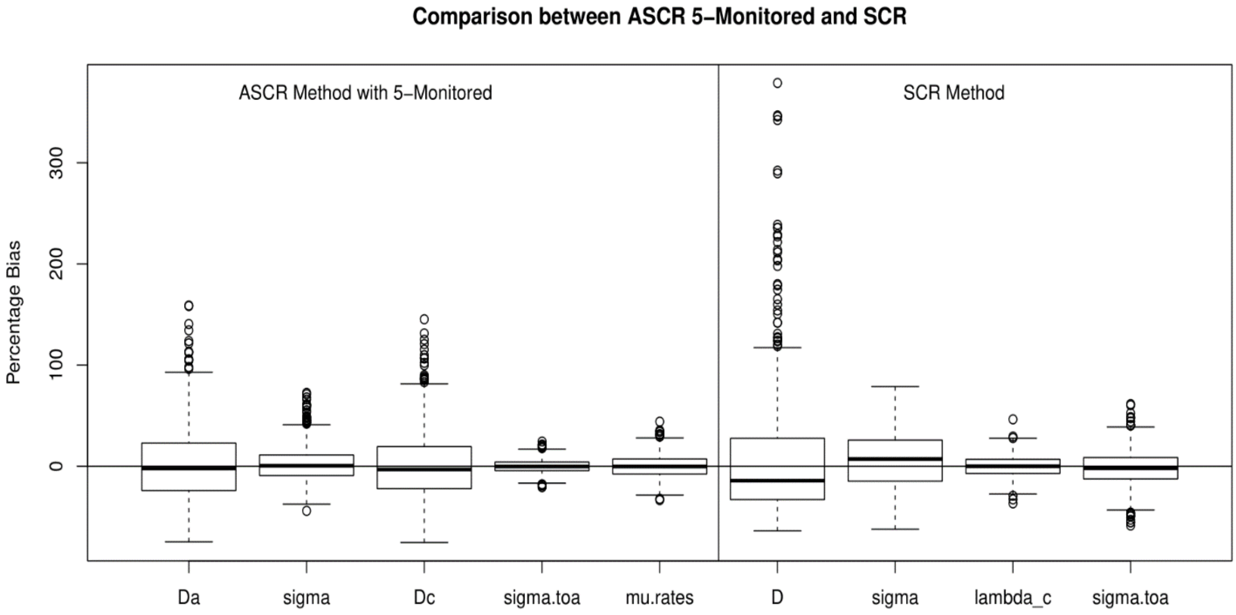

Figure 2:

Da (Animal Density)	ASCR 2-monitored	ASCR 5-Monitored	ASCR 10-Monitored	SCR
% Bias	5.017984	1.955563	1.072962	4.744002
%CV (Coefficient of Variation)	40.71024	34.64599	32.65466	56.33103
%RMSE (Root Mean Square Error)	41.01834	34.70113	32.67228	56.53044

References

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