Literature review

This literature review offers threads from which theory and insights could be woven, including efficient method in animal population density study, problems and solutions in classical animal density study and spatial capture-recapture study, research on encounter probability study and effective method to connect animal density study with landscape covariates. This chapter reviews most relevant studies for each thread in animal population density study. Each thread is related to the topic of this article, but also these streams has some problems that could be improved. Royle ‘s research (2003) argues a new way in animal density research which could deal with heterogeneity problem and could achieve financial benefit. Research by Efford (2004), Borchers (2008) and Royle (2008) focus on the problem of undefined effective trapping area, and each research state new method to solve this problem. Studies by Rolye (2013a, b) concentrates the analysis that connect animal space usage in spatial capture-recapture model with environment effect on animals. To conclude, this literature review shows traditional capture-recapture model in animal density study could not contain landscape effect in density study, and that is the method in this research addressed could solve.

For Biologists, animal population density is one of the most important parameters in animal population study. (Krebs 1985, Turchin 1998) And collecting animal population data from traps might be the most common method in animal population density analysis. ([Thompson *et al*. 199](https://onlinelibrary.wiley.com/doi/full/10.1111/j.0030-1299.2004.13043.x#b54)8) Capture-recapture method is a normally used method for population size study (Borchers & Efford [2008](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0003)). Royle (2003) introduces such method to estimate occupancy rate when heterogeneity in trapping probability exists. The basic idea in the method is that the detect probability could be affected by the variance of abundance. From this method, scientists could estimate animal abundance distribution by making model of heterogeneity detection probability. This method could accept animal data from repeated trapped records instead of unique individual population document. (Royle & Nichols 2003) By using this method an animal population research could do several times and save large amount of money during recording observations. In this capture-recapture method, population size could be converted to or treated as density, by dividing effective trapping area; however, effective trapping area could be very hard to calculate (Efford 2004). Dice (1938) suggests the distance from the traps W could be used to calculate the effective trapping area. There also exist some other ways to get trapping area, but none of these methods are commonly used or strongly reliable. (Efford 2004) Several method to avoid effective area in population study, like trapping webs ([Anderson et al. 1983](https://onlinelibrary.wiley.com/doi/full/10.1111/j.0030-1299.2004.13043.x#b1)), require specific trapping conditions and these method has less reliability to scientists in study of population density for most cases. (Efford 2004). In Parmenter’s study (2003) about the density estimation of rodent from 11 data sets, the author compares grid-based density estimation method and web-based density method with given density value datasets. Both methods require several assumptions of the datasets, and the results of two method seems met the assumptions. The result of this study shows most web-based method shows better accuracy than most grid-based method; the best web-based method shows comparable performance to best grid-based method; the method using “effective trapping area” shows lack of performance in rodent density study, but the application of rodent movement distance improves the performance of density estimation a lot. The web-based method seems has good performance than grid performance, but web-based method requires several assumptions and well-defined effective trapping area. Therefore, a good performance of trapping web method need the good measured trapping area, which is hard to estimate for most studies.

To solve the problem of lack efficient way to define and estimate effective sampling area, Efford (2004) argues a new method in his study to estimate density from capture and recapture animal population data without the step of calculating effective trapping area, by using a two- parameter spatial capture function to make a simulating model and do simulation and inverse prediction to estimate population density. During the research, his method provides an unbiased estimate of population from simulation data. (Efford 2004) There are some problems appear in his method when trap saturation level becomes high enough and when trap competition happens, and this method has some limitations in model selection and covariates analysis. (Borchers & Efford [2008](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0003))

A very similar method relate to Efford’s method is the Spatially Explicit Maximum Likelihood Methods developed by Borchers (2008), this method solves the problem that capture-recapture method has lack of ability to analyze spatial nature during population density study. In capture-recapture study, spatial component could affect the trapping progress; traps could record animals closer to the trap with more probability than record animals far from trap. This problem is not solved in previous population estimate study and may cause the result not reliable enough for spatial density analysis. (Borchers & Efford [2008](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0003)) The new method could achieve spatial nature analysis by estimating animal spatial probability from animal location and trap location based on maximum likelihood; by adding spatial components into model, the density estimation could be “well defined” because of the population abundance could be defined.

The other problem in animal density study from close populations is the existence of population movement, most in short terms; this will cause effective population area changes and makes estimate result not strongly reliable. (Royle & Young [200](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0032)8) Royle’s new method (2008) based on capture-recapture data involves a hierarchical model calculating with sample spatial unit area, then individual activity center and individual activity movement could be estimated by hierarchical model. The density of individuals could be estimated by this method, and the problem of population movement could be solved.

For these three methods, one common part in their research is the application of spatial capture-recapture method. The elementary theory in spatial capture-recapture method is use function which contains distance between animal individual location center and the trap location to get encounter probability. (Borchers & Efford [2008](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0003)) This method makes it is possible to finish spatial population density research. Although spatial capture-recapture models are new class of method, the use of it is relatively widespread in population density and movement estimation. (Efford *et al*. [2009](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0007), Gardner *et al*. [2010](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0014), Gopalaswamy *et al*. [2012](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0016), [Royle *et al*. 2013a, b)](https://onlinelibrary.wiley.com/doi/full/10.1111/j.0030-1299.2004.13043.x#b1) Efford (2009) used a new spatial capture-recapture model to find animal density of close-population with stable home range, the author also introduces a new longtime single sampling interval which has some financial benefits compared to previous sampling time intervals. Gardner’s hierarchical spatial capture-recapture model (2010) uses spatial explicit components of black bear detected by traps to make analysis on black bear. Gopalaswamy (2012) makes a comparison capture-recapture research on tiger density, tiger photographic data analysis and tiger fecal sample analysis. According to the result of the research, making inference on parameters from more information could improve the model, SCR model could be improved by adding more landscape information to the model. The widely application of spatial capture-recapture model comes from spatial capture-recapture’s ability to solve critical problems in non-spatial capture-recapture method (Royle *et al*. 2013a, b) such as the heterogeneity in encounter probability from juxtaposition of individuals with traps and ill-defined sampling area. (Borchers 2012, Royle *et al*. 2013a, b) The axillary spatial information produced by capture-recapture research is also a benefit of using spatial capture-recapture method.

Despite the widely utility of spatial capture-recapture method in population density analysis, Royle (2013b) points out the encounter probability model makes the estimation of space becomes too stationary and too symmetric to represent animal’s spatial resources selection. The encounter probability model, which most capture-recapture model based on, uses Euclidean distance to calculate encounter probability by simple functions in spatial capture-recapture model; some different encounter models are proposed in resent year including binomial, Poisson and multinomial encounter models.(Royle *et al*. 2013a) The encounter probability model implies stationary and symmetric animal home range, which is unreasonable because animal will make temporally movement decision by environment effect; for example, water buffalos tend to move to areas where has plenty of water and leopards prefer those area which is their prey habitat. The function in encounter model can’t achieve analysis of landscape effect nor get encounter probability which influenced by resources. Even though such stationary distribution could show good performance in some sparce data, for most cases these simple encounter probability models can’t represent animal home range size and shape for animal’s unevenly spatial resources selection. (Royle *et al*. 2013b) The location where animal lives on and the state of surrounding environment could affect animal spatial usage, so the encounter model should countian irregular and non-stationary properties on animal home range and could deal with local resource effect.

Landscape connectivity, which define as the level of landscape components affect animal movement ([Tischendorf and Fahrig 2000](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/12-0413.1#i0012-9658-94-2-287-Tischendorf1)), is recognized widely to become the population viability’s importance element. ([With and Crist 1995](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/12-0413.1#i0012-9658-94-2-287-With1)) In ecological research, ranking the landscape connectivity in animal density effect is one of the most important properties. (Royle *et al*. 2013a) In previous research, scientist normally estimate landscape connectivity values based on expert’s subjective opinion or some temporary method.  ([Adriaensen *et al.* 2003](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/12-0413.1#i0012-9658-94-2-287-Adriaensen1), [Beier *et al.* 2008](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/12-0413.1#i0012-9658-94-2-287-Beier1), [Zeller *et al.* 2012](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/12-0413.1#i0012-9658-94-2-287-Zeller1)) The lack method to predict animal density and landscape connectivity values simultaneously makes it becomes very hard to predict the effect of landscape in animal density study. This problem could cause huge bias exists in population density estimation result.

Royle (2013a) develops a model based on spatial encounter probability with alternative distance which could represent connectivity, Royle calls it “ecological distance”. This distance is related to the least-cost path with cost-weighted distance metric, and could define the distance between animal activity center and traps in cost-weight metric. The ecological distance could be calculated from the cost of moving between different cells in sample data and consider some environment variables that could affect animal movement between two cells during calculation, like elevation, snow cover, landcover and range limitations. ([Cushman *et al.* 2006](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/12-0413.1#i0012-9658-94-2-287-Cushman2), [Schwartz et al. 2009](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/12-0413.1#i0012-9658-94-2-287-Schwartz1), [McRae and Beier 2007](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/12-0413.1#i0012-9658-94-2-287-McRae2)) By using such distance, the landscape structure influence could be added to the spatial density analysis; and the parameters of cost-weight distance could be calculated and used directly in spatial capture-recapture method to connect the animal spatial density with landcover covariates. From the result of Royle’s simulation study (2013), the model use Euclidean distance produces huge bias while the model with least-cost path distance has better result. One problem of this method is that it cannot estimate the precise location of animal’s path of movement and the decision of animal when they move in different landscapes. (Royle *et al*. 2013a)

Second model that could deal the spatial capture-recapture process with animal’s space usage states by Royle (2013b); he improves the spatial capture-recapture model by add one or more clear landscape covariates to encounter probability model, this could extend the model with space usage and resources selection. By extending the model with some landscape covariates, those unpresented elements in previous encounter probability model such as animal home range size and shape could be included in Royle’s new model, and the new model could relate capture-recapture analysis with the trend of animal space usage. The new model also avoid bias during estimating process, especially in those situations where landcover covariates could influence animal spatial usage and selection. (Royle *et al*. 2013b)

According to previous research about animal population density research (Efford 2004, Borchers & Efford [2008](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12039#mee312039-bib-0003), Royle & Young 2008, Royle *et al*. 2013a, b), spatial capture-recapture method could be used in animal population density analysis because it has financial benefits compared to previous trapping method and it could solve the problem in classical non-spatial methods. And the application of encounter probability model in spatial capture-recapture model could avoid the problem of undefined sample trapping area and deal with spatial elements in population density study, which are two big problem in traditional population density analysis method; however, the encounter probability model might cause some problem in estimation from animal density data with landscape effect, since the encounter model could not connect to the animal home range with around landcover situations. Because of the limit of analysis for animal surrounding environment components in encounter probability model, the animal home range estimations from the model function show stationary and symmetric nature and causes the estimation unable to represent environment effect in density study. Thus, it is necessary to add landscape covariates in spatial capture-recapture model to provide connection between animal spatial components and landcover resource elements. This method could improve the estimation of density when landscape covariate has influence on animal spatial movement and usage, and could provide landscape effect analysis in animal population study.