

Effects of sampling regime on the estimation of animal space use

(調査の頻度と期間が野生動物の行動範囲の推定に与える影響)

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Animal movement and space use provide fundamental knowledge in basic and applied ecology of wild animals. Wild animals have the area typically used for activities such as foraging and reproduction, and peripheral sites outside the main area of activity that are utilized occasionally. The home range, an important concept in basic ecology, is restricted to the area utilized by an individual in its normal activities, and peripheral sites outside the normal utilization area are not included in the home range. There is increasing evidence that peripheral sites outside the home range are important in applied ecology such as wildlife conservation and management. The concept "maximum utilization area (MUA)" includes both the home range and peripheral sites.

There are a variety of estimators to calculate animal space use based on location data. Among these estimators, the minimum convex polygon (MCP), the kernel density estimation (KDE), and the dynamic Brownian bridge movement model (dBBMM) have been commonly used for estimation of animal space use. MCP, in which the home-range boundary encompasses all the data including occasional locations beyond the main area of activity, is applied for estimation of MUA including sites scarcely utilized. KDE, an alternative estimator based on the density of locations, is applied for estimation of the main area of activity. In addition, dBBMM is developed for home-range estimation to handle spatiotemporally high-resolution datasets. In recent studies on animal home ranges, KDE and dBBMM are considered as superior estimators to MCP, because the home range is restricted to the area utilized by an individual in its normal activities and peripheral sites outside the normal utilization area should not be included in the home range.

Recent advances in animal tracking technology such as a global positioning system (GPS) have allowed researchers to collect location data of animals accurately. However, GPS devices are inevitably subject to the trade-off between observation period and frequency of data collection because of their limited battery life. Previous studies on animal space use suggested that the areal estimates for animal space use can vary depending on both frequency and duration of observation, but simultaneous effects of the sampling regime on estimates of animal space use have not been examined using empirical data.

The thesis consists of four chapters. For the estimation of MUA using MCP, the estimated area generally increases with the number of location data (i.e., sample size), but the MCP estimator is sensitive to stochastic effects which are often unpredictable (i.e., animal activity and environmental conditions). To reduce these stochastic effects, in Chapter 2, I propose a new method based on simulation studies where outcomes of replicated simulations are averaged. In Chapter 3, I examine the effects of reductions in sampling frequency and duration on the home range calculated using

KDE and dBBMM and MUA calculated using the new method proposed in Chapter 2. Analyses are conducted based on my location data of Japanese monkeys in Chapters 2 and 3.

Chapter 2: Estimation of the maximum utilization area including home range and peripheral sites

I estimated the maximum utilization area (MUA), including home range and peripheral sites, based on asymptotic curves of utilization area plotted against sample size. In previous studies, these curves have conventionally been plots of cumulative utilization area versus sample size, but this cumulative method is sensitive to stochastic effects. I proposed a new method based on simulation studies where outcomes of replicated simulations are averaged to reduce stochastic effects. In this averaged method, possible combinations of sample size with the same number of location data replicated from a dataset were averaged and applied to the curves of utilization area.

The estimated MUA based on the area–duration curve in the cumulative and averaged methods exhibited three patterns. Troops exhibiting Pattern 1 (TID1 and TID2) were sufficiently sampled to estimate MUA. Pattern 2, in which the area–duration curve in the cumulative method did not reach an asymptote with a duration of one year, was produced for troops exhibiting Pattern 1 when the observation period was reduced. According to the concept that estimates of utilization area should reach an asymptote with an adequate sample size, this result indicates that the observation period was not sufficiently long enough to accurately estimate MUA for troops exhibiting Pattern 2 (TID3 and TID4). For troops exhibiting Pattern 3 (TID5 and TID6) in which MUA in the averaged method had a tendency to be an underestimate, their distributions of monthly utilization sites considerably overlapped and utilization sites at the beginning of observation were relatively large.

The cumulative method resulted in a large variation of MUA estimates, depending on the start date as well as total sample size of the dataset. In the averaged method, MUA estimates were robust against changes in the start date and total sample size. The large variation of MUA estimates arose because location data on any day including the start date are affected by unpredictable effects associated with animal activity and environmental conditions. In the averaged method, replicates of sample size resulted in a reduction of temporal stochasticity, suggesting that the method stably provides reliable estimates for MUA.

Chapter 3: Effects of sampling frequency and duration on the estimation of home range and maximum utilization area

I assessed how different combinations of sampling frequency and duration would affect estimates of home range and MUA, using manipulated datasets subsampled by reducing frequency and/or duration from the original dataset.

MUA, including home range and peripheral sites, calculated from area–duration curves that details were described in Chapter 2. For the home-range estimators, KDE and dBBMM, I calculated the areas of 95% isopleths. In KDE, I used the reference bandwidth method (KDE_{href}) as the bandwidth selection algorithm. In dBBMM, I used a moving window size of 13, a margin of 3, and a location error of 22 m.

Effects of reductions in sample size (i.e., decreased sampling frequency and duration) on the predicted area differed between MUA and home range. Estimates of MUA were not sensitive to a reduction in frequency or duration as long as the sampling duration was longer than 80–120 days for medium-sized mammals. Reductions in sampling frequency and duration had opposite effects on estimates of home range: the estimated area decreased with decreasing sampling duration, while it increased with decreasing sampling frequency. Moreover, these opposite effects can be more or less offset when the sampling frequency and duration were simultaneously reduced.

Chapter 4: Summary and conclusion

In previous studies on animal space use, the sampling regime (i.e., sampling frequency and duration) of location data considerably varied depending on study animals and research objectives. Here I assessed how different combinations of sampling frequency and duration affected estimates of home range and MUA in order to link space-use estimates calculated based on datasets with different sampling regime.

In chapter 2, I estimated MUA including home range and peripheral sites, based on asymptotic curves of utilization area plotted against sample size. In previous studies, these curves have conventionally been plots of cumulative utilization area versus sample size, but this cumulative method is sensitive to stochastic effects. I proposed a new method based on simulation studies where outcomes of replicated simulations are averaged to reduce stochastic effects. In this averaged method, possible combinations of sample size with the same number of location data replicated from a dataset were averaged and applied to the curves of utilization area. The cumulative method resulted in a large variation of MUA estimates, depending on the start date as well as total sample size of the dataset. In the averaged method, MUA estimates were robust against changes in the start date and total sample size. The large variation of MUA estimates arose because location data on any day including the start date are affected by unpredictable effects associated with animal activity and environmental conditions. In the averaged method, replicates of sample size resulted in a reduction of temporal stochasticity, suggesting that the method stably provides reliable estimates for MUA.

In Chapter3, I assessed how different combinations of sampling frequency and duration would affect estimates of home range and MUA, using manipulated datasets subsampled by reducing frequency and/or duration from the original dataset. Estimates of MUA, using the new method proposed in Chapter 2, were not sensitive to a reduction in frequency or duration as long as the

sampling duration was longer than 80–120 days for medium-sized mammals. Reductions in sampling frequency and duration had opposite effects on estimates of home range: the estimated area decreased with decreasing sampling duration, while it increased with decreasing sampling frequency. Moreover, these opposite effects can be more or less offset when the sampling frequency and duration were simultaneously reduced.

Because the battery attached to GPS devices to collect location data of wildlife animals has a limited life, the sample size (i.e., the number of location data) is limited and there is a trade-off between sampling frequency and duration. Using location data of Japanese monkeys, I showed how estimates of home range and MUA were affected by changes in sampling frequency and duration. The insights provided here can help calibrate estimates of space use calculated based on existing datasets with different sampling frequency and duration. These insights can also help design the sampling regime (i.e., trade-off between sampling frequency and duration) in future research.