MONTE CARLO SIMULATION TESTS FOR NON-RANDOMNESS IN THE SPATIAL DISTRIBUTION OF BREEDING SHRIKES

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ABSTRACT

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Loggerhead Shrikes (*Lanius ludovicianus*) from several populations have been reported to form territorial aggregations. I describe a method for testing for deviations from randomness in the spatial distribution of nests based on Monte Carlo simulation. The method may also be used to test for non-random spatial distributions while controlling for resource distributions. When applied to 41 nests from southwestern Oklahoma, the test showed marginally significant nest aggregation ($p = 0.056$). When simulated nests were constrained to within 200 m of a road, there was a non-significant trend toward aggregation ($p = 0.142$). When simulated nests were constrained to suitable trees within 200 m from a road, the data showed no evidence of aggregation ($p = 0.457$) Simple Visual Basic programs for these simulations are available from the author.

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INTRODUCTION

Loggerhead Shrikes (*Lanius ludovicianus*) in at least three populations have been reported to form territorial aggregations. In Indiana, Burton and Whitehead (1990) found 77% (90/117) of the Loggerhead Shrike (*L. l. migrans*) nests discovered in the state were concentrated in four counties in the southwest portion of the state. Cade and Woods (1997) found territorial aggregations in Loggerhead Shrikes (*L. l. gambeli*) in shrub-steppe habitats of southern Idaho. The patterns of interaction they observed between neighbouring pairs suggested that conspecific attraction might be a cause for territorial aggregation in this population (Cade and Woods

1997: 28). Territorial aggregations have also been reported in the San Clemente Island Loggerhead Shrike – *L. l. mearnsi* (T. Scott – pers. comm.). Such aggregations, if they do occur in Loggerhead Shrikes, might be caused by many factors that could be assigned to two basic categories: (1) behavioural traits intrinsic to shrike sociobiology, and (2) resource distribution factors extrinsic to the birds themselves. The first step toward understanding the causes of territorial aggregation is to develop and apply rigorous statistical tests of distributional patterns to determine whether populations really are aggregated.

In this paper, I describe a method based on Monte Carlo simulation for testing patterns of spatial distribution that can be adapted to apply to any sampling scheme, regardless of how irregular, as long as the sampling pattern can be mapped. To illustrate the test I apply it to the distribution of nesting Loggerhead Shrikes (*L. l. excubitorides*) in southwestern Oklahoma, USA. I also show how it can be used to test explicitly whether observed spatial patterns are a function of the pattern of distribution of an underlying resource. The use of Monte Carlo simulation to analyse spatial patterns was originally suggested by Besag and Diggle (1977) and since then has been developed by many authors. Manly (1997: 70-72) provides an example based on plant spatial patterns.

METHODS

Field surveys

I selected a study site in southwestern Oklahoma, where Loggerhead Shrikes are known to breed in sufficient numbers to allow spatial analysis (Tyler 1992, 1994). The study area encompasses 156 mi^2 (404 km^2) of which 116 mi^2 (300 km^2) are in private lands over which a grid of county roads is superimposed with a 1 mi^2 (2.6 km^2) grid pattern as laid out in the original land survey (Fig. 1). The remaining 40 mi^2 (104 km^2) are on the East Range of Fort Sill Military Reservation. The predominant land use on private lands is grazed grasslands (both native and introduced) in small landholdings with scattered agricultural fields. The East Range of Fort Sill is an artillery training area and is a mosaic of burned and hayed grasslands, and early successional scrub.

I surveyed for shrikes by driving slowly (15 km/h) along the county roads and stopping to scan both sides for signs of shrikes or for signs of the presence of shrikes (such as impaled prey items). I surveyed the entire study area in this manner three times during the 1998 breeding season (1 April – 15 June). I used a Trimble Pathfinder mobile GPS unit with a simultaneous bay station on Fort Sill Military Reservation, to record the precise location of each nest (accurately to about 1 m). The coordinate system used for recording nests and for all subsequent analysis is the Universal Transverse Mercator, North American Datum 1927.

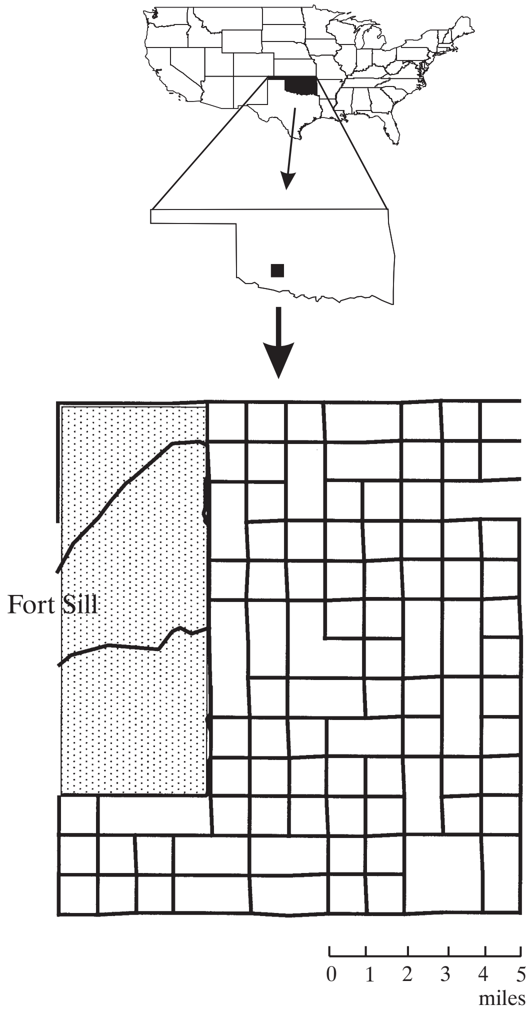

Fig. 1. Study site, Comanche County, Oklahoma, USA. The original road system was cut in a grid pattern of 1 mi^2, following the original land survey (1 mi = 1.61 km).

Test statistic

The appropriate null hypothesis against which to test for aggregation is that nests are distributed randomly across the study area. To measure local dispersion around each nest I measured first, second, third, and fourth nearest neighbour (*NN*) distances from each nest. I then took the sum of these four neighbour distances as a test statistic for dispersion (*D*) at each nest:

$$D = \sum_{i=1}^{4} NN_i$$

I then took the median (D_{md}) of this sum over all nests as my test statistic for local dispersion in the population.

Smaller than expected values of this average dispersion statistic for the observed data (D_{obs}) suggest aggregation, whereas larger than expected values suggest uniform distribution. In 1998, I found 41 nests on the study area (Fig. 2A). I generated a null distribution of expected values of D_{md} for these 41 nests by using the computer to randomly distribute 41 points across the study area (Fig. 2B). I repeated this process 9999 times and for each iteration, I calculated D_{md} for the 41 randomly generated nests. Thus, I generated 9999 values of the test statistic under the null hypothesis of random distribution of nests. The value of the statistic for the observed data (D_{obs}) is taken as the 10000^{th} value and the probability of observing that value under the null hypothesis is the rank of the observed statistic among the 10000 values, divided by 10000.

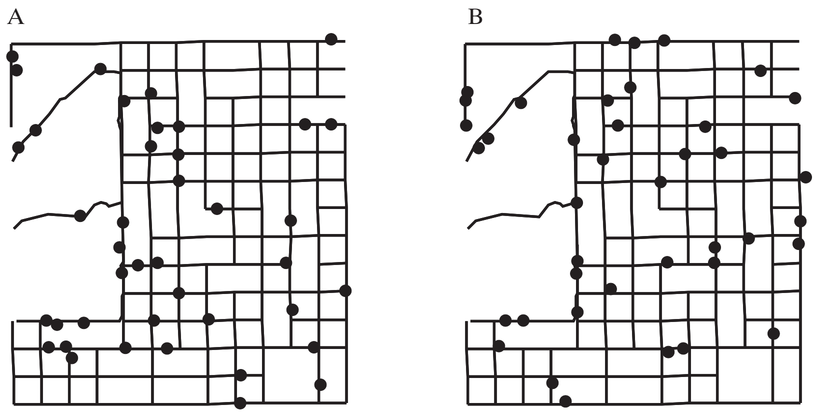

Fig. 2. A. Shrike nests found on the study area 1 April – 15 June 1998, $N = 41$. B. Sample iteration of the randomisation.

Survey pattern

To accommodate my roadside survey pattern I allowed the randomisation to place nests along any road in the study area, but excluded those segments in the road grid that were not cut (therefore unsurveyed). I also constrained the simulation to place nests no further than 200 m from a road, corresponding to the maximum distance from the road at which I detected a shrike nest. This allowed me to incorporate the actual search pattern I used to find shrikes. This is especially important on Fort Sill where the road system is quite idiosyncratic (Fig. 1).

Joining two data sets

Of the 41 Loggerhead Shrike nests found in 1998, I found 12 on Fort Sill, and 29 on the county roads (Fig. 2A). Because the search patterns differed fundamentally

between Fort Sill and the county roads, I constrained the randomisation to place 12 nests on Fort Sill and 29 on the county roads. In this way, any (unknown) bias in nest discovery rate between the two areas is transferred to the simulations, maintaining the integrity of the comparison between the observed and simulated data.

Distribution of nests with respect to trees

To give an example of how the distribution of resources may be incorporated into this type of simulation I used 7.5-minute digital orthophotos produced by the United States Geological Survey (USGS) to map the distribution of all suitable nest trees. I chose only trees that resembled nest trees actually used by shrikes on my study area – isolated trees or shrubs or trees in linear hedgerows. Trees or shrubs in a forest or thicket were excluded and only trees within 200 m of a road were eligible. I digitised the locations of 14 295 nest trees in this manner and then used these 14 295 trees as the domain, over which I resampled shrike nests and ran the simulations again.

RESULTS

I found 41 nests on my study area between 1 April and 11 June 1998 (Fig. 2A). Simulation results suggest that Loggerhead Shrike nests on my study area are significantly aggregated ($p = 0.056$), though only barely so. Simulations, which constrained nests to within 200 m of roads showed only a slight trend toward aggregation ($p = 0.142$). Simulations, in which nests were constrained to the distribution of trees showed no evidence of aggregation ($p = 0.457$).

DISCUSSION

These results suggest that territorial aggregation in Loggerhead Shrikes in southwestern Oklahoma is largely a function of the availability of nest trees. The probability of obtaining the observed results more than doubled when nests were restricted to within 200 m of a road, suggesting that survey pattern may also interact with the distribution of nests to increase the apparent aggregation those nests. Therefore, conclusions about the degree of aggregation observed should carefully consider the survey method used. This may be especially true for shrikes, for which roadside surveys are a common survey methodology.

Several behavioural factors might contribute to aggregation in territorial birds. Individuals might use each other as cues to the availability of high quality habitat. This hypothesis predicts that aggregations should have a temporal component. Individuals close in distance should also be close in time. Shrikes might also aggregate their territories for cooperative defence. This does not appear to be a common behaviour in Loggerhead Shrikes, though benefit could accrue from the information contained in alarm calls, in the absence of actively cooperative defence. Shrikes

might also aggregate territories to increase their access to reproductive partners. Recent research in mating systems theory has shown a correlation between density and extra-pair paternity (Hoi and Hoi-Leitner 1997, Wagner 1998) in several avian taxa and the authors suggest that choice of extra-pair fertilization partner by females leads to the development of aggregations in these taxa.

Numerous resource factors could lead to territorial aggregation in Loggerhead Shrikes. These results show how the distribution of available nest trees can influence the distribution of breeding shrikes. Other research has also related the spatial ecology of Loggerhead Shrikes to density of perch sites (Yosef *et al.* 1994), food availability (Yosef and Deyrup 1998), grass height (Prescott and Collister 1993), and configuration of dispersal corridors (Haas 1995). Any combination of these and, presumably, other yet unknown habitat factors, if distributed heterogeneously across the landscape, could result in an aggregated distribution of shrike nests.

Monte Carlo simulation is a powerful tool for exploring resource distribution hypotheses like those described above. As I have shown, it can be used to test hypotheses, for which no analytical expectation of null results is feasibly generated such as the distribution of shrike nests within 200 meters of an idiosyncratic road system, or the distribution of shrike nests with respect to the empirical distribution of nest-trees. This is particularly true for spatial data, for which the sampling domain may be quite complex, yet readily mapped. The simulations are also relatively easy to perform using commonly available computer software packages such as Microsoft Excel (1996 Microsoft Corp.). Many analytical methods also exist for the analysis of spatial data (see papers by Campbell and Clark 1971, Burgess *et al.* 1982, Burgess 1983, Mumme *et al.* 1983, Perry 1995; see also texts by Ripley 1981 and Diggle 1983). Interested readers are urged to consult these as well as standard texts (Noreen 1989, Manly 1997) on resampling techniques before carrying out spatial analyses.

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