

Assessing independence of animal locations with association matrices

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Abstract

We developed and used association matrix, association pattern, and pattern recognition software (ASSOC1) to investigate the spatio-temporal association of individual radio-collared elk with other radio-collared elk in a study area in western Montana. These procedures were used to approximate the amount of time each individual spent with another individual, and assess the level of independence at which these elk acted. The results of this study will allow wildlife biologists to better understand animal movements and herd dynamics, and evaluate the independence of animal locations for home range calculation and habitat use-availability analysis.

Key Words: elk, wildlife, herds, home range, similarity

Independence of animal observations is paramount to any home range calculation (Hayne 1949, Metzgar 1972, Dunn and Gipson 1977, Swihart and Slade 1985a, 1985b, Worton 1989). Yet, relatively few tests of independence exist that are available to field biologists (cf. Cole 1949, Hurlbert 1969, Knight 1970, Swihart and Slade 1985b, 1997). Two issues of independence are of concern, 1) auto-correlation: independence of consecutive locations of the same individual (Swihart and Slade 1985a, 1985b, 1997, White and Garrott 1990), and 2) pseudoreplication: independence of individuals that are associated in groups (Hurlbert 1984). This paper deals strictly with understanding and evaluating the latter concern.

An important delineation between traditional statistics and spatial statistics is that no assumption of independence can be made because, to some degree, every location on the earth's surface is related (Cressie 1991, Wong 1995). The degree to which the data are dependent upon other data in the data set is the essence of independence relative to spatial statistics. Locations that show nominal dependence are typically treated as independent observations.

In the past, elk herds have been considered social groups with a high degree of group constancy (Darling 1937, Altmann 1952, 1956, 1960). As a result, when >1 radio-collared elk was found at

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Resumen

Desarrollamos y utilizamos matrices de asociación, patrones de asociación y programas computacionales de reconocimiento de patrones (ASSOCI) para investigar la asociación espacio-temporal de individuos de alces portadores de radio-collares con otros individuos de alce también de radio-collares en un área de estudio del oeste de Montana. Estos procedimientos fueron utilizados para estimar aproximadamente la cantidad de tiempo que cada individuo pasa con otro individuo y evaluar el nivel de independencia con el que actúan estos alces. Los resultados de este estudio permitirán a los biólogos de fauna silvestre a tener un mejor entendimiento de los movimientos de los animales y la dinámica del hato y a evaluar la independencia de los sitios animal para el cálculo del área de apacentamiento y el análisis de uso-disponibilidad del hábitat.

the same location, field biologists often used only 1 of these locations in home range estimation, because using all locations may violate the assumption of statistical independence. The potential error in this logic is it treats all animals in the herd as a single discrete unit, and assumes any observed spatio-temporal association among individuals should be attributed to a lack of independence. Alternatively, if each individual in the herd was assumed to act independently, all points could be used in home range estimation. Thus, establishing independence for as many observations as possible would allow more accurate delineation of core use areas.

Historical Methodology

One approach to address statistical independence has been the use of an association test. An association index was described by Dice (1945) that calculated the percent of occurrences where animal A was found with animal B. Cole (1949) and Knight (1970) described a coefficient of association that was calculated by doubling the number of observations where animal A and B were found together, and dividing that value by the sum of observations for animal A and B. Cole's coefficient of association was intended to measure interspecific association. Later, Knight (1970) and Schoen (1977) applied the equation to intraspecific association. Similarly, Shoemith (1980) based a test of intraspecific association (joint occurrence) on the methods described by Cole (1949) and Hurlbert (1969). Each method involves numerous calculations and/or database manipulations on the part of the biologist. Further, these techniques only provide an association

Table 1. Sample matrices illustrating spatial association frequency (left^a) and proportion (right^b) among 5 radio collared elk.

n =	AN	1	2	3	4	5	AN	1	2	3	4	5
50	1	50					1	1.00	0.57	0.08	0.75	0.14
49	2	28	49				2	0.56	1.00	0.60	0.70	0.23
25	3	2	15	25			3	0.04	0.31	1.00	0.50	0.43
40	4	30	28	20	40		4	0.60	0.57	0.80	1.00	0.29
35	5	5	8	7	10	35	5	0.10	0.16	0.28	0.25	1.00

AN = Animal Number

^aFrequency of association among 5 individual elk (Animal Numbers 1–5). In this example, spatial association was defined as a radio–telemetry location occurring within 200 m of another individual elk during the same flight.

^bThe proportion of association among the same 5 individual elk. Note: these values have been corrected for sample size variation.

index or coefficient of association (which may not be sufficient to address the concern of pseudoreplication) and fail to assess any association patterns (cf Darling 1937, Altmann 1952) that may exist between individuals.

The majority of literature dealing with independence of animal locations concerns the potential for auto-correlation between consecutive observations of an individual (Hayne 1949, Metzgar 1972, Dunn and Gipson 1977, Swihart and Slade 1985a, 1985b, 1997, Worton 1989, White and Garrott 1990, Loft et al. 1991). All association tests reviewed concerning pseudoreplication were created prior to the advent and widespread use of radio-telemetry (Forbes 1907, Michael 1920, Dice 1945, Cole 1949, Hurlbert 1969). Many of these tests have been modified and applied to intraspecific association (Knight 1970, Schoen 1977, Shoesmith 1980), but none were designed specifically for this purpose. Statistical analyses of telemetry data (e.g., home range analysis, utilization distribution functions, and habitat use-availability tests) have placed unique demands on the methods and techniques used by biologists. Earlier researchers could not have foreseen the requirements of statistical independence under the circumstances encountered with telemetry studies. Thus, a technique to specifically address pseudoreplication in telemetry studies is required.

Methods

Prior to performing an association test, we first selected spatial and temporal threshold values. Spatial threshold is the maximum distance at which any 2 individuals can be separated and still considered associated. By definition, pairs of individuals separated by an Euclidean-distance that exceeds the spatial threshold are considered non-associated. When choosing a spatial threshold (using Euclidean-distance) the biologist should consider the species, its known or reported movement potential, size of the study area and/or

herd home range, and telemetry error. Temporal threshold is the minimum amount of time 2 associated individuals spent together over the sampling period. Pairs of individuals showing a temporal association less than the temporal threshold are considered non-associated. When choosing a temporal threshold (1–100%), the user should consider the objectives of the study, frequency and number of observations, and the desired scale of definition (e.g., primary herd units, sub-herd units, etc.). Using a large spatial threshold and low temporal threshold will result in the most liberal test of association.

A matrix was created containing the frequency each individual was found within the spatial threshold of another individual during a telemetry flight. A second matrix was used to convert frequency to proportions to account for variation in sample size (Table 1).

The matrices were then examined using 2 criteria; (1) Individuals having <10 observations or <10% of the maximum number of observations were not analyzed for association pattern (e.g., if the maximum number of observations for any individual was 500, any individual having <50 observations would not be analyzed for association pattern). (2) Pairs of individuals that failed to demonstrate association exceeding the temporal threshold were considered non-associated and were not included in the association pattern procedure (Table 2). The association pattern

Table 2. The resulting matrix after applying the temporal threshold^a to sample data for 5 individual elk (cf. Table 1).

n =	AN	1	2	3	4	5
50	1	yes	yes	no	yes	no
49	2	yes	yes	yes	yes	no
25	3	no	no	yes	yes	no
40	4	yes	yes	yes	yes	no
35	5	no	no	no	no	yes

AN = Animal Number

^aCells containing 'yes' indicate the pair of individual elk have demonstrated association that exceeds the temporal threshold (e.g., 50%) and are considered associated. Cells containing 'no' indicate the pair of individuals are considered non-associated. This table corresponds to Table 1 and the grid cell illustration shown in Fig. 1.

procedure consists of creating a grid for each individual with each cell of the grid representing 1 individual. The cells that correspond to the Animal Number of each individual with which the given individual had associated were shaded (Fig. 1). We then compared the association grid created for each individual with the association grid of each other individual, and calculated the percent similarity between the association grid patterns. Close examination of these patterns allowed us to categorize individuals into herd or sub-herd units based on the similarity observed among the association grid patterns.

Description of Association Software

We developed software (ASSOC1¹) that used association matrices, association patterns (cf. Darling 1937, Altmann 1952, Shoesmith 1980), and pattern recognition, to approximate the amount of time each individual radio-collared elk spent with each other radio-collared elk. The software also assessed the level of independence at which these elk acted, and categorized individual elk into herd or sub-herd units.

To categorize individuals into herds, sub-herds, or associated groups ASSOC1 was designed to select >1 association grids to act as template grids, against which all other individual association grids would be compared. Selection of a template grid was based on the number of other individuals a given individual associated with. The individual showing association with the largest set of other individuals had the highest probability of being selected as a template grid (e.g., Fig. 1, Animal Number 4). In addition, each template grid was

¹ASSOC1 was developed using Microsoft Visual Basic version 5 for Windows NT and Windows 95/98 PC's. Help documentation accompanies the 32-bit application. The software is available free of charge at

<http://giscenter.isu.edu/software/software.htm>.

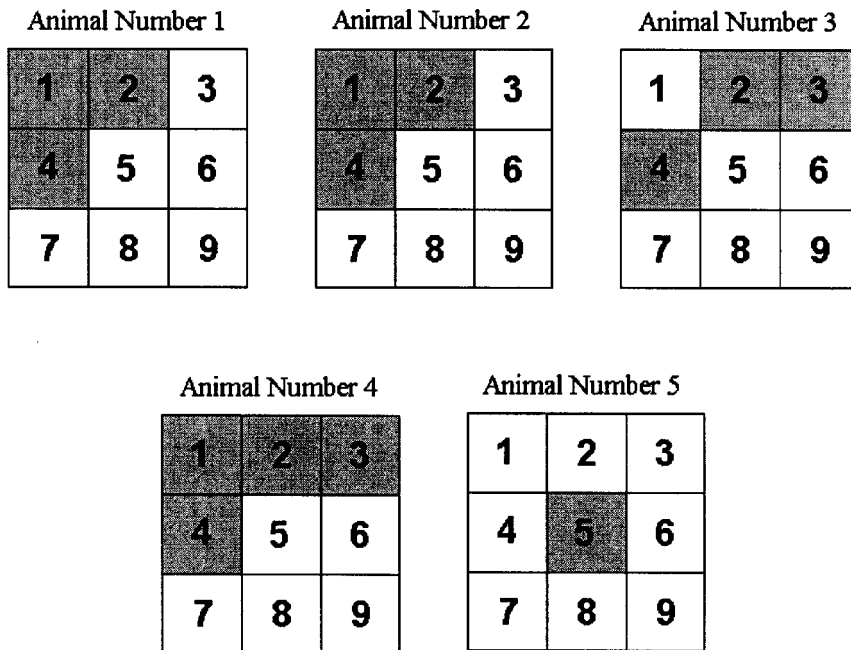


Fig. 1. Example of association pattern grids for 5 individual elk where the temporal threshold was 50% (i.e., to be considered associated, individual elk were required to have been found together (within 200 m of one another) in $\geq 50\%$ of all radio telemetry locations). Each shaded cell represents an individual elk that is considered associated with the animal listed above the grid cell. This figure corresponds with data given in Tables 1 and 2 (e.g., Animal number 3 is considered associated with Animals Numbered 2, 3 (itself), and 4).

required to identify a mutually exclusive set of individuals. When a template grid could not be selected without overlapping the set of individuals already identified by a previously selected template grid; the selection process was terminated. Each individual association grid was then compared to the template grid(s) to determine percent similarity. Individuals demonstrating a similarity to the template grid exceeding the temporal threshold were grouped into the same herd/sub-herd.

This test of association can be performed using any number of individuals. All matrices are saved in a data file for user review and, regardless of the assigned thresholds, the actual association for each individual is reported in the output from ASSOC1.

Chamberlain Creek Case Study

Two elk herds (henceforth referred to as the Chamberlain and Greenough elk herds) were identified and analyzed in this study using radio-telemetry locations. The study area was located approximately 56 km east of Missoula, Mont. in the Garnet Mountains. We radio-collared approximately 10% of the estimated elk population. Of those radio-collared elk, 80% were cows and spike bulls that were considered members of herd units (Franklin

and Lieb 1979, Geist 1982). Radio-telemetry locations for each individual were recorded in UTM coordinates (± 100 m) and obtained weekly using a 5-element Yaggi antenna mounted on fixed-wing aircraft. We ran several iterations of ASSOC1 software using various spatial and temporal thresholds. All elk locations were first divided into known primary herd units (the Chamberlain and Greenough elk herds) and then analyzed for association within herds. We defined the spatial threshold as any 2 radio-collared elk within 200 m of each other during a telemetry flight, and set the temporal threshold at 70%. This particular spatial threshold was chosen to account for our telemetry error of ± 100 m and our method of recording joint occurrences as duplicates of the first elk located. The temporal threshold of 70% was chosen so that only closely associated individuals were used in the association pattern, and pattern similarity analyses.

The overall mean association (corrected for annual variation in sample size) between individual elk within a herd was found to be only 16% for the Chamberlain elk herd, and 11% for the Greenough elk herd. This indicates these elk act independently of one another, and do not move across the landscape as a discrete unit. More importantly, the highest association

observed between any 2 individuals throughout this study was 57%. These results suggest that the structure and composition of elk herds are relatively dynamic over even brief time periods. However, any 2 radio-collared elk were found together 64% of the time. Based on this result, it seems safe to assume that a given cow elk can be found with another elk nearly 100% of the time. This observation describes the gregarious nature of elk (Craighead and Shoemith 1966), and does not address independence. It must be remembered that $< 20\%$ of an individual cow elk's time was spent with the same individual. Therefore, elk herds should be viewed as gregarious aggregations and not discrete social groups. The aggregations observed were probably due more to forage availability, family unit fidelity, and predator-prey relationships (cf. herd effect, Hamilton 1971) than dependent movement patterns.

It should be clear that absolute independence does not exist. Elk movements are influenced by forage availability (which is influenced by weather, slope, aspect, elevation, etc.), disturbance from predators and human activity (Marcum 1975), the location of other elk, weather, and each individual's response to these influences. Based on these results, home range estimations for this study were calculated using all elk observations.

Two additional iterations of ASSOC1 were performed using different thresholds (Table 3). When the temporal threshold was decreased and the spatial threshold was held constant, the frequency of association among herd members increased. Similarly, when the temporal threshold was held constant and the spatial threshold was increased the frequency of association increased. However, because spatial threshold determines the percent association, increasing the spatial threshold also increases the percent association. The affect of varying thresholds on the number of herd members identified (the number of individuals associated with template individuals) is shown in Table 3. As the association percent and association frequency increases, so does the number of

Table 3. Resulting frequency and percent association for the Chamberlain Creek Case Study using 3 alternative thresholds.

Threshold	Temporal	Association		
		Frequency	Mean %	Maximum %
200	70	1.0	9.5	56.9
200	15	7.0	9.5	56.9
5000	15	12.8	21.0	87.6

herd members associated with a herd template individual.

At coarse scales, where the spatial threshold was high (e.g., 10,000 m), we were able to distinguish between primary herd units, but were not able to discern sub-herd units that may have existed. At fine scales (e.g., 200 m) we were capable of distinguishing not only primary herd units, but sub-herd units as well. However, due to the complex procedure used to select template grids, this technique gave the best resolution when analyzing individuals that had been previously categorized into primary herd units.

Other studies that have addressed elk associations have reported similar findings (Craighead and Shoesmith 1966, Knight 1970, Schoen 1977, Shoesmith 1980), concluding that elk herds are best described as aggregations instead of social groups. Still, the question of statistical independence persists, requiring the biologist to determine the degree of association among the radio-collared animals used in the study. We feel that use of the association index (Dice 1945) is inadequate because it does not account for disproportionate sample sizes between individual animals, and like the coefficient of association, it was designed to measure interspecific association. Further, neither technique incorporates any landscape variable such as spatial threshold.

Discussion

Potential applications of this technique include not only assessing independence of herd animal locations, but distinguishing herd and sub-herd (within herd) units as well. By adjusting the spatial threshold (the maximum distance between associated individuals), biologists can vary the scale of assessment. By adjusting the temporal threshold (the minimum amount of time spent together by associated individuals), the fidelity of herd units can be described.

This technique utilizes a crisp logic system (McNeill and Freiberger 1993). If an individual is found within the spatial threshold of another individual, and spends an adequate amount of time with that individual (exceeding the temporal threshold), those individuals are considered associated. However, another individual may show very similar association yet not meet the thresholds set by the user. Hence, those individuals are considered non-associated. For this reason, we urge biologists to use this technique with several different thresholds and scales, and to report the thresh-

olds used with any results derived from this software. ASSOC1 software was not developed to provide a rigorous statistical test with critical values and a probability statement. Rather, this software acts as a spatial analysis tool that provides the biologist with a set of measures, upon which, a decision of association or independence can be more easily determined.

Many biologists have applied the recommendations from earlier studies of autocorrelation (Swihart and Slade 1985a, 1985b, White and Garrott 1990), interspecific association (Cole 1949, Hurlbert 1969), or treatments of pseudoreplication (Hurlbert 1984) to the issue of independence of herd animals. This paper differentiates these issues (auto-correlation and pseudoreplication) and addresses the question of independence of herd animals with ASSOC1 software. An advantage of this technique is the user can review each step in the procedure by examining the output association matrices (frequency and proportion), association pattern similarity, and herd assignment tables. The flexibility of this software allows ASSOC1 to handle any number of individuals at any scale by varying the user-defined spatial and temporal thresholds. Further, this technique is relatively simple, allowing the user to readily comprehend and critically examine each procedure used to produce the output. Over-complicated tests and techniques may not provide any additional information, and tend to mask errors in logic with complexity.

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