

## An Analysis of Spatial Clustering and Implications for Wildlife Management: A Burrowing Owl Example

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**Abstract** Analysis tools that combine large spatial and temporal scales are necessary for efficient management of wildlife species, such as the burrowing owl (*Athene cunicularia*). We assessed the ability of Ripley's *K*-function analysis integrated into a geographic information system (GIS) to determine changes in burrowing owl nest clustering over two years at NASA Ames Research Center. Specifically, we used these tools to detect changes in spatial and temporal nest clustering before, during and after conducting management by mowing to maintain low vegetation height at nest burrows. We found that the scale and timing of owl nest clustering matched the scale and timing of our conservation management actions over a short timeframe. While this study could not determine a causal link between mowing and nest clustering, we did find that Ripley's *K* and GIS were effective in detecting owl nest clustering and shows promise for future conservation uses.

**Keywords:** *Athene cunicularia*; burrowing owl; California; GIS; mowing; Ripley's *K*; wildlife management.

### Introduction

Although most bird species nest as solitary pairs for purposes of concealment or territoriality, many birds have been observed to nest colonially in close association with each other (Horn 1968, Lack 1968, Krebs 1971, Hoogland and Sherman 1976). Burrowing owl nest densities vary widely from randomly-located to clusters (Desmond et al. 1995). Nest clustering and distribution patterns may be due to a clustered food source, limited suitable nesting habitat, habitat continuity, and/or reduced predation risk due to owls alerting each other to predators (Coulombe 1971, Green and Anthony 1989, Desmond et al. 1995, Todd 2001). Close nest proximity, however, can also result in increased competitive interactions between adults (Butts 1973) and/or owl nest failure (Green and Anthony 1995). Because burrowing owl habitat is being lost rapidly in many urban areas (DeSante et al. 2004), conservation managers may seek to maintain clustered owl nests on smaller areas of high-quality, managed habitat, if these densities do not hinder owl survival and reproduction. One management approach, mowing tall grass habitat, has been used widely to provide the short grass habitat owls prefer and, thereby, attract nesting owls. To assess the effects of mowing, managers will first want to determine if habitat mowing attracts owls and results in clustering. Our objectives in this study were to test the value of Ripley's *K*-function (Ripley 1976) used in conjunction with GIS as techniques to detect changes in the timing and spatial scale of burrowing owl nest clustering at NASA Ames Research Center in California, USA.

The burrowing owl is unique in that it is the only owl species that lives in underground burrows and is often active in broad daylight. It is ranked second to the barn owl as the most economically beneficial bird in North America because it eats agricultural pests (primarily

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rodents and Orthoptera—e.g., crickets, katydids, grasshoppers) and is relatively tolerant of non-threatening human activity (Campbell et al. 1990, Green et al. 1993, Plumpton and Lutz 1993b, York et al. 2002). Burrowing owl populations are declining throughout its range, however (Holroyd et al. 2001). In Mexico the burrowing owl is listed as a federally threatened (amenazada) species (Diario Oficial de la Federación 1994), and in Canada the burrowing owl is listed as endangered (Wellicome and Haug 1995). In the U.S., the Department of Interior has designated the burrowing owl as vulnerable (U.S. Department of Interior 1992), and the U.S. Fish and Wildlife Service listed the burrowing owl as a national priority species in the Birds of Conservation Concern (U.S. Fish and Wildlife Service 2002). The burrowing owl was first included in 1972 on the U.S. Audubon Blue List, which records North American bird species undergoing population or range reductions (Tate 1986). Many states, including California, consider the burrowing owl a special status species (James and Espie 1997) as populations have been declining since at least the 1960s. Research and management in northern California, where our study site is located, have focused on mitigating further population decreases (Thomsen 1971, Burrowing Owl Consortium Mitigation Committee 1993, Trulio 1995; 1997).

Two primary analysis methods combined with statistical techniques have been used by researchers to assess burrowing owl spatial patterns. Orth and Kennedy (2001) used GIS and spatial analysis to analyze if nest-site selection in Colorado was altered by a decrease in the availability of preferred foraging habitat. They used circles with radii of 1000 and 2500 m centered on prairie dog towns to assess the landscape characteristics within the average home range of male burrowing owls and immediate foraging habitat (Haug and Oliphant 1990). Desmond et al. (1995) analyzed the spatial patterns of burrowing owls in Nebraskan prairie dog towns. Using the *T*-square index (Diggle et al. 1976) to compare the square of the distance from a random point to the nearest burrow and the distance from

that burrow to its nearest neighbor (Ludwig and Reynolds 1988), they found that nests were located randomly in small prairie dog towns ( $<35 \text{ ha}^{-1}$ ) and clumped in large prairie dog towns ( $\geq 35 \text{ ha}^{-1}$ ), though clumping was not due to burrow or space availability. They calculated average nearest neighbor distances of 125.0 m within the clusters, and 105.1 m within the random patterns. As the size of prairie dog towns increased, burrowing owls occurred in higher numbers but lower densities (Desmond and Savidge 1996), although there may be a time lag in owl response to changes in active burrow densities (Desmond et al. 2000).

Though each of these techniques is informative and complementary, each has limitations. The radii-dependent GIS approach is subject to arbitrary and discrete lengths of radii (e.g., 100 and 2500 m), while nearest neighbor assessments do not account for group pattern, but only the single closest point to another single point. To overcome these problems, our spatial point pattern analysis is based on Ripley's *K*-function (Ripley 1976), which assesses the distances between all points thereby delineating the scale of the pattern on the whole. Ripley's *K* examines the test statistic across a continuum of spatial scales, hence avoiding discrete and arbitrary scale lengths; this analysis therefore reveals the scale(s) at which the pattern of events is operating most strongly. The function has been applied broadly in ecological spatial patterns such as landscape dynamics and distribution patterns of forest disease (Kelly and Meentemeyer 2002), tropical forests (Sturner et al. 1986), conifer forests (North and Greenberg 1998, Song et al. 2004, Shaw et al. 2005), herbs (Kenkel 1993), and shrubs (Prentice and Werger 1985, Skarpe 1991). This method has not been applied previously to colonially-nesting birds.

Because the burrowing owl is increasingly confined to managed habitat islands in urban settings (Trulio 1995, DeSante et al. 2004), burrow clustering analysis of these habitats provides important and applicable management information. At NASA Ames Research Center, the location of our study site, space is limited in

this urban environment yet wildlife managers are tasked to set aside and manage conservation areas for the burrowing owl by federal mandate. They require data to determine what effect those management strategies are having and whether there is a connection between their conservation efforts and burrowing owls. Managers must also know the temporal pattern of the spatial distribution to protect owls from harmful or disruptive activities that might overlap with the birds' habitat.

We assessed the clustering of owl nests in response to large-scale mowing, a common management recommendation to enhance owl habitat to provide short-grass conservation areas for owl nesting and foraging (Plumpton and Lutz 1993a, Trulio 1997, Uhmman et al. 2001, Belthoff and King 2002). We measured the locations of burrowing owls for the entire year before the management implementation and the entire year during and following. We used Ripley's  $K$  in a GIS to assess the spatial clustering of the burrowing owls as correlated with the spatial size of the conservation areas; we show nearest neighbor distances in comparison to the literature. Additionally, we track cluster variation temporally to show the seasonal variation in cluster size. Our null hypothesis was that the owls would not cluster to the size of the areas subjected to mowing, suggesting there was no connection with our management strategy and burrowing owl nest cluster patterns. It is important to realize that the results of this study do not show a causal link between mowing and nest clustering as there are no replications of the mowing treatment nor control sites. Rather, this study tests the ability of Ripley's  $K$  to detect burrowing owl clustering at small spatial and time scales. We designed this test in the context of the mowing treatment as we suspected that this management action would affect owl nest locations.

### Study Site

We observed burrowing owls in 2003 and 2004 at the NASA Ames Research Center, located Moffett Field, California, approximately 56 km (35 miles)

south of San Francisco (37° 23'N, -122° 4'W). The study site was a combination of large areas of open, non-native grassland habitat in a matrix of urban and industrial development. The Mediterranean climate of the region was characterized by wet winters and dry summers. Rainfall in 2003 and 2004 averaged from 5 – 8 cm (November through March) and 0 – 2 cm (April through October) and temperatures ranged from 4 – 12° C in the winter to 10 – 26° C in the summer. The site was adjacent to the San Francisco Bay and consequently received some wind and moisture influence from the Bay. Land use and land cover, as determined through the GIS, included coastal salt marsh (0.18 km<sup>2</sup>), coyote brush scrub (0.23 km<sup>2</sup>), disturbed areas (0.02 km<sup>2</sup>), ditches (0.30 km<sup>2</sup>), fresh and brackish water marsh (1.06 km<sup>2</sup>), non-native grassland (17.44 km<sup>2</sup>), seasonal salt marsh and transition (1.69 km<sup>2</sup>), and weed dominated areas (0.56 km<sup>2</sup>). The total area of the site, including built structures, was 7 km<sup>2</sup>.

The western burrowing owl ranges throughout Canada, the U.S., and Mexico. The life history of the burrowing owl in Northern California consists of owls pairing up and laying eggs in Spring (February – May), and breeding in Summer (May – September). In Fall, chicks molt into adult plumage and most seek burrows separate from their parents. Adults and young of the year may disperse from their nest burrows and some may migrate throughout Fall and Winter. A comprehensive burrowing owl bibliography can be found at:

[http://uwadmnweb.uwyo.edu/fish\\_wild/buow/index.html](http://uwadmnweb.uwyo.edu/fish_wild/buow/index.html).

## Methods

### Field Techniques

All suitable burrowing owl habitats (fields, mounds, landscaping, and embankments) were visually examined for nests between April and June each year by researchers performing daily surveys walking along transects 5 – 15 m apart, as

dictated by vegetation height and density. During walk-through transect surveys, observers looked for owls that flushed when approached and/or burrows that showed evidence of owl activity such as whitewash, pellets, feathers, bedding material, prey item remains, or nest decoration. Any burrow that contained evidence of owl activity was marked with a flag or stake and received further observations to determine whether a nest was active or inactive. Active nests were identified by an owl pair. If, after three to four observations we did not see an owl pair at a potential nest site, we did not count it as a nest. During the breeding season, from 1 April to 31 July, we observed each potential owl nest for 30 minutes every week to identify adults and count numbers of chicks. We continued to walk habitat and track birds to nests throughout the nesting season. During the rest of the year, single or multiple owls occupied burrows (not considered nesting burrows) and we recorded all these non-breeding season locations two times per month, a much lower level of effort than during the breeding season.

In most presence/absence sight-detection studies, detection ability increases over time. We took extensive measures to minimize the variance due to uneven visibility of the owls by initiating the study once detection ability had reached a plateau from our field biologists—approximately two years of prior observation at our site from the experienced biologists. Error counts were quantified and stabilized across time and observers at  $\pm 1 - 3$  owls.

We used binoculars (10 X 50) and spotting scopes (15 – 45 X 60 zoom) mounted on tripods or window mounts to locate new owls and resight previously banded owls. All active nests were numbered. Universal Transverse Mercator coordinates (NAD83) were recorded with a Global Positioning System (GPS) unit for every nest that was assigned a number. We did not record GPS coordinates for satellite burrows used by adults or chicks; thus, these auxiliary burrows were not included in this analysis. To correct for GPS positional accuracy and for coordinate offset in points that we could not access with our unit (to avoid owl disturbances, for example) we manually

and visually corrected for each point within the GIS using a high resolution georectified aerial photograph of our site.

In 2003, we cut the grass by hand (so as not to disturb burrows) in areas approximately 8 m in diameter around active burrows; there was no large-scale mowing. Cutting grass around each nest allowed us to observe adults and chicks, even if they were located in tall grass areas. In 2004, NASA mowed a total of 54 ha of non-continuous owl habitat (8% of the total site area) with a mechanical flail mower, first during the period from 28 April to 14 May and again 7 – 29 July. Of that 54 ha, the owls occupied five conservation areas that were 0.23, 4.2, 4.6, 4.7 and 10.3 ha in size. Our primary focus was to determine if significant spatial clustering of nests could be detected in this setting. We compared nest clustering in Fall (i.e., August) 2003 before the large-scale mowing to nest clustering in Fall 2004 after the large-scale mowing, keeping season constant, to see if nest clustering differed between the two years. We also compared nest clustering in Spring (i.e., April) 2004 before the large-scale mowing to nest clustering in Fall 2004 after the large-scale mowing.

### Spatial Analysis

We calculated nearest neighbor distances to assess adjacency of immediate neighboring burrows to one another. The nearest neighbor index (Diggle 1983, Manly 1991) compares the average distance of the nearest other point (nest) with a spatially random expected distance based on area size and number of points. The empirical average nearest neighbor distance is divided by the expected random distance (the nearest neighbor index).

We identified clusters of burrows through point pattern analysis that combined intensity distributions and Ripley's *K*-function (Ripley 1976). Intensity is defined as the mean number of points (nests) per unit area; intensity distributions reveal first-order properties of a spatial point process and variation through space to assess the spatial dependence between points. First-order

properties of a spatial point process describe how the mean number of points per unit area (the intensity) varies through space. For a stationary process, the intensity is assumed to be constant over the bounded region of interest. Intensity distributions show where owl nests are occurring, and Ripley's  $K$  reveals statistical significance in the clustering of those nests. Grid size for intensity was set to normalize the maximum count per grid cell at 0.5 to match an approximate Gaussian spatial distribution. Both first- and second-order statistics are used often in conjunction with each other as both are complementary and reveal different types of information (e.g., Nekola and Kraft 2002).

Ripley's  $K$  is a second-order (covariance of distances) function for spatial point pattern and is used to detect spatial randomness (Ripley 1976). A spatial point pattern is a collection of points irregularly located within a bounded region of space (e.g. burrows within a field site). The data set may consist of locations only, or it may be a marked point process, with data values associated with each location (e.g. longitude/latitude with number of burrowing owls). The analysis is termed "second-order" because of its focus on the variance of the test statistic across a series of progressively larger areas—the size of the step is set to reveal the inter-event distances at which clustering, if present, is strongest. By examining the test statistic at various spatial scales (e.g. region, county, city), the scale at which the pattern of events (points) is operating most strongly (highest statistical significance and confidence) can be determined. We initially followed a weighted edge correction (Ripley 1977), though Lancaster and Downes (2004) specify that edge correction is not necessary for length-scale assessment of clusters.

We used Ripley's  $K$  to examine the null hypothesis of Complete Spatial Randomness (CSR) for a mapped spatial point pattern (Haase 1995). CSR is defined by the following criteria: a) the intensity of the point pattern does not vary over the bounded sampling region, and the pattern follows a homogeneous Poisson distribution; b) there are no interactions among the points.

Ripley's  $K$  can reject the null hypothesis that the spatial pattern of points is random. Certainly, little in nature at large scales is perfectly uniform so that 100% CSR would be highly unlikely. Thus, Ripley's  $K$  identifies scales of clusters.

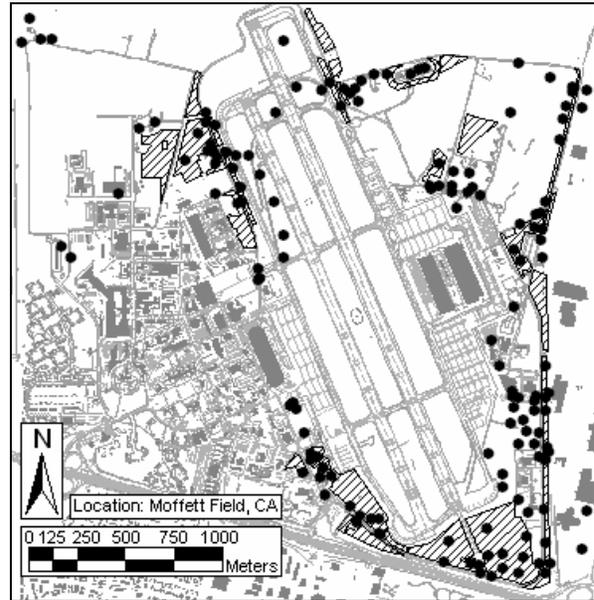
After the data were analyzed by the Ripley's  $K$  method, a plot of count  $K(h)$  versus distance  $h$  revealed deviations as expected under CSR (Ripley 1976). The deviation was tested for statistical significance. One test employed the calculation of constant approximate confidence intervals around CSR (Getis and Franklin 1987, Szwagrzyk and Czerwczak 1993). Another test used Monte Carlo methods to determine statistical significance of the results by determining the amount of variation to be expected in sample statistics from computer-generated data (e.g., Diggle 1983, e.g., Manly 1991, Cressie 1993). In the context of spatial pattern analysis, Monte Carlo methods simulate randomly generated plots of the same dimensions of the observed plot thus creating confidence intervals around  $K(h)$  (Haase 1995). We conducted 1000-run Monte Carlo simulations to provide confidence intervals around the data. We plot  $(K(h)/\pi)^{0.5} - h$  or simply  $L(h) - h$  against  $h$  to show the deviation of  $K(h)$  from CSR. If the deviation of the sample statistic from zero expectation is positive and above the upper limit of the confidence interval, then a clumped distribution can be assumed, while negative deviation indicates a regular pattern, and the null hypothesis of CSR (between the confidence intervals) cannot be rejected (Haase 1995).

We processed the data in a GIS with ESRI's *ArcGIS* 8.1 and *S-Plus* 6.0. The main statistical processing of point pattern analyses relied on *S-Plus* 6.0, and analyses and map production on the *ArcMap* component of *ArcGIS* 8.1. The data were projected into Universal Transverse Mercator Zone 10N with the North American Datum 1983. Nearest neighbor distances were calculated with *CrimeStat* 2.0 (Ned Levine & Associates).

## Results

As a general indication of owl dispersal at NASA Ames Research Center, we show all burrowing owl nest locations (N=152) from 1998-2004 in Figure 1. There were a total of 40 unique burrowing owl nests in 2003 and 67 in 2004. The gray lines and polygons represent paint lines (indicating roads) and buildings. Typically, the owls were distributed along the buffered perimeter of the site and around inactive runways where there is open grassy vegetation away from people and buildings. The site is visibly fragmented, with large buildings preventing owl access to all tracts of land at the site. Because the owls cannot move randomly everywhere on the site, clustering larger than 25 ha is impossible to detect. The polygons with diagonal striping indicate the mowed areas in 2004 (pictured here are the boundaries of the second mowing event, though the first mow was in approximately the same locations). Roughly half of the observed owls in 2004 were located in the conservation mowed areas. Most corridors between mowed areas were continuous. The owls tended to select habitats of non-native grassland and weed-dominated areas. The conservation areas were predominantly focused on weed-dominated areas; the owls that were not located in the weed-dominated conservation areas were generally in the non-native grass habitats (e.g., outlying golf course and runway areas).

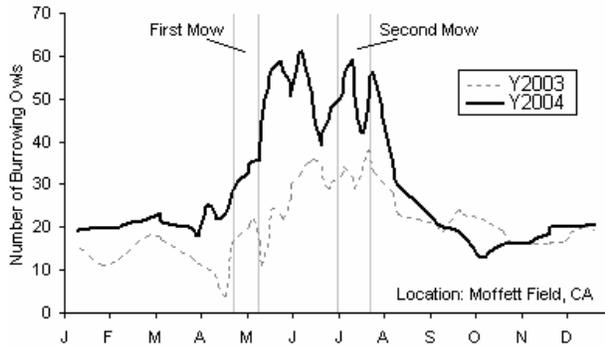
In both 2003 and 2004, a clear seasonal pattern is exhibited with an increase in burrowing owls per month due largely to the breeding season and the presence of adults and young in the summer months 1 April – 31 August (Figure 2). We observed approximately 20 burrowing owls per month throughout the rest of the year (1 Sept – 30 March) for both years. The time periods of the two mowing events in 2004 are indicated in between the two sets of vertical lines. The first mowing event was from 28 April – 14 May, and the second mowing event was from 7 – 29 July. The summer counts in 2004 were larger than in 2003, but in particular a large and early peak in 2004 occurs directly after the first large-scale mowing. This 2004 peak was not due to improved nest visibility



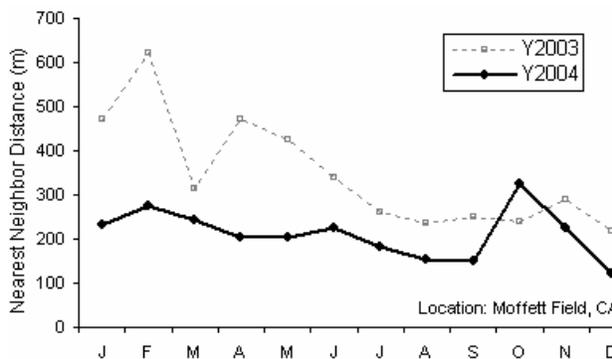
**Fig. 1.** Distribution of all burrowing owls (filled black circles) observed from 1998-2004 at NASA Ames Research Center, California. Polygons with diagonal striping indicate mowed areas. Gray lines and polygons represent buildings and paint lines.

as we had already cut the grass by hand around each nest burrow and could see each well before the large-scale mowing.

Nearest neighbor distances between nests did not follow the seasonal pattern as in Figure 2, but showed a decreasing trend whereby nearest neighbors became closer into the summer season for both years (Figure 3). The high values at the beginning of 2003 and in October and November 2004 correspond to the dips in the time series of Figure 1 when we observed the fewest burrowing owls for each year. Our nearest neighbor values for 2004 (211.4 m average) were roughly double that of Desmond et al. (1995) due, in part, to the characteristic that our site was over a larger area; our minimum value (121.5 m) corresponds to the maximum values of Desmond et al. We report nearest neighbor values on a monthly basis to address month-to-month temporal changes in spatial change, whereas Desmond et al. report yearly nearest neighbor values. We draped the first-order intensity distribution on all active burrows during 2004 (Figure 4). The largest



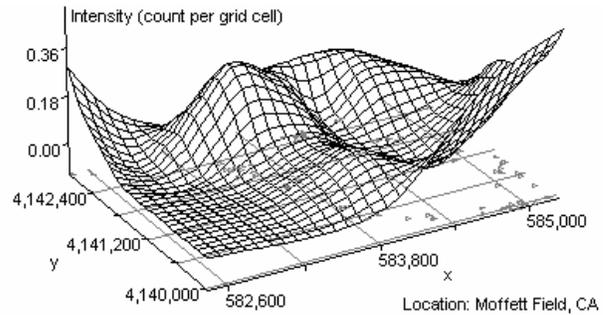
**Fig. 2.** Number of burrowing owls cited per month for 2003 and 2004. The durations of the two mows in 2004 are indicated in between the two sets of vertical lines; the first mow was from 28 April – 14 May, and the second mow was from 7 – 29 July.



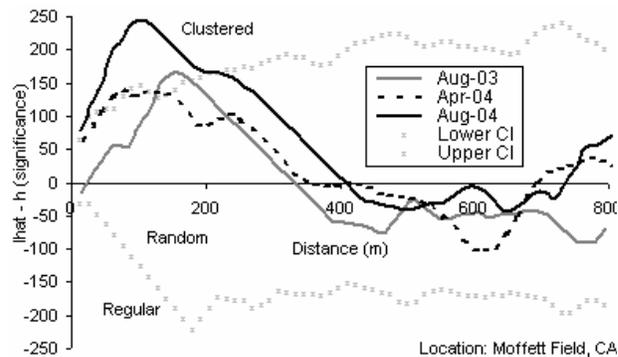
**Fig. 3.** Mean nearest neighbor distances between nests and non-breeding season occupied burrows by month for 2003 and 2004.

peaks (trough-to-trough) appear to be on the order of 600 m, which is misleading because those peaks included multiple clusters operating on smaller scales. The second-order Ripley’s *K* analysis quantified any spatial clusters that were statistically significant.

The Ripley’s *K* plot (Figure 5) was analyzed specifically for two seasonal (we show monthly) comparisons: 1) before the first mow (April 2004) and after the last mow of the year (August 2004), and 2) August 2003 versus August 2004. A three-dimensional spatial-temporal picture of cluster change over time shows month-to-month changes as the difference between the Ripley’s *K*-function and the upper confidence



**Fig. 4.** First-order intensity distribution for all active burrows during 2004. The distribution is draped over the burrow locations.



**Fig. 5.** Ripley’s *K* plot for August 2003, April 2004 and August 2004. The distribution of Ripley’s *K* above the upper confidence interval indicates clustering, between the confidence intervals indicates random spatial pattern, and below the lower confidence interval indicates a regularly distributed pattern. The y-axis represents the deviation of the sample statistic from CSR; the units are in count numbers, but have been transformed as per Haase (1995). The x-axis represents distance (units are in meters here), and the distance shows the extent of the clustering.

interval for each month in 2004 (Figure 6). Note that the non-breeding period (September – March) sampling effort was less than during the breeding period. The plot in Figure 5 shows that in April 2004 the burrowing owls were generally randomly distributed throughout the area. In August 2004, however, clustering with a peak of 100 – 120 m (1 – 1.4 ha) became strongly evident and statistically significant. The Ripley’s *K* plot for August 2003 shows that burrowing owls were randomly distributed except for a small peak at the scale of 160 m; clustering in April 2003 (not

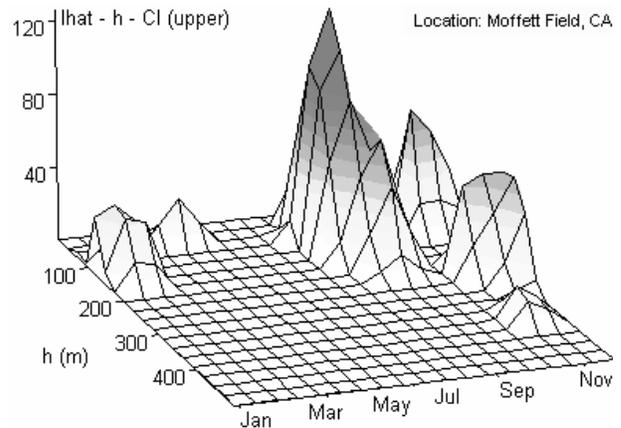
shown) was similar to that in August 2003. To summarize, clustering was not statistically significant in August 2003 nor April 2004, but it was statistically significant in August 2004.

The minimum statistically significant cluster size (above the upper confidence interval) part of the Ripley's  $K$  plot for August 2004 ( $h = 45$  m) was 0.20 ha, which is consistent with the minimum conservation area of 0.23 ha. The mowed conservation areas were on average 1.8 ha. Likewise, the maximum scale of clustering of owl nests was 4.4 ha (210 m), which is consistent with our larger (but not largest) conservation areas (4.2, 4.6 and 4.7 ha). These results are expanded in Figure 6 where throughout the first half of 2004 very little statistically significant spatial clustering occurred. After the second mowing (July) the strong clustering became apparent, and clustering remained throughout the rest of the year.

## Discussion

A simple count of the number of burrowing owls within the areas per month seems logical to assess changes in nest and bird numbers, but this count is correlated with the total number of burrowing owls observed over the entire study site—an apparent rise in the number of owls within the areas may therefore simply be an artifact of a rise in total owls at the study site. Counts (presence/absence) can be affected by environmental variables in different time and space scales—aggregation and nest clustering can be determined by different factors. As percentages, owls within the mowed areas remained higher post-management than pre-management—39% in August 2004 versus 20% in April 2004. The Ripley's  $K$  analysis provided additional information on distribution patterns, clustering or not, at whatever spatial scale they occur.

Because we did not include satellite burrows in the breeding season analysis, we eliminated superficial clumping behavior during the breeding season that may have been due to broods that moved but stayed close to their natal burrows. From a spatial statistics standpoint, an



**Fig. 6.** Cluster change over time based on the difference of the Ripley's  $K$  plot and the upper confidence interval for each month in year 2004.

increase in occupied burrows near nest sites would result in a decrease in nearest neighbor distances. We found, however, that the spatial patterns of nearest neighbors (Figure 3) and of cluster scale (Figure 6) over time do not follow the seasonal count pattern of Figure 2. Additionally, if clumping were due to dispersing young near natal burrows, then we would expect the same pattern in August 2003 and 2004, but this is not the case.

Our analysis revealed differences in nest distribution between seasons and years. Specifically, in August 2003, we found the owls were randomly distributed as they were earlier that year in April, but significant clustering appeared in 2004. In addition, the Ripley's  $K$  analysis indicated statistically significant clustering at spatial scales consistent with the size of the mowed areas. The smallest conservation area was 0.23 ha and the larger conservation areas were 4.2, 4.6 and 4.7 ha. The minimum significant area from the Ripley's  $K$  plot in August was 0.20 ha and the maximum was 4.4 ha: the clustering in the Ripley's  $K$  plot corresponds directly with the conservation areas from the mows. The size of areas with clustered nests corresponds to the scale of the mowed conservation areas. There may be a maximum scale of clustering possible, however. For instance, the maximum clustering from the

Ripley's  $K$  analysis corresponds to our second, third, and fourth largest conservation areas (4.7, 4.6, and 4.2 ha). Our largest area, however, was 10.3 ha, which was not significant in the Ripley's  $K$  plot. This may be due to habitat heterogeneity within the 10.3 ha area or a more random distribution.

While these data suggest that owls may have clustered in response to the timing and extent of mowing, they are in no way conclusive. Multiple treatments and controls are needed to statistically test this effect. Another limitation in our study is the relatively short 2-year time scale. Alternative factors for nest clustering include area constraints, food availability, inter-annual population changes that induce density-dependent processes, habitat continuity, and/or reduced predation risk due to owls alerting each other to predators (Coulombe 1971, Green and Anthony 1989, Desmond et al. 1995, Todd 2001). In addition to the uniformly shorter grass over large areas, mowed areas might be attractive for other reasons. For example, debris piles were moved and coyote bushes and other "weeds" were removed. Prey density, which was not quantified, may have been inconsistent in space and time. Additionally, NASA Ames employees were alerted to proceed with caution around the areas so perhaps the reduced disturbance was a major contributing factor to the appeal.

Our work found that Ripley's  $K$  as a tool, in conjunction with GIS and 1<sup>st</sup>-order point pattern processes, was effective in assessing the extent to which owl nests are clustered, the spatial scale and timing of clustering, and lends an element of statistical significance that can be quite powerful for wildlife managers in the struggle to manage habitat and limited resources. We were able to show differential clustering and inter-annual differences while avoiding arbitrary length-scales and limitations due to count-dependent analyses. The GIS alone can show monthly patterns and distributions, can track individual owls around the study site, and visually display extensive datasets in maps easily understood by policy-makers. Ripley's  $K$  provides a more detailed assessment of

the scale of spatial and temporal patterns, which can help managers understand wildlife response to management actions.

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