STREAKED HORNED LARK *(EREMOPHILA ALPESTRIS STRIGATA)* NEST PREDATION ON LOWLAND PUGET PRAIRIE REMNANTS, WASHINGTON STATE – THE EFFECTS OF INTERNAL EDGES AND SCOT'S BROOM *(CYTISUS SCOPARIUS)*

by,

Hannah E. Anderson

Submitted in partial fulfillment
of the requirements for the degree
Master of Environmental Studies
The Evergreen State College
Olympia, Washington
June 2006

ABSTRACT

STREAKED HORNED LARK *(EREMOPHILA ALPESTRIS STRIGATA)* NEST PREDATION ON LOWLAND PUGET PRAIRIE REMNANTS, WASHINGTON STATE – THE EFFECTS OF INTERNAL EDGES AND SCOT'S BROOM *(CYTISUS SCOPARIUS)*

Hannah E. Anderson

Predation is the leading cause of nest failure for the streaked horned lark *(Eremophila alpestris strigata)*. I examined potential factors affecting streaked horned lark nest predation and nest predators at three lowland Puget prairie sites in Washington State. I identify likely primary predators and discuss their potential contribution. Contrary to results reported in the literature for grassland birds, the primary predators of the streaked horned lark are most likely avian, corvids in particular. Many studies document the occurrence of deleterious "edge effects" within 50m of an external edge of both forests and grasslands. Streaked horned larks do not nest within this 50m range, but do nest among light-use roads and airport runways/taxiways present at their breeding sites. Few studies have addressed internal fragmentation of this nature and the effect on breeding birds. At each site, the distance from nest site to nearest internal edge was measured and the corresponding edge type (pavement, gravel, or dirt) was recorded for all nests discovered during 2002-2004 (n = 166). Also measured in 2004 was the distance from nest site to the nearest Scot's broom *(Cytisus scoparius)* plant and the estimated percent cover of Scot's broom within a 25m radius around the nest site was recorded (n = 45). Logistic regression was used to examine the relationship between nest outcome (depredated or successful) and the above listed factors. None of the factors examined affected streaked horned lark nest outcome. Using nearest neighbor analyses in ArcGIS 9.0, significant aggregation of nest sites was detected at two study sites. Nest clustering has been shown to be an effective defense against avian predators. Additional independent data is needed to confirm the aggregation. Future study of nest predation issues such as positive identification of lark predators, the importance of habitat patch size, and the effects of fragmentation and urbanization is needed.

I. Introduction

Predation is the primary cause of nest failure for many passerines (Duguay et al. 2000, Luck et al. 1999, Martin 1992, Heske et al 2001) including those in most North American grassland ecosystems (Best 1978, Johnson and Temple 1990). This is also true of the streaked horned lark *(Eremophilia alpestris strigata)* at lowland Puget prairie sites where predation accounted for 70% of nest failure during the 2002-2004 breeding seasons (Pearson and Hopey 2005). The streaked horned lark is one of 21 recognized subspecies of the horned lark *(Eremophila alpestris)*(American Ornithologists' Union 1957). Subspecies are designated by differences in size and plumage, the streaked horned lark being one of the brightest.

The streaked horned lark is a federal candidate for listing under the Endangered Species Act by the U.S. Fish and Wildlife Service, is considered endangered by the Committee on the Status of Endangered Species in Canada, is Red-listed in British Colombia, and considered a sensitive species by the Oregon Department of Fish and Wildlife. Most recently, on March 2, 2006, the streaked horned lark was listed as endangered by the Washington Department of Fish and Wildlife.

Both range and abundance of the streaked horned lark have been dramatically reduced. Population estimates range from about 500-1000 birds, most likely around 800 (Pearson and Hopey 2005). The lark has been extirpated from both the northern and southern extents of its historic range, and now only exists in small pockets of available habitat in the south Puget Sound, on the Washington coast on the north shore of Gray's Harbor at Damon Point, on dredge spoil islands of the Columbia River, and in the Willamette Valley.

Identification of streaked horned lark primary predators is of extreme importance. Evolutionary pressures faced by nesting birds is strongly influenced by the behavioral ecology of the nest predator and therefore affects the counter-behavior of the nesting bird within the predator-prey system (Lariviere 1999). Nest predator identification, and their relative impact, is also important when making conservation or management decisions and assigning management guidelines (Heske et al 2001, Chalfoun et al 2002). Differences in predator suites greatly influence the observed patterns of predation (Donovan et al. 1997, Marzluff and Retsani 1999). Currently, little is known about the suite of predators responsible for nest failures of the streaked horned lark (Pearson and Hopey 2005).

Many studies show that nest predation rates are negatively affected by their decreasing distance from forested edge (Paton 1994, Luck et al. 1999 and citations therein). Identified edge effects include increased predation and nest parasitism as nest locations near the edge of habitat (Heske et al 2001). Although it is evident that edge effects vary considerably within and among regions (Heske et al 2001), most edge effects probably occur less than or equal to 50m from a forested edge (Johnson and Temple 1990, Paton 1994, Winter et al 2000, Keyser 2002). A similar pattern emerges from studies addressing the edge effects on grassland-nesting birds (Johnson and Temple 1990, Winter and Faaborg 1999). In grasslands with surrounding pastures the edge effect likely extends beyond 50m (Renfrew and Ribic 2003).

The majority of edge studies have addressed exterior edges, which are described either as transitional zones or abrupt distinct changes from one habitat type to another (Luck et al. 1999, Keyser 2002). These edges are characterized by "abiotic and biotic features distinct from the habitats on either side of the edge (Keyser 2002)." The streaked horned lark is not found nesting within 50m of the exterior edge at lowland Puget prairie sites (pers. obs., S. Pearson, pers. comm., Bock et al. 1999). However, the lark is found nesting in interior grassland areas that are fragmented by one- or two-lane pavement, gravel or dirt roads, runways, taxiways, and aircraft ramps. In contrast to exterior edges, few studies have looked at how internal fragmentation of this nature affects bird communities (Miller et al 1998).

The suite of nest predators and predation rates adjust with respect to habitat type, landscape structure and landscape composition (Picman 1988, Møller 1989, Picman et al 1993, Major et al 1994, Major and Kendall 1996, Heske et al 2001). The invasion of the non-native shrub Scot's broom *(Cytisus scoparius)* is rapidly changing the vegetative structure and composition of the grassland habitat. Biological invasions are second only to habitat loss as reasons for endangerment of rare species (Reichard et al. 2001). The vegetative structural modification of invading Scot's broom could have a substantial effect on bird species, such as the streaked horned lark, who select interior habitats for breeding. These effects include providing perches for avian predators and nest parasites and also could serve as cover or burrow sites for small mammal predators (Heske et al 2001, Davis 2004). The change in vegetation is likely modifying the predator community.

Streaked horned lark nest sites are often found clustered in potentially suitable habitat. Historic records document the apparent aggregation of lark occurrence - "Six miles south of

Tacoma, where dense woods change suddenly into long stretches of prairie, the streaked horned lark is one of our common summer residents, though peculiar in its distribution, large areas being almost untenanted, where the conditions are to all appearances perfect. This seems strange, since, half a mile further, one comes upon very similar surroundings where a bird may be flushed on an overage of every hundred feet. (Bowles 1898)." Over 100 years later, it is still unclear whether nests simply appear clustered or if significant aggregation is occurring.

The current study's objectives relate to predation issues. First, I look at the comprised list of streaked horned lark predators and address their potential contribution to nest predation at Puget lowland sites. I ask the question, what species are the primary predators of the streaked horned lark at lowland Puget prairie sites? I address the relationship between nest outcome and the fragmentation of interior grassland habitat by roads and runways. I ask the question, does the distance to road or other internal grassland interruption edge affect nest predation? I also look at the relationship between nest outcome and the invasion of Scot's broom on the remaining lowland Puget prairie sites. I ask the question, are depredated nests correlated with the distance to and the relative abundance of Scot's broom at the nest site? Finally, I analyze the spatial arrangement of nest sites to detect if streaked horned lark nests exhibit a clustered pattern.

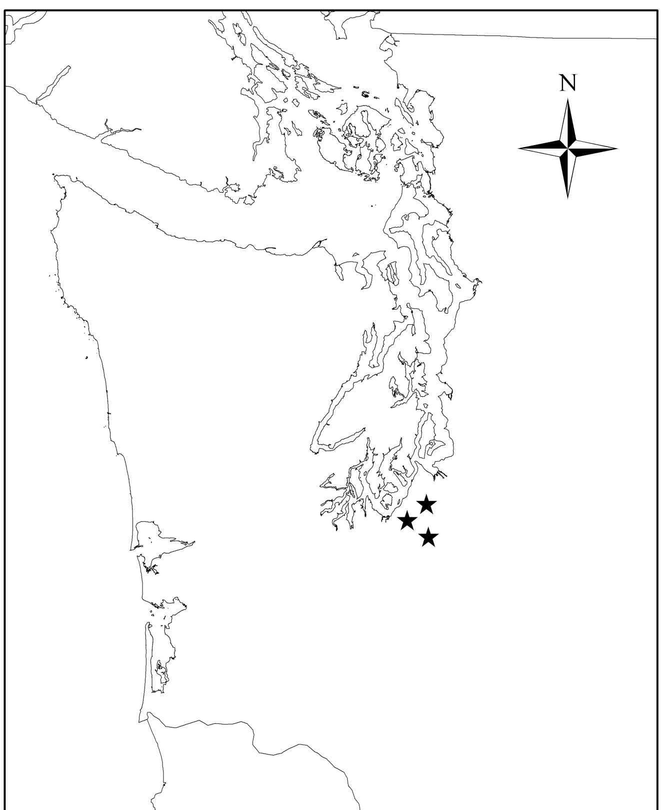


Figure 1. Lowland Puget prairie study sites. From north to south - McChord Air Force Base, Gray Army Airfield, 13th Division Prairie

II. Study Sites & Methods

II.a. Study Sites

During 2002-2004, streaked horned larks were monitored by several observers at three sites in the south Puget Sound, Washington State - one at McChord Airforce Base and two on Fort Lewis (Figure 1). All sites retain glacial outwash prairie remnants containing native Puget prairie species. Similar to the American northeast (Vickery et al. 1994), airports provide some of the last remaining extensive patches of grassland habitat in the Puget lowlands. Two of the three lowland Puget prairie study sites examined were at airports. In 2004 at McChord Air Force Base (MAFB) (47° 12'N 122° 45'W) larks were monitored in the northeast portion of the airfield, (68.8 ha). There were two sites monitored at Fort Lewis: the Grays Army Airfield (GAAF) (47° 08'N 122° 58'W) and the 13th Division prairie (13th) (47° 02'N 122° 44'W). In 2003 and 2004, larks were monitored over the entire GAAF (160 ha.), and 13th division prairie (202.6 ha.). Differences in study sites sizes were due to access limitations on military bases. The MAFB site was not monitored in 2003. In 2002, all sites were monitored but the study areas were smaller (GAAF = 65.63 ha.; 13th = 201.72 ha.; MAFB = 47.6 ha.). It is important to note that these study sites do not represent the entire grassland fragments upon which the larks are breeding, but are, in a sense, fragments of fragments.

II.b. Nest Discovery and Monitoring

Most nests were found by observing behavior of adult birds, but some were found by searching of appropriate habitat, and by luck. Once found, nests were visited not more than once every 3 days. Nest contents and developmental stage were recorded.

II.c Nest outcome

Nests were considered successful if one or more nestlings survived the nest phase and fledged from the nest. This was determined by either observing parent birds feeding young near, but outside the nest, or if the rim of the nest was flattened and droppings were present near and outside the nest. Nesting attempts were considered abandoned by the parent birds if eggs were still present past the time when they should have hatched or if nestlings died of exposure or starvation. Nests were considered depredated when eggs or nestlings present on one visit were completely missing on the next visit and/or there was clear evidence of predation such as nest material pulled apart, broken eggs, scattered feathers, etc. Nest failures were considered human caused when abandonment was instigated by anthropogenic disturbance or when human activities cause direct failure of a nest (such as by mowing). All nests that could not be assigned into one of the above categories were considered of unknown outcome.

II.d. Breeding Bird Survey

I accessed the Breeding Bird Survey (BBS) online database (http://www.mbr-pwrc.usgs.gov/bbs/) to analyze regional changes in American crow *(Corvus brachyrhynchos)* abundance in Washington State from 1968-2003. I also recorded the relative abundance of selected species along the survey route nearest the study sites (BBS route number - 89910, route name – McChord) (Sauer et al. 2004). For a complete description of BBS methods, please see Robbins & Van Velzen (1967).

II.e. Transects

Transects of varying lengths were laid out at all three study sites in 2002 and 2003. Areas covered by transects relative to the total area at the study sites differed between sites. Transect length was determined by measuring distances from GPS recorded points at either end of the transect using ArcGIS 9.0 (ESRI 1999-2004).

Transect data was taken by walking the transect lines and recording all birds detected, both by visual and auditory cues, within 75 meters on either side of the transect. Species and behaviors were noted for all birds detected. Survey duration was also noted.

2004 transect data was analyzed to compare corvid detections and behaviors among sites. For each site the total distance covered and time input for all transect surveys was quantified. The number of corvids detected was divided by the total time input (in minutes) and then divided by the total distance (in meters). The resulting index represents the total number of corvids per minute per meter. This index method was used to display total crows, total ravens *(Corvus corax)*, flyover crows, flyover ravens, ground foraging crows and ground foraging ravens. Flyover behaviors were recorded when the bird flew over the transect area during the survey. Ground foraging behaviors were recorded when the observer detected the bird on the ground, foraging within the defined transect area.

II.f. Edge

On the ground measurements were taken at all lowland prairie lark nest sites regarding their distance to the nearest edge and edge type for the 2004 field season. The same observer measured distance by pacing the distance from the nest to the edge and then converting the paced distance to meters (1 pace = 0.657 meters). Edge has been described as a "transitional zone from one habitat type to another (Keyser 2002)" and as a "junction between two dissimilar habitat types (Faaborg et al. 1993)." In this study, internal edge was defined as the interruption of grassland habitat by road or patch of differing substrate. Each edge interruption type was put into one of three categories: pavement, gravel or dirt.

Similar to methods employed by Renfrew and Ribic (2003), remote measurements were taken on 2002 and 2003 nest data using ArcGIS 9.0 (ESRI 1999-2004) distance measuring tools. Nest site locations were recorded with GPS at the end of the breeding seasons. Recent orthographic photographs taken in 2000 with a 3 ft. resolution were used to determine distance from the nest to nearest internal edge and edge interruption type.

To ensure the measurement results of the GIS method were not significantly different than the on-the-ground measurements, the GIS method was also used to measure the distance from nest to edge on 2004 data. Both remote and on-the-ground data sets were log-transformed for normality. Using t-tests, I then compared the paced measurements to the GIS measurements for 2004 data.

I used logistic regression to examine the relationship between nest fate (depredated or successful, other nest fates excluded from analyses) and distance to grassland edge and edge type category. Logistic regression is the appropriate test when dependent variables are binary and independent variables are continuous, as is found in this study (Hosmer and Lemeshow 1989, Zar 1984) Analyses were conducted using SYSTAT (version 7.0.1, copyright 1997, SPSS Inc.).

I used an ANOVA with a Bonferroni adjustement to test for differences in the distances of nests to each edge type.

II.g. Scot's Broom

I estimated the percent cover of Scot's broom in a 25m radius circle around the nest site. Relative cover of Scot's broom was estimated to be in one of 7 categories (0%, <1%, 1-5%, 6-25%, 26-50%, 51-75% and >75%). To reduce variability and observer bias, the same observer conducted all estimates. The distance from the nest site to the nearest broom plant was measured by pacing the distance from nest to shrub. Paced measurements were then converted to meters (1 pace = 0.657 meters). Nearest broom plant measurement was not truncated by the 25m radius circle. Rather, distances were paced regardless of the distance to the nearest plant. Logistic regression was used to examine the correlation between depredated or successful nests (other nest fates excluded from analyses) and the relative abundance of Scot's broom or distance from the nest to the nearest Scot's broom plant.

II.h. Nest Site Point Pattern Analysis

Using ArcGIS 9.0 (ESRI 1999-2004), I conducted nearest neighbor analyses on all nests at each site to determine if nest sites were clustered together, dispersed evenly over the study site or if they displayed a random distribution. Nearest neighbor analyses calculate the distances between neighboring data points and test those against distances expected by chance, using a random Poisson distribution. The resulting index (observed over expected) and related Z-score indicate the level of clustering. An index of 1 indicates a random distribution. Index levels less than 1 indicate clustering, and those greater than 1 indicate even dispersal.

III. Results

III.a. Breeding Bird Survey

Table 1. BBS values represent averages from 1989-1998 of total birds detected during a 2.5 hour survey along a 24.5 mi. stretch of roadside running adjacent to MAFB and on Fort Lewis (Sauer et al. 2004).

American Crow	*Corvus brachyrhynchos*	31.71
Common Raven	*Corvus corax*	1.43
Horned Lark	*Eremophila alpestris*	0.29
Redtail Hawk	*Buteo jamaicensis*	1.43
Brown-headed Cowbird	*Molothrus ater*	12.43
Killdeer	*Charadruis vociferous*	4.71

III. b. Transect Data

2004 transect survey results show that crows were detected on both airfields but not at 13th (Table 1). Ravens were detected at all sites. Crows were detected foraging on the ground at GAAF. Ravens were detected flying over at 13th and MAFB, but never detected on the ground during transect surveys. Anecdotal sightings of ground foraging crows and ravens outside the transect area were observed at MAFB. Although not detected by Breeding Bird Surveys, northern harriers *(Circus cyaneus)* were recorded during transect surveys at the study sites.

Table 2. Index represents the total number of corvids detected for each category on transects, divided by the total time invested on transects, divided by the total distance covered - # corvids per minute per meter.

	GAAF	13^{th}	MAFB
Total Crows Detected	4.99^{10-7}	0.00	2.44^{10-6}
Total Ravens Detected	7.14^{10-9}	1.24^{10-7}	9.76^{10-7}
Flyover Crows	2.85^{10-7}	0.00	2.44^{10-6}
Flyover Ravens	0.00	1.24^{10-7}	9.76^{10-7}
Ground Forage Crows	2.14^{10-7}	0.00	0.00

III.c. Edge

I found that the distances recorded from the two measurement methods, on-the-ground paced measurements and remote measurements derived by measuring distances with ArcGIS 9.0 (ESRI 1999-2004), did not significantly differ ($p = 0.398$).

Results of logistic regression for 2002, 2003, and 2004 demonstrate that the distance to internal edge and the corresponding edge type did not significantly affect nest outcome ($Rho^2 = 0.021$). Figures (2) and (3) visually depict this finding by displaying the proportion of nests depredated within distance categories and within edge type categories.

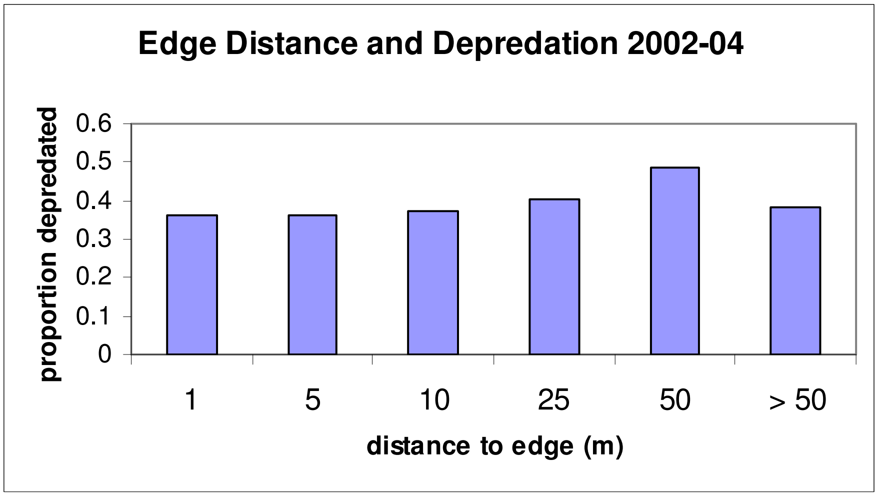


Figure 2. Proportion of depredated nests within a range of distances to internal edge at all sites combined (mean proportion of depredated nests in distance to edge categories = 0.40, range 0.36-0.49, n=166).

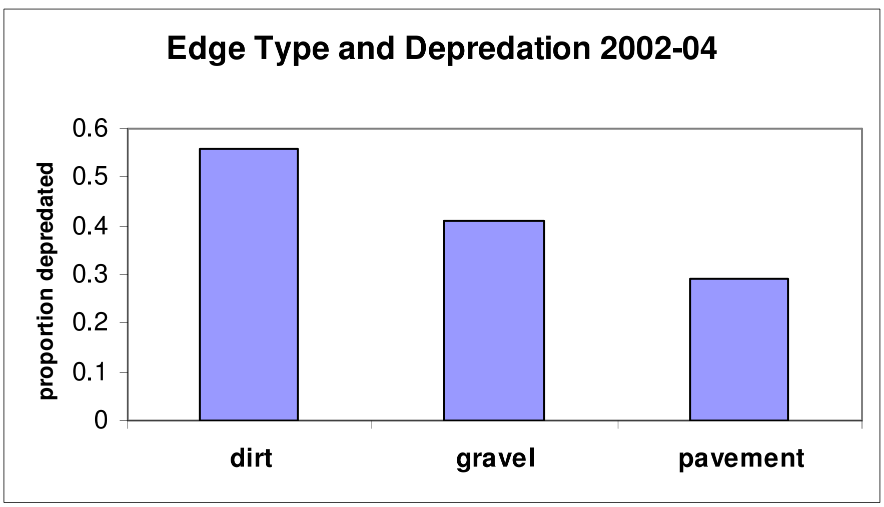


Figure 3. Chart depicting the proportion of depredated nests at all sites categorized by edge type. (dirt n=25, dep/tot=0.56, gravel n=83, dep/tot=0.41, pavement n=58, dep/tot=0.29)

ANOVA results indicate that nests nearest to pavement edges were significantly closer to the edge than nests in which the nearest edge was either gravel or dirt ($F = 5.856$, $p = 0.003$, $df = 2$).

III.d. Scot's Broom

Logistic regression results indicate that neither estimated relative abundance of Scot's broom nor distance to nearest broom plant explain any of the variability in the 2004 nest outcome data ($Rho^2 = 0.06$). See figures (4) and (5) for a visual representation of these results displayed as described above for edge.

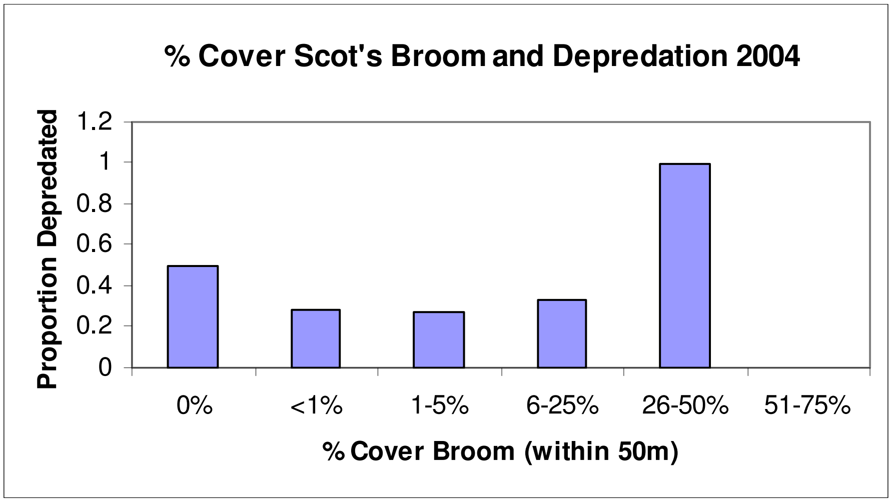


Figure 4. Proportion of depredated nests at all sites categorized by the percent cover of Scot's broom in a 50m radius circle around the nest (all nests n=45, mean dep/tot=0.39, 0% n=4, dep/tot=0.50, <1% n=25, dep/tot=0.28, 1-5% n=11, dep/tot=.27, 6-25% n=3, dep/tot=.33, 26-50% n=1, dep/tot = 1.0, 51-75% n=1, dep/tot=0.0).

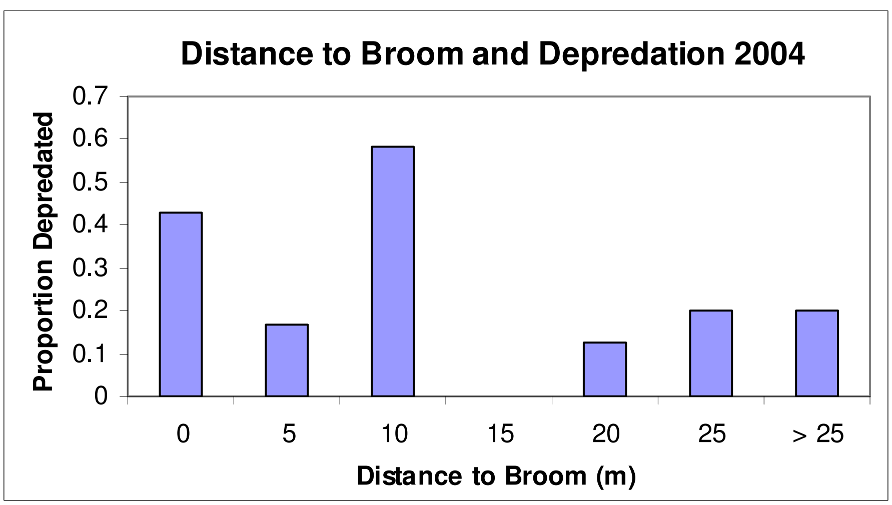


Figure 5. Proportion of depredated nests at all sites categorized by their distance to the nearest Scot's broom plant (all nests n=45, mean dep/tot=0.31, 0m n=7, dep/tot=0.43, 5m n=6 dep/tot=0.17, 10m n=12, dep/tot=0.58, 15m n=2, dep/tot=0.00, 20m n=8, dep/tot=0.13, 25m n=5, dep/tot=0.20, >25m n=5, dep/tot=0.20).

III.e. Nest Site Point Pattern Analysis

Nearest neighbor analyses run on all nest data sets for each year at each site indicate significant nest clustering at GAAF and MAFB (table 2). At 13^{th}, nests were not significantly clustered when analyzed separately. In 2003, at 13th the data set approached significance (p = 0.06, n = 15). It is possible that nest clusters are not being detected due only to a small sample sizes. For example when 2003 and 2004 nests were combined (n = 15 & n = 10, respectively) a significant nest cluster was detected (p = 0.002) . However, larger and independent samples are required to determine if this is the case. See appendices 2-9 for nest location figures.

Table 3. Nearest neighbor analyses for nest sites at 13th, GAAF and MAFB. Index ratio values < 1 indicate clustering, values at 1 indicate a random distribution, > 1 indicate a dispersed pattern. See appendices 2-10 for visually represented nest site locations within study areas.

Site	Year	# nests	Index Ratio	Z - Score	P = 0.05
13^{th}	2002	8	1.1998	1.0808	0.8750
13^{th}	2003	15	0.7945	-1.15226	0.0600
13^{th}	2004	10	0.8293	-1.0326	0.1470
13^{th}	2003 & 2004	25	0.6965	-2.9027	0.0020
GAAF	2002	12	0.3434	-4.3474	0.0000
GAAF	2003	72	0.6715	-5.3329	0.0000
GAAF	2004	26	0.7275	-2.6582	0.0040
GAAF	2003 & 2004	98	0.7144	-5.4080	0.0000
MAFB	2002	16	0.7401	-1.9886	0.0200
MAFB	2004	10	0.6586	-2.0652	0.0160

IV. Discussion

There have been only three documented, observed incidences of streaked horned lark nest predation at lowland Puget prairie sites, two by American crows and the other a garter snake *(Thamnophis spp.)* (Pearson and Hopey 2005). It is also suspected that a killdeer may have pecked a hole in a lark egg. The relative contribution of these species and others to lark nest predation is unclear (Pearson and Hopey 2005). However, studies have shown that nests are depredated by predator species in approximate proportion to their relative abundance (Angelstam 1986). Specifically, a positive correlation between corvid relative abundance and nest predation rates has been documented (Angelstam 1986, Johnson et al. 1989, Andren 1992, Luginbuhl et al. 2001). Breeding Bird Survey data indicate that corvids are quite common near the lark breeding sites examined.

Potential nest predators of the streaked horned lark at lowland Puget prairie sites include: corvids, snakes, coyotes *(Canis latrans)*, various small mammals, domestic cats *(Felis cattus)*, domestic dogs *(Canis familiaris)*, northern raccoons *(Procyon lotor)*, striped skunks *(Mephitis mephitis)*, long-tailed weasels *(Mustela frenata)*, Virginia opossums *(Didelphis virginiana)*, red foxes *(Vulpes vulpes)* black-tailed deer *(Odocoileus)*, northern alligator lizards *(Elgaria coerulea)*, northern harriers, redtail hawks and other raptors, and various song birds (Pietz and Granfors 2000, Renfrew and Ribic 2003, Pearson and Hopey 2005). See appendix 1 for some additional information regarding these groups of potential predators.

Further, primary predators differ dependent upon nest phase development, with avian predators dominating the incubation phase, and mammalian and snake depredation occurring most often during the nestling stage (Luginbuhl et al 2001). Mammals may be more prone to moving and foraging in open habitats (Eriksson 2001) and are most often reported as the primary predators of ground-nests (Soderstrom 1999) and in grasslands and pastures (Eriksson 2001).

In 2002-2004 the majority of streaked horned lark nest mortality occurred during the incubation stage (Pearson and Hopey 2005) suggesting predation by birds at lowland Puget prairie sites. Some possible explanations for the discrepancy between these results and those predicted by the literature include the details of the surrounding landscape, the availability of contiguous habitat, and the particular habitat preferences of the streaked horned lark.

The surrounding urban and suburban matrix greatly affects the predator suite found within remaining “natural” habitat fragments (Thorington and Bowman 2003). Patchy native habitat combined with anthropogenic foraging opportunities provides ideal habitat for generalist predators (Thorington and Bowman 2003). Nest predation in areas adjacent to urban or suburban landscapes has been shown to be higher than in areas with surrounding "natural" landscapes (Wilcove 1985). Conversely, some studies have demonstrated that nest predation declines in urban areas (Thorington and Bowman 2003). 1968-2003 BBS data reveal that in Washington state counts of American crows display an increasing trend in relative abundance (Sauer et al. 2004). Development and resulting urbanization have undoubtedly contributed to the rise. Both airport sites are surrounded by a suburban/urban matrix. The food bonanzas provided by nearby fast food restaurants, human housing, and associated litter are attractive to generalist scavenger/predators like corvids.

The size of available contiguous habitat may be an important factor in streaked horned lark breeding ecology. Nest predators such as raccoons and others, may have the highest densities in fragmented, heterogeneous landscapes (Gates and Gysel 1978, Andren 1992, Oehler and Litvaitis 1996, Thorington and Bowman 2003). One study reports that grassland nesting birds on large fragments have higher nest success than those on smaller fragments (Herkert et al. 2003). Davis (2004) reports that horned lark density was not related to patch size in northeastern Colorado, but rather the edge to area ratio was a better predictor of occurrence. Bock et al. (1999) reported greater lark abundance in interior plots vs. those near exterior edges. Unfortunately, high variation yielded non significant results in that study. Bobolink *(Dolichonyx oryzivorus)* nest success was reported as high near fragment edges as in interior locations (Bollinger and Gavin 2004). The authors suggest that interior grassland fragmentation may not be as detrimental as has been reported for forest fragmentation. At the three sites examined, the 13th division prairie has the largest area but also the lowest nest success (Pearson and Hopey 2005), supporting the idea that habitat patch size is not the most important predictor of nest success. Little is currently known about the relationship between grassland bird nest success and habitat fragmentation, patch size, or edge to area ratio (Winter et al. 2000). More research is needed to address this issue with streaked horned larks.

Streaked horned larks forage and breed in areas with short grass and sparse vegetation (Davis 2004, Pearson and Hopey 2005). This habitat preference further supports the suspicion that avian species are the primary threat to streaked horned lark nests. The short, sparse vegetation preferred by the larks may benefit already abundant corvids by allowing them easy access to nests by walking through the open habitat. Short, sparse vegetation could also provide visual benefits to other avian predators such as the northern harrier, brown-headed cowbird, redtail hawk, and other raptors by making the nests easier to locate than those of other prey species who build their nests in denser vegetation. Crows were detected at MAFB and GAAF, and were detected ground-foraging at GAAF suggesting it may be a significant predator of the streaked horned lark.

The 13th division prairie is unique among the three study sites. The surrounding matrix at 13th is not urbanized, as found at the other two sites, but rather surrounded by second-growth Douglas-fir *(Pseudotsuga menziesii)* dominated forest. At the 13th division prairie, crows were not detected during transect surveys. Due to the low level of urbanization, it is not surprising that crows are found more at GAAF and MAFB than at the comparatively undeveloped 13th division prairie. Additionally, 13th is not an airport and therefore is not managed by a mowing regime, which keeps the native and non-native vegetation quite tall and dense. These factors may contribute to a different predator assemblage and relative contribution of those predators at the 13th division prairie than at GAAF and MAFB. An analysis of each site independently could elucidate some of these differences.

In addition to corvids, small mammals have been shown to be important nest predators for passerines, (Guillory 1987, Marini 1988, Reitsma et al.1990, Cotterill 1996, Hanski et al. 1996, Blight & Ryder 1999) and especially for ground nesting birds (Maxson and Oring 1978). Small mammals such as chipmunks, mice, and shrews may be underestimated as nest predators in the literature due to the use of quail eggs, which are too large for small-mouthed predators, in artificial nest experiments (Heske et al 2001). Small mammals detected on the prairies of Fort Lewis include the deer mouse *(Peromyscus maniculatus)*, pacific jumping mouse *(Zapus trinotatus),* long tailed vole, *(Microtus longicaudus)* and Oregon vole *(Microtus oregoni).* (Unpublished data, US Army, Fort Lewis 1998).

Coyotes may play a role in lark nest depredation. Coyote scat has often been found while surveying for larks and coyotes have been spotted at all sites. Coyotes have increased their range and numbers in recent years (Crete and Lemieux, 1996) and they have demonstrated an ability to adapt to the rapidly changing urban and suburban environment and the anthropogenic food sources found therein (Quinn 1992, Bounds 1994). Although coyotes prefer areas with cover, they are not restricted to forest habitat. They may use open habitats to forage for small mammals

(Arjo & Pletscher 2004). Unlike wolves, coyotes use areas close to roads (Arjo & Pletscher 2004) and, since lark nests are often found near roads, they may be more likely depredated by coyotes

Streaked horned larks often occur along roadsides. At the lowland Puget prairie study areas they are attracted to the internal edges as forage and display sites. Results from the current edge study indicate the distance from the nest to internal edge or edge type does not affect lark nest outcome. Internal roads could however still be affecting the general area of breeding larks by attracting additional predators such as corvids and other scavengers who are conditioned to forage for road-kill, a reliable and easily obtainable food source (Luck et al. 1999). Knight and Kawishima (1993) report increased raven abundance along paved roads as opposed to areas away from roads. Roads could also serve as travel lanes for predators such as coyotes, raccoons and other generalist, terrestrial predators (Yahner and Mahan 1997, Heske et al 2001), although this has not been empirically established (Boag et al. 1984). Small and Hunter (1988) also suspect that mammalian predators such as foxes, skunks, and coyotes use linear corridors while foraging (Yahner and Mahan 1997). While lark nest placement near internal edges such as roads was not shown to affect lark predation at the sites examined, the roads may be attracting predators into areas where larks are nesting.

The edge study revealed that nests that had pavement as its nearest edge were significantly closer to that edge than nests who's nearest edge was gravel or dirt. Streaked horned lark males were often observed singing and defending territories on the pavement. The pavement provides a slightly raised, unvegetated expanse with long horizons over nearby grassland habitat, which the males use regularly for song and display. These ideal display areas may be very important to females when selecting a nest site.

Heske et al (2001) reported that nest predation was greater on both natural and artificial nests in grasslands with more internal structure and shrubby growth than in relatively homogenous grasslands. Winter et al. (2000) showed that nest success was lower on nests within 50m of a shrubby edge. Davis (2004) found cowbird abundance to be greater in pastures with more dispersed shrubs than in grasslands without a shrub component. Invasion of Scot's broom at all sites examined was predicted to have a negative effect on lark nest outcome. However, results of logistic regression indicate that neither the relative cover of broom within a 25m radius around the nest site nor the distance to the nearest broom plant explained any of the variation in nest outcome data. The larks typically avoid nesting in areas with a high Scot's broom component (pers.obs., S.Pearson, pers.comm.) It could be that because they are choosing nest sites away from broom patches they are not affected by the potentially deleterious effects of that structural modification.

The nearest neighbor analyses demonstrate that streaked horned larks aggregate their nest locations at the Gray Army Airfield and at McChord Airforce base. However, it is important to note that the larks re-nest in the same territory after a failed or successful nesting attempt possibly skewing the cluster data by over-representing individual pairs. Further analysis with individual pairs, or cluster detection of territories could amend this independence issue. Larger sample sizes and independent analyses are important to confirm the aggregation.

At the 13th division prairie significant nest clusters were not detected, although the cluster indicated by the index in 2003 did approach significance (table 2). When data from two years at 13th were pooled and the analysis run with a larger sample size, a significant cluster was detected. These results suggest that if there were a large enough sample of nest sites, the analysis may detect clustering of nests at 13th as well. Unfortunately, nest site point patterns are temporally specific to each year. The fact that the cluster was detected by pooling 2003 and 2004 data indicates that at 13th the larks may be choosing the same fine-scale sites for breeding each year. For a description and analysis of streaked horned lark nest site habitat selection see Pearson 2003, Pearson and Hopey 2004 and 2005.

It remains unclear why the larks seem to cluster their nests. Historical records (Bowles 1898) indicate that the clustering is typical of the lark's behavior. This behavior likely evolved as an adaptive advantage. Possible explanations for clustered nest patterns include - a colony nesting strategy; selecting nest site for habitat characteristics and display areas; or clustering due to a social cue, such as settling as a flock.

Martin (1993) reports that birds choose nest sites with reduced risk of predation. However, Keyser et al. (1998) found no significant difference in predation rate between clustered and unclustered nests in ground-nesting passerines. Alternatively, Major et al. (1994) concluded that clustered nests had higher predation rates than unclustered nests. The composition of the predator suite has a large effect on the spatial distribution of prey nests (Newton and Heske 2000). Strategies employed by prey species to reduce predation are dependent upon whether a mammalian or avian predator assemblage is observed. Hogstad (1995) reports that strategies of colonial nesting Fieldfares *(Turdus pilaris)* were effective against corvids but not against mustelids. Hogstad (1995) concludes that birds benefit from a clustered nest pattern when the primary predators are avian. If mammalian predators are the primary threat then nest clustering is disadvantageous. It is possible that streaked horned larks form clustered nest patterns to defend against avian depredation, such as that by corvids and raptors.

V. Summary and Conclusions

It is likely that the primary predators of streaked horned larks at Puget prairie sites are avian. Corvids, American crows in particular, may be responsible for a substantial proportion of depredation events at the airport sites and their numbers have increased in response to surrounding human development (Sauer et al. 2004). Several factors were considered before reaching this conclusion. The majority of streaked horned lark nest predation occurred during the incubation stage (Pearson and Hopey 2005) when avian predators have been shown to be the primary threat (Luginbuhl et al. 2001). The larks seem to demonstrate an aggregated nest site point pattern, which has been reported as an effective strategy against avian predators (Hogstad 1995). Further, the larks prefer sparse habitat with relatively low vegetation densitys (Davis 2004, Pearson and Hopey 2005). The open-ness of lark habitat and the visual search strategy employed by avian predators may give them an advantage over mammalian predators. Mammals, both mid-sized and small, should not be discounted as nest predators. Mammals present on lark breeding sites are known to be nest predators. Specifically, generalist predators such as coyotes, raccoons, and skunks may reach high densities due to the fragmentation of habitat and the surrounding urban/suburban matrix at some sites (Gates and Gysel 1978, Andren 1992, Oehler and Litvaitis 1996, Thorington and Bowman 2003).

The study clearly indicates that neither nearness to the internal edges present at the three study sites nor the corresponding edge type affects nest outcome. Interestingly, nests with pavement as their nearest edge were significantly closer to the paved edge than nests near gravel or dirt. Perhaps the raised, wide expanses provided by paved roads and runways are valuable as display areas. It is also clear from this study that the nearness to Scot's broom and its estimated relative cover around the nest site do not affect nest depredation of the streaked horned lark.

VI. Recommendations for Further Research

To conclusively identify streaked horned lark nest predators I recommend the use of infrared, remote sensing cameras placed at artificial nests designed to mimic those of the streaked horned lark. To fully capture the nest predator assemblage, eggs of a small passerine such as the house sparrow *(Passer domesticus),* should be used in artificial nest experiments rather than the historically common use of Japanese quail *(Coturnix japonica)* eggs, which may be too large for small-mouthed predators (Maier and DeGraff 2000, Niehaus et al. 2003). Although artificial nest experiments have many inherent problems and require the acceptance of several assumptions (see Major and Kendal 1996), I suggest their use because of the rarity and sensitive nature of streaked horned lark populations, and the potential for negative effects due to the presence of cameras and researchers.

I recommend investigation regarding the habitat patch size and the limited continuity of remaining streaked horned lark habitat in relation to nest success and depredation. Although it appears that streaked horned larks continue to persist near to human settlements, their range and available habitat has dramatically decreased. Additional information regarding nest predation and habitat patch size could help biologists and managers develop plans for the continued conservation and management of this and other grassland species.

VII. References

American Ornithologists' Union. 1957. Check-list of North American birds. 5th edition. American Ornithologists' Union, Washington, D.C.

Andren, H. 1992. Corvid density and nest predation in relation to forest fragmentation: A landscape perspective. Ecology 73:794-804.

Angelstam, P. 1986. Predation on ground-nesting birds' nests in relation to predator densities and habitat edge. Oikos. 47:365-373.

Arjo, W.M and D.H. Pletscher. 2004. Coyote and wolf habitat use in northwestern Montana. Northwest Science. 78(1):24-32.

Ardizzone, C.D. and C.J. Norment. 1999. Experimental analysis of nest predation in a New York grassland: Effects of habitat and nest distribution. Studies in Avian Biology. 19:122-127.

Arnold, K.E. 2000. Strategies of the cooperatively breeding noisy miner to reduce nest predation. Emu. 100:280-285.

Best, L. B. 1978. Field sparrow reproductive success and nesting ecology. The Auk 95:9-22.

Blight, L.K., J.L. Ryder and D.F. Bertram. 1999. Predation on Rhinoceros Auklet eggs by a native population of *Peromyscus*. The Condor. 101:871-876.

Boag, D.A., S.G. Reebs and M.A. Schroeder. 1984. Egg loss among spruce grouse inhabiting lodgepole pine forests. Canadian Journal of Zoology 62:1034-1037.

Bock, C.E., J.H. Bock and B.C. Bennett. 1999. Songbird abundance in grasslands at a suburban interface on the Colorado High Plains. Pp 131-136. In: P.D. Vickery and J.R. Herkert, eds. Ecology and conservation of grassland birds of the western hemisphere. Studies in Avian Biology 19.

Bollinger, E.K. and T.A. Gavin. 2004. Responses of nesting bobolinks *(Dolichonyx oryzivorus)* to habitat edges. The Auk. 121(3):767-776.

Bounds, D. L. 1994, Managing coyotes in U.S. national parks: Human-coyote interactions: Natural Areas Journal. 14:280–284.

Bowles, J.H. 1898. Notes on the Streaked Horned Lark. Osprey 3:53-54.

Bowman, G.B. and L.D. Harris. 1980. Effect of spatial heterogeneity on ground-nest depredation. Journal of Wildlife Management. 44(4):806-813.

Chalfoun, A. D., I. F.R.Thompson, and M. J. Ratnaswamy. 2002. Nest predators and fragmentation: A review and meta-analysis. Conservation Biology 16:306-318.

Cotterill, S.E. 1996. Effect of clearcutting on artificial egg predation in boreal mixedwood forests in north-central Alberta. M.S. thesis, Univeristy of Alberta, Edmonton.

Crete, M., and R. Lemieux. 1996, Population dynamics of coyotes colonizing the boreal forests of southeastern Quebec: J. Wildl. Res. 1 99–105.

Davis, S.K. 2004. Area sensitivity in grassland passerines: Effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewan. The Auk. 121(4):1130-1145.

Donovan, T.M., P.W. Jones, E.M. Annand and F.R. Thompson III. 1997. Variation in local-scale edge effects: mechanisms and landscape context. Ecology 78:2064-2075.

Duguay, J.P., P.B. Wood and J.V. Nichols. 2001. Songbird abundance and avian nest survival rates in forests fragmented by different silvicultural treatments. Conservation Biology. 15(5):1405-1415.

Eriksson, L.M., L. Edenius, V. Areskoug and D.A. Meritt, Jr. 2001. Nest-predation at the edge: An experimental study contrasting two types of edges in the dry Chaco, Paraguay. Ecography 24:742-750.

Environmental Systems Research Institute (ESRI). 1999-2004. ArcGIS: Release 9.0 [software]. Redlands, California: Environmental Systems Research Institute.

Faaborg, J., M. Brittingham, T.M. Donovan, and J. Blake. 1993. Habitat fragmentation in the temperate zone: a perspective for managers, p. 331-338. In: D.M. Finch and P.W. Stangel (eds.), Status and management of Neotropical migratory birds. U.S.Dept. Agriculture, Forest Service. GTR RM-229, Fort Collins, CO.

Gates, J.E. and L.W. Gysel. 1978. Avian nest dispersion and fledgling success in forest-field ecotones. Ecology 59:871-883.

Grinder, M.I. and P.R. Krausman. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. Journal of Wildlife Management. 65(4):887-898.

Guillory, H.D. 1987. Cavity competition and suspected predation on Prothonotary Warblers by *Peromyscus* spp. Journal of Field Ornithology 58:425-427.

Hanski, I.K., T.J. Fenske and G.J. Niemi. 1996. Lack of edge effect in nesting success of breeding birds in managed forest landscapes. Auk 113:578-585.

Herkert, J.R., D.I. Reinking, D.A. Wiedenfeld, M.winter, J.L. Zimmerman, W.E. Jensen, E.J. Finck, R.R. Koford, D.E. Wolfe, S.K. Sherrod, M.A. Jenkins, J. Faaborg and S.K. Robinson. 2002. Effects of prairie fragmentation on the nest success of breeding birds in the midcontinental United States. Conservation Biology. 17(2):587-594.

Heske, E. J., S. K. Robison, and J. D. Brawn. 2001. Nest predation and Neotropical migrant songbirds: Piecing together the fragments. Wildlife Society Bulletin 29:52-61.

Hogstad, O. 1995. Do avian and mammalian nest predators select for different nest dispersion patterns of Fieldfares *Turdus pilaris?* A 15-year study. Ibis 137:484-489.

Hosmer, D.W. and S. Lemeshow. 1989. Applied logistic regression. John Wiley and Sons, New York.

Johnson, D.H., A.B. Sargeant and R.J. Greenwood. 1989. Importance of individual species of predators on nesting success of ducks in the Canadian Prairie Potholes Region. Canadian Journal of Zoology 67:291-297.

Johnson, R. G., and S. A. Temple. 1990. Nest predation and brood parasitism of tallgrass prairie birds. Journal of Wildlife Management 54:106-111.

Keyser, A.J., G.E. Hill and E.C. Soehren. 1998. Effects of forest fragment size, nest density, and proximity to edge on the risk of predation to ground-nesting passerine birds. Conservation Biology. 12(5):986-994.

Keyser, A.J. 2002. Nest predation in fragmented forests: landscape matrix by distance from edge interactions. Wilson Bulletin. 114(2):186-191.

Knight, R.L. and J.Y. Kawashima. 1993. Responses of raven and red-tailed hawk population to linear rights-of-way. Journal of Wildlife Management 57:266-271.

Lariviere, S. 1999. Reasons why predators cannot be inferred from nest remains. The Condor 101:718-721.

Luck, G.W., H.P. Possingham and D.C. Paton. 1999. Bird responses at inherent and induced edges in the Murray Mallee, south Australia. Nest predation as an edge effect. Emu. 99:170-175.

Luginbuhl, J. M., J. M. Marzluff, and J. E. Bradley. 2001. Corvid survey techniques and the relationship between corvid relative abundance and nest predation. Journal of Field Ornithology 72:556-572.

Maier, T.J. and R.M. DeGraaf. 2000. Predation on Japanest quail vs. house sparrow eggs in artificial nests: Small eggs reveal small predators. The Condor. 102:325-332.

Major, R.E., G.H. Pyke, M.T. Christy, G.Gowing and R.S. Hill. 1994. Can nest predation explain the timing of the breeding season and the pattern of nest dispersion of New Holland honeyeaters? Oikos 69:364-372.

Major, R. E., and C. E. Kendal. 1996. The contribution of artificial nest experiments to understanding avian reproductive success: A review of methods and conclusions. Ibis 138:298-307.

Marini, M. A., and C. Melo. 1998. Predators of quail eggs, and the evidence of the remains: implications for nest predation studies. The Condor 100:395-399.

Martin, T. E. 1992. Nest predation among vegetation layers and habitat types: revising the dogmas. The American Naturalist 141:897-913.

Martin, T. E. 1993. Nest predation and nest sites. New perspectives on old patterns. Bioscience 43:523-532.

Marzluff, J.M. and M. Restani. 1999. The effects of forest fragmentation on avian nest predation, pp. 155-169. In: J.A. Rochelle, L.A. Lehmann and J.Wisniewski, eds. Forest fragmentation: wildlife and management implications. Koninklijke Brill, Boston.

Maxson, S. J., and L. W. Oring. 1977. 1978? Mice as a source of egg loss among ground-nesting Birds. The Auk 95:582-584.

McClennen, N., R.R.Wigglesworth, S.H. Anderson and D.G. Wachob. 2001. The effect of suburban and agricultural development on the activity patterns of coyotes *(Canis latrans).* The American Midland Naturalist: Vol. 146, No. 1, pp. 27–36.

Miller, S.G., R.L. Knight and C.K. Miller. 1998. Influence of recreational trails on breeding bird communities. Ecological Applications. 8(1):162-169.

Møller, A.P. 1989. Nest site selection across field-woodland ecotones: An experiment. Oikos 50:91-94.

Niehaus, A.C., S.B. Heard, S.D. Hendrix and S.L. Hillis. 2003. Measuring edge effects on nest predation in forest fragments: Do finch and quail eggs tell different stories? American Midland Naturalist. 149:335-343.

Newton, J.L. and E.J. Heske. 2000. Predation on artificial nests in small grassland patches in east-central Illinois. American Midland Naturalist. 145:29-38.

Oehler, J.D. and J.A. Litvaitis. 1996. The role of spatial scale in understanding responses of medium-sized carnivores to forest fragmentation. Canadian Journal of Zoology 74:2070-2079.

Paton, P.W.C. 1994. The effect of edge on avian nest success: How strong is the evidence? Conservation Biology. 8(1):17-26.

Pearson, S.F. 2003. Breeding phenology, nesting success, habitat selection, and census methods for the streaked horned lark in the Puget lowlands of Washington. Washington Department of Natural Resources. Natural Areas Report. 2003-02.

Pearson, S.F. and M. Hopey. 2004. Streaked horned lark inventory, nesting success and habitat selection in the Puget lowlands of Washington. Washington State Department of Natural Resources. Natural Areas Report. 2004-01.

Pearson, S.F. and M. Hopey. 2005. Streaked horned lark nest success, habitat selection and habitat enhancement experiments for the Puget lowlands, coastal Washington and Columbia River islands. Washington State Department of Natural Resources. Natural Areas Report. 2005-01.

Picman, J. 1988. Experimental study of predation on eggs of ground-nesting birds: Effects of habitat and nest distribution. Condor 90:124-131.

Picman, J., M.L. Milks and M. Leptich. 1993. Patterns of predation on passerine nests in marshes: Effects of water depth and distance from edge. Auk 110:89-94.

Pietz, P. J., and D. A. Granfors. 2000. Identifying predators and fates of grassland passerine nests using miniature video cameras. Journal of Wildlife Management 64:71-87.

Quinn, T. 1992, The distribution, movements, and diet of coyotes in urban areas of western Washington: Ph.D. Dissertation, University of Washington, Seattle. 105 pp.

Reichard, S.H., L. Chalker-Scott and S. Buchanan. 2001. Interactions among non-native plants and birds. In: Avian Ecology and Conservation in an Urbanizing World. J.M. Marzluff, R. Bomman and R. Donnelly, eds. Kluwer Academic Press. Norwell, Massachusetts.

Renfrew, R. B. and C. A. Ribic. 2003. Grassland passerine nest predators near pasture edges identified on videotape. The Auk 120:371-383.

Retisma, L.R., R.T. Holmes and T.W. Sherry. 1990. Effects of removal of red squirrels, *Tamiasciurus hudsonicus*, and eastern chipmunks, *Tamias striatus,* on nest predation in a northern hardwood forest: An artificial nest experiment. Oikos 57:375-380.

Robbins, C.S. and W.T. Van Velzen. 1967. The breeding bird survey, 1966. U.S. Bureau SportFish. Wildl., Spec. Sci. Rep. Wildl. 102.

Sauer, J. R., J. E. Hines, and J. Fallon. 2004. The North American breeding bird survey, results and analysis 1966 - 2003. Version 2004.1. USGS Patuxent Wildlife Research Center, Laurel, MD.

Small, M.F. and M.L. Hunter. 1988. Forest fragmentation and avian nest predation in forested landscapes. Oecologia 76:62-64.

Soderstrom, B. 1999. Artificial nest predation rates in tropical and temperate forests: A review of the effects of edge and nest site. Ecography. 22(4):455-463.

SYSTAT. 1997. SYSTAT 7.0 for Windows. Version 7.0. SPSS Inc., Chicago, IL.

Thorington, K.K. and R. Bowman. 2003. Predation rate on artificial nests increases with human housing density in suburban habitats. Ecography. 26:188-196.

Vander Haegen, W.M., M.A. Schroeder and R.M. DeGraaf. 2002. Predation on real and artificial nests in shrubsteppe landscapes fragmented by agriculture. The Condor. 104:496-506.

Vickery, P.D., M.L. Hunter Jr. and S.M. Melvin. 1994. Effects of habitat area on the distribution of grassland birds in Maine. Conservation Biology. 8(4):1087-1097.

Wilcove, D. S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. Ecology 66:1211-1214.

Winter, M. and J. Faaborg. 1999. Patterns of area sensitivity in grassland-nesting birds. Conservation Biology 13:1424-1436.

Winter, M., D. H. Johnson, and J. Faaborg. 2000. Evidence for edge effects on multiple levels in tallgrass prairie. The Condor 102:256-226.

Yahner, R.H. and C.G. Mahan. 1997. Effects of logging roads on depredation of artificial ground nests in a forested landscape. Wildlife Society Bulletin. 25(1):158-162.

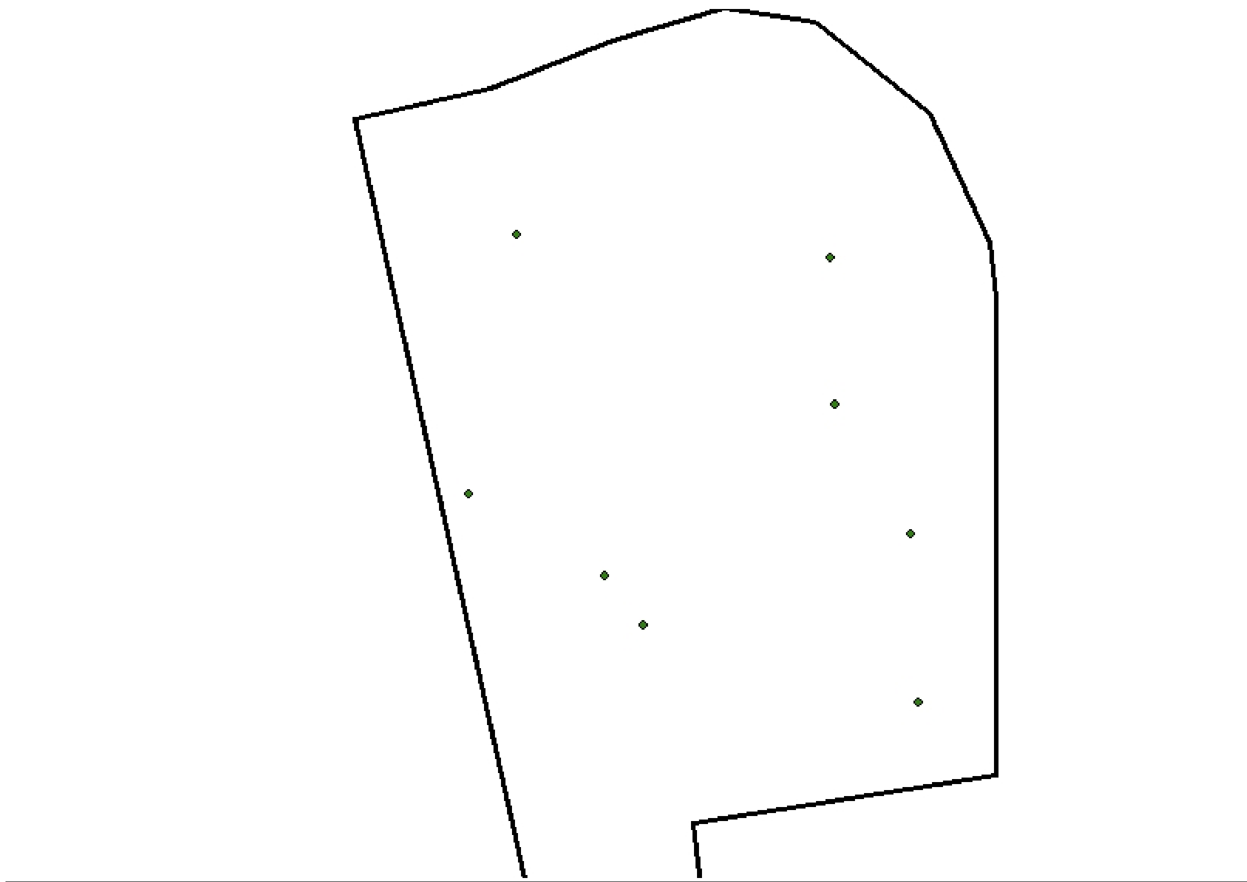
Yahner, R.H. and D.P. Scott. 1988. Effects of forest fragmentation on depredation of artificial nests. Journal of Wildlife Management 52:158-161.

Zar, J.H. 1984. Biostatistical Analysis. Prentice-Hall. 718 pp.

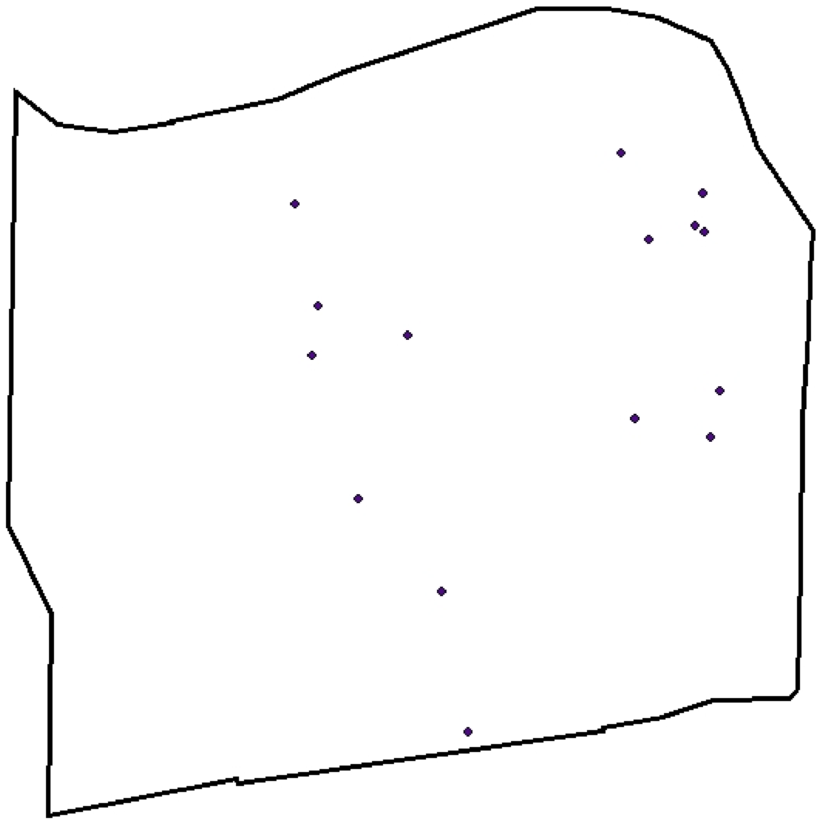
VIII. Appendices

predator	search strategy	urbanization effect	Nest phase preference	edge association	fragmentation
corvid	visual and auditory (3)	increased abundance (13)	egg (7)	more common near edges (10)(11)	high density in fragmented heterogeneous landscapes (1)(14)(15)
raptor	visual and auditory (3)		egg (7)		
other birds	visual and auditory (3)		egg (7)		
coyote	visual, olfactory and auditory (3)	present in urbanized areas, but will shift temporal activity patterns to avoid human contact (8)	nestling (7)	more common near edges (5)(11)	
raccoon	primarily uses olfactory and tactile senses (4)	increased abundance (13)	nestling (7)	more common near edges (5)(11)	high density in fragmented heterogeneous landscapes (12)
skunk	visual, olfactory and auditory (3)	increased abundance (13)	nestling (7)	more common near edges (5)(11)	
other mid-sized mammals	visual, olfactory and auditory (3)	increased abundance (13)	nestling (7)	more common near edges (10)	
mice, shrews and other small mammals	visual, olfactory and auditory (3)	increased abundance (13)	nestling (7)	commonly depredates nests in interior habitats (2)	abundance and depredation rates not influenced by fragmentation (6), depredates nests in both fragmented and continuous landscapes (14)
alligator lizard			egg (7)		
garter snakes	olfactory and heat detection (3)	increased abundance (13)	nestling (7)		abundance and depredtion rates not influenced by fragmentation (6)

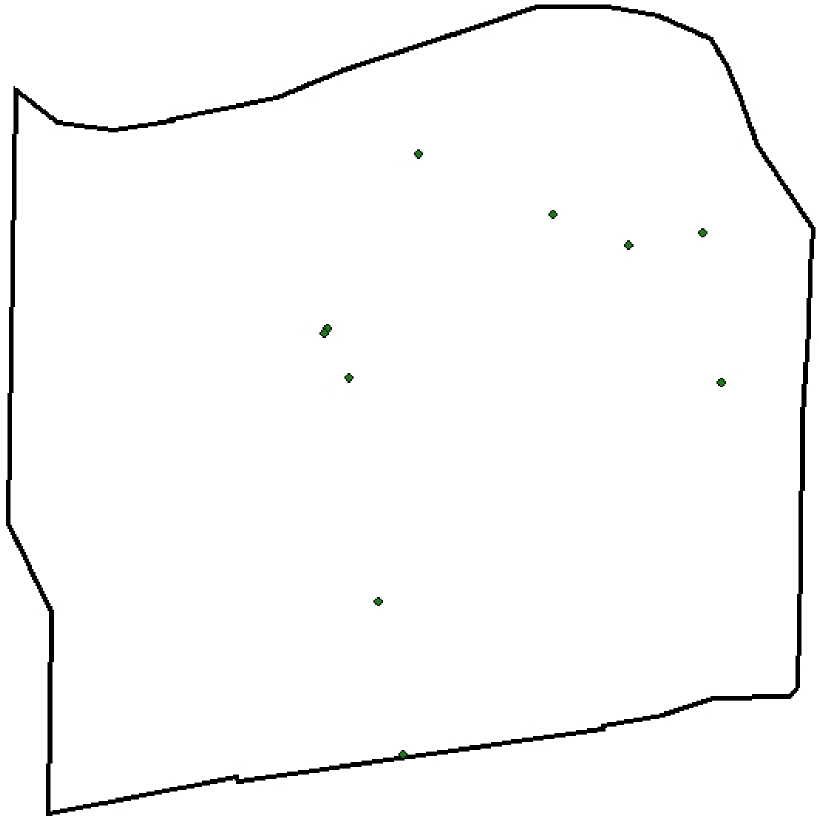
Appendix 1. Supplementary information (not exhaustive) of streaked horned lark potential nest predators compiled from the literature. References: (1) Andren 1992 (2) Ardizzone and Norment 1999 (3) Arnold 2000 (4) Bowman and Harris 1980 (5) Gates and Gysel 1978 (6) Herkert et al. 2003 (7) Luginbuhl et al. 2001 (8) McClennen et al. 2001 (9) Grinder and Krausman 2001 (10) Miller et al. 1988 (11) Niehaus et al. 2003 (12) Oehler and Litvaitis 1996 (13) Thorington and Bowman 2003 (14) Vander Haegen 2002 (15) Yahner and Scott 1998.



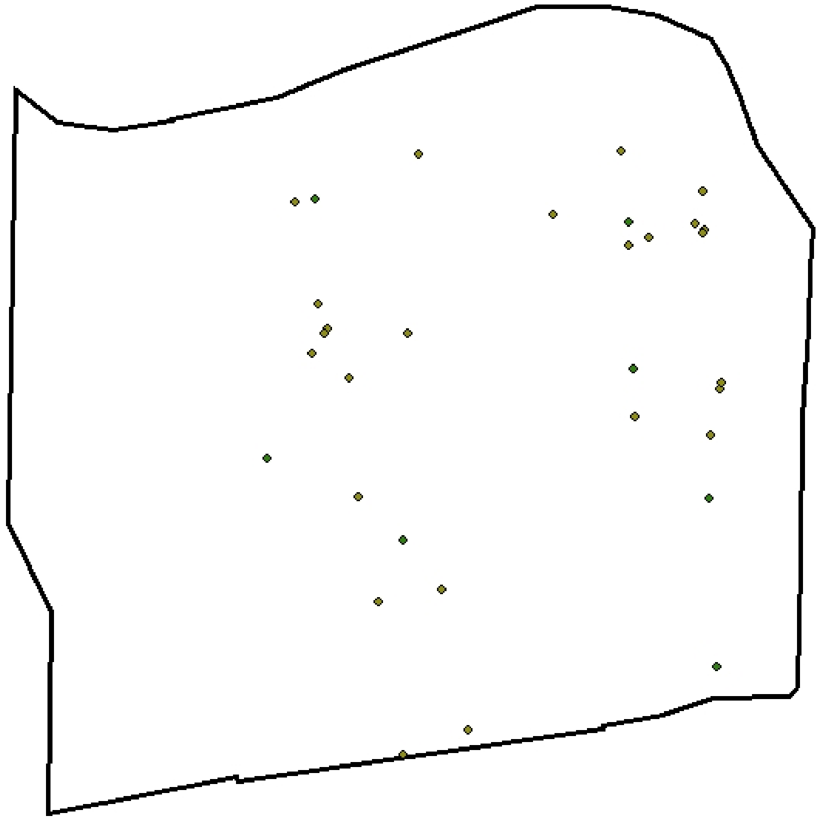
Appendix 2. 2002 13th Division study area (47° 02'N 122° 44'W) 201.72 ha. 2002 nests (n=8). Significant nest cluster not detected (nearest neighbor index ratio = 1.20, p = 0.86)



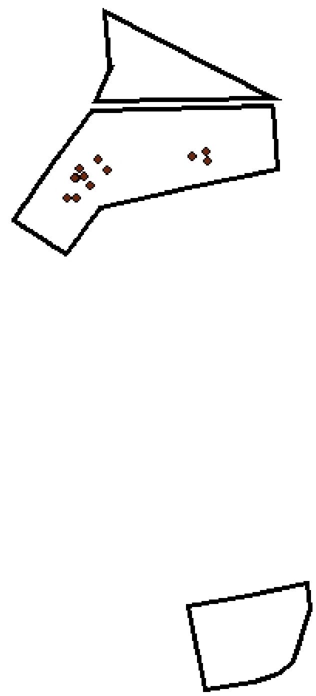
Appendix 3. 2003 13th Division study area (47° 02'N 122° 44'W) 202.6 ha. 2003 nests (n=15). Significant nest cluster not detected (nearest neighbor index ratio = 0.79, p = 0.06).



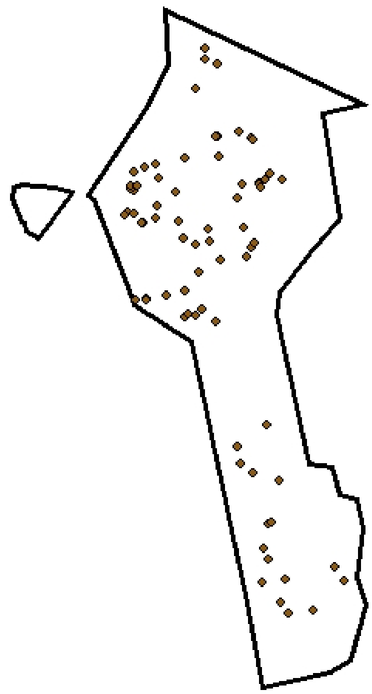
Appendix 4. 2004 13th Division study area (47° 02'N 122° 44'W) 201.72 ha. 2004 nests (n=10). Significant nest cluster not detected (nearest neighbor index ratio = 0.83, p = 0.15).



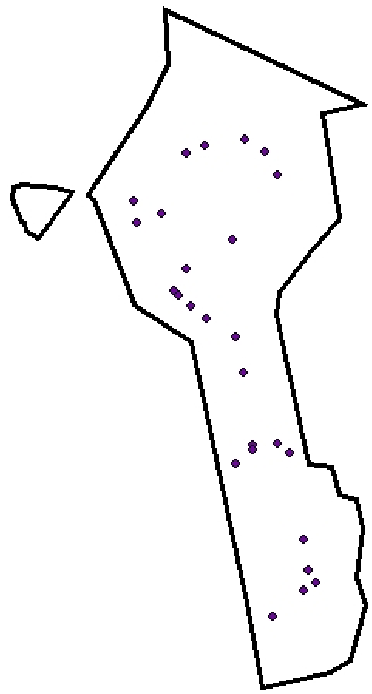
Appendix 5. 2003 &2004 13th Division study area (47° 02'N 122° 44'W) 201.72 ha. 2003 & 2004 nests (n=25). Significant nest cluster detected (nearest neighbor index ratio = .69, p = 0.00)



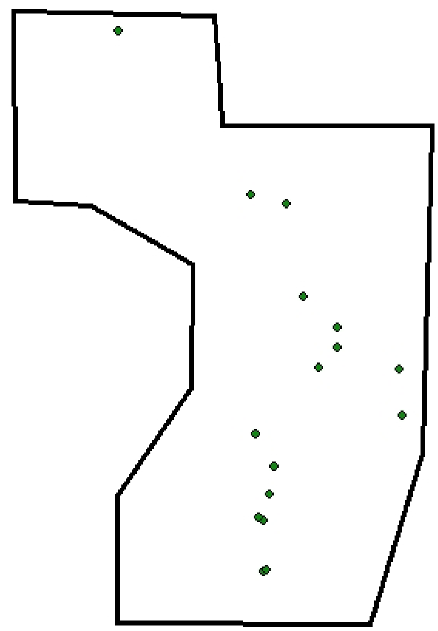
Appendix 6. 2002 Grays Army Airfield study area (47° 08’N 122° 58’W) 65.63 ha. 2002 nests (n=12). Significant nest cluster detected (nearest neighbor index ratio = 0.34, p = 0.00)



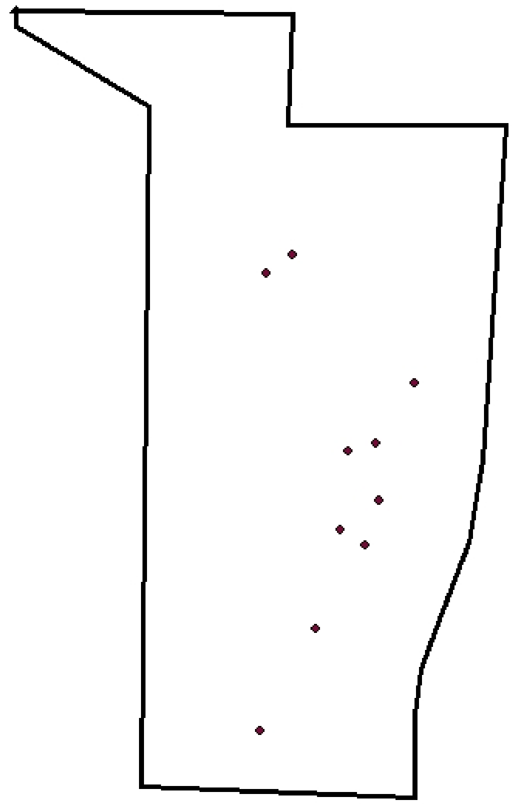
Appendix 7. 2003 Grays Army Airfield study area (47° 08'N 122° 58'W) 160 ha. 2003 nests (n=72). Significant nest cluster detected (nearest neighbor index ratio = 0.67, p = 0.00).



Appendix 8. 2004 Grays Army Airfield study area (47° 08'N 122° 58'W) 160 ha. 2004 nests (n=26). Significant nest cluster detected (nearest neighbor ratio = 0.72, p = 0.00)



Appendix 9. 2002 McChord Air Force Base study area (47° 12'N 122° 45'W) 47.6 ha. 2002 nests (n=16). Significant nest cluster detected (nearest neighbor index ratio = 0.74, p = 0.02).



Appendix 10. 2002 McChord Air Force Base study area (47° 12’N 122° 45’W) 68.8 ha. 2004 nests (n=10). Significant nest cluster detected (nearest neighbor index ratio = 0.66, p = 0.01).