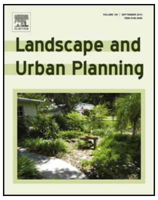
Landscape and Urban Planning 129 (2014) 65–72

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan



Research Paper

Monk parakeet nest-site selection of electric utility structures in Texas

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HIGHLIGHTS

- Monk parakeets often build their bulky twig nests on electric utility structures.
- The nests have caused economic damage.
- There is a nesting preference for electric utility structures with flat, multi-angled surfaces.
- Monk parakeets nest on multi-angled electric stations within small fenced enclosures surrounded by large trees and other tall structures nearby.
- Modifying multi-angled electric stations may reduce monk parakeet nesting.

ARTICLE INFO

Article history:
Received 25 July 2013
Received in revised form 10 March 2014
Accepted 21 April 2014
Available online 24 June 2014

Keywords:
Multi-scaled selection
Myiopsitta monachus
Texas

ABSTRACT

Monk parakeets (*Myiopsitta monachus*) build nests of twigs and use them year-round for both breeding and roosting. In their native South American range, monk parakeets historically nested in the tallest, sturdiest trees in an area. In their North American range, monk parakeets often construct nests on anthropogenic structures, most notably electric utility structures. This nesting behavior causes economic damage. We investigated monk parakeets nesting in Dallas and Tarrant counties, Texas, United States, to identify which features and spatial scales influenced their selection of electric stations as nest sites. Examining 28 pairs of electric stations (with and without nests), we found monk parakeets selected those with flat, multiple surfaces and acute-angled construction within small fenced enclosure areas and surrounded by large canopy trees and taller anthropogenic structures within 100 m. Further analysis of land use and land cover classifications (pavement, building, canopy, grass, and water) on 3 scales (100 m, 625 m, and 1250 m) suggested the surrounding landscape had little impact on monk parakeet nest-site selection. We recommend that electric utility managers who want to prevent monk parakeets from nesting on vulnerable structures conduct a cost–benefit analysis exploring the feasibility of retrofitting or replacing existing construction style elements preferred by monk parakeets. Managers should also consider redesigning future electric station construction to reduce risk of monk parakeets nesting on new structures.

1. Introduction

Where a bird chooses to build its nest is an important decision for its reproductive success (Gill, 1990; Latif, Heath, & Rotenberry, 2012). Avian nest-site choice is often associated with structural stability (reducing destruction by inclement weather, human disturbance, etc.; Coon, Nichols, & Percival, 1981), concealment (decreasing predation risk), and proximity to usable habitat (Gill, 1990). Nest sites vary among avian taxa and occur in and on various substrates, including vegetation, cavities, ground, and anthropogenic structures (Gill, 1990). Furthermore, the placement of nests is often a function of the features surrounding the site at different spatial scales (Wiens, 1989).

Members of the parrot family (Psittacidae) are well-known cavity nesters (Forshaw, 1989). An exception is the monk parakeet (*Myiopsitta monachus*), which constructs enclosed nests of tightly

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http://dx.doi.org/10.1016/j.landurbplan.2014.04.016
0169-2046/

intertwined twigs and uses them year-round for both breeding and roosting (Bucher, Martín, Martella, & Navarro, 1991; Eberhard, 1996; Forshaw, 1989; Martella & Bucher, 1993; Navarro, Martella, & Bucher, 1992). Monk parakeet nests are often joined, forming large nest structures with separate chambers for individual breeding pairs, and those nest structures are often clustered in areas, forming large colonies of many individuals (Forshaw, 1989; Goodfellow, 1977).

The monk parakeet is native to and common in the temperate to subtropical lowlands of Bolivia, Paraguay, Brazil, Uruguay, and Argentina, South America (Lever, 1987). In their native range, monk parakeets nest in open environments with good visibility, usually in a cluster of tall, sturdy structures (i.e., native and non-native trees, and anthropogenic structures) with minimal understory (Burger & Gochfeld, 2005; Eberhard, 1996; Forshaw, 1989; Humphrey & Peterson, 1978). Nonetheless, monk parakeet nests are still vulnerable to predation from a host of different predators (e.g., mammals, birds, and snakes) and their large, heavy nests can fall if not securely placed (Martín & Bucher, 1993; Spreyer & Bucher, 1998). Accordingly, it has been suggested monk parakeets select nesting sites to avoid predators and high winds (Burger & Gochfeld, 2005).

From the late 1960s until 1992, >160,000 monk parakeets were legally imported into the United States (US) as part of the pet bird trade (CITES, n.d.; Davey, Davey, & Athan, 2004). Accidental and intentional releases of monk parakeets in the continental US resulted in naturalized populations in several states, where populations exhibited exponential growth and range expansion (Neidermyer & Hickey, 1977; Pruett-Jones & Tarvin, 1998; van Bael & Pruett-Jones, 1996). By the early 1970s, monk parakeets were reported in at least 30 states (Garber, 1993; Neidermyer & Hickey, 1977; van Bael & Pruett-Jones, 1996). During the 2011–2012 Christmas Bird Count, 2482 monk parakeets were counted in the US; however, the populations were not evenly distributed, with Florida and Texas home to 68% of the monk parakeets recorded (National Audubon Society, n.d.).

Monk parakeets in the US are found predominately in urban and suburban environments (Garber, 1993; Neidermyer & Hickey, 1977; Stevenson & Anderson, 1994; Trimm, 1973), where they build their nest structures in trees and on anthropogenic structures, such as buildings, light poles, communication towers, and electric utility structures (Hyman & Pruett-Jones, 1995; Minor et al., 2012; Roscoe, Zeh, Stone, Brown, & Renkavinsky, 1973; Spreyer & Bucher, 1998). One concern surrounding the growth and range expansion of naturalized monk parakeet populations is their propensity for constructing their nest structures on electric utility structures, particularly the tall steel support towers of substations (changes the voltage levels) and switchyards (connects and disconnects lines on the power grid; hereinafter grouped as electric stations; Fig. 1). When monk parakeet nest material interferes with electric utility equipment, it can cause short circuiting or overheating, resulting in power outages, fires, and electrical service disruption to both residential and business customers (Avery, Greiner, Lindsay, Newman, & Pruett-Jones, 2002; Avery, Lindsay, Newman, Pruett-Jones, & Tillman, 2006; Pruett-Jones, Newman, Newman, & Lindsay, 2005). The economic costs of power outages caused by monk parakeet nest structures include sales revenue loss (including loss of operations for business customers), damaged equipment repair, and power restoration; plus, the cost of repeated nest structure removal (Newman et al., 2008). To illustrate, the estimated costs associated with outages caused by monk parakeet nests in south Florida during 2001 were $585K, affecting >21,000 electricity customers (Avery et al., 2002). Therefore, there is clear economic incentive to prevent monk parakeets from nesting on electric utility structures (Avery et al., 2002).

Currently, there is insufficient information about how the structural characteristics and surrounding land uses at electric stations influence monk parakeet nest-site selection at multiple scales. However, if electric utility companies hope to prevent nesting on their structures, it is important we obtain a better understanding of the structural, vegetative, and landscape variables that promote and dissuade monk parakeets from nesting on electric stations. In this manuscript, we aim to specifically (1) understand how features of the electric stations and their surrounding environment (<100 m) influence monk parakeet nest-site selection and (2) understand how different land use and land cover (LULC) classifications influence nest-site selection at three scales (100 m, 600 m, and 1250 m). Based on monk parakeet natural history, we formulated the following hypotheses: (1) monk parakeets would nest on electric stations if they were the tallest structures in the immediate vicinity; (2) monk parakeets would select electric stations with multiple flat surfaces and acute angles for nest sites to improve stability of nests (Avery et al., 2006); (3) in urban environments without sizable forest patches (i.e., Dallas/Fort Worth Metroplex), monk parakeets would select areas with more trees and canopy cover for nest twigs, food resources, shaded perches, and protective cover; and (4) as highly gregarious birds, monk parakeets would be more likely to nest on an electric station if it was close to an active colony.

2. Methods

2.1. Study area

Our study site encompassed Dallas and Tarrant counties in north central Texas, USA. Both counties are metropolitan areas with high human activity and residential, commercial, and industrial development. Human population density was 1040/km^2 for Dallas County and 809/km^2 for Tarrant County (U.S. Census Bureau, n.d.). Both counties are located in the Blackland Prairie and Oak Woods and Prairies ecoregions of Texas (Texas Parks and Wildlife, n.d.); however, human activity has severely altered the native vegetation. Dominant large canopy tree species in the two counties included native oak (*Quercus* spp.) and elm (*Ulmus* spp.), and non-native Chinaberry (*Melia azedarach*) and Chinese tallow (*Triadica sebifera*). Areas of manicured grass were dominated by non-native St. Augustine (*Stenotaphrum secundatum*) and Bermudagrass (*Cynodon dactylon*).

Monk parakeet populations have been increasing in Texas since the early 1980s (Pruett-Jones et al., 2005). Around the same time, the north Texas power utility, Oncor Electric Delivery (hereinafter called Oncor), experienced an increase of monk parakeets nesting on its electric utility structures in Dallas and Tarrant counties (D. A. Boyle, personal communication, February 17, 2010). During our research, there were 268 electric stations collectively within Dallas ($n = 183$) and Tarrant ($n = 85$) counties.

2.2. Nest-site locations

From June 2010 to August 2012, we located monk parakeet nest structures throughout Dallas and Tarrant counties using sightings provided by Oncor personnel, residents, business owners, local bird club members, ebird.org (http://ebird.org/content/ebird/), and Texbirds (http://listserv.uh.edu/archives/texbirds.html). We defined a monk parakeet nest structure as a twig structure with one or more nesting chamber attended by at least one monk parakeet (see Hyman & Pruett-Jones, 1995). We defined a monk parakeet colony as one or more nest structure on the same substrate or different substrates within 200 m of each other (see Burger & Gochfeld, 2005). When we located a nest structure, we used adaptive cluster sampling (Morrison, Block, Strickland, Collier, & Peterson, 2008) to search for additional nest structures within 200 m and considered them all part of the same colony (see Burger & Gochfeld, 2005). We used a handheld GPS unit to obtain a UTM point for each

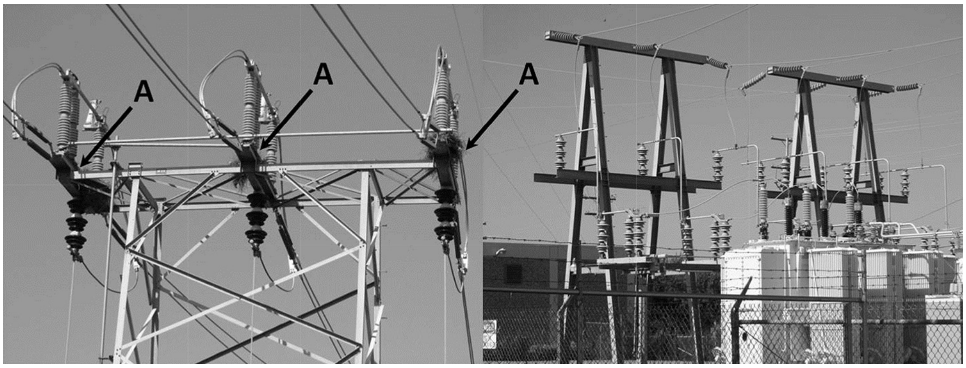

Fig. 1. Examples of two electric station steel support structure towers commonly used on substations and switchyards in Dallas County, Texas, USA. One is constructed with multiple flat surfaces and acute angles (left) with monk parakeet nest structures (A) and the other is constructed with minimal flat surfaces and minimal acute angles without nest structures (right).

individual electric transmission tower, distribution pole, athletic field light, communication tower, and tree with a nest structure, and one UTM point in the center of each electric station's two steel support structures with one or more monk parakeet nest structures. We mapped all UTM points on 2010 NAIP 1 m NC/CIR DOQQ imagery (1-m pixel resolution, 4-band Digital Orthophoto Quarter-Quad aerial imagery) of Dallas and Tarrant counties (Texas Natural Resources Information System, n.d.) in ArcMap 10.0 (Environmental Systems Research Institute, Inc., Redlands, CA, USA). We acquired the UTM points of Oncor electric stations within Dallas and Tarrant counties and mapped them on the same 2010 NAIP 1 m NC/CIR DOQQ imagery in ArcMap 10.0. From the UTM points projected onto the imagery, we created a monk parakeet distribution map (Fig. 2).

2.3. Nest-site characteristics

We identified electric stations with a monk parakeet colony and paired each with its nearest electric station without a colony. In ArcMap 10.0, we measured the distance from each electric station with a monk parakeet colony to its nearest electric station. When we visited electric stations we discovered two distinct construction styles. One construction style consisted of multiple flat girder surfaces with multiple acute angles and other construction styles consisted of rounded surfaces or minimal flat girder surfaces with few, acute angles (see Avery et al., 2006; Fig. 1).

At each electric station, we quantified seven variables at the station and the immediate vicinity (<100 m) that we believed biologically relevant to nesting monk parakeets: (1) "construction style" of the electric station, either multiple flat girder surfaces and acute angles (hereinafter called "multi-angled") or minimal flat girder surfaces and acute angles (hereinafter called "minimal angles"); (2) "nestable height," the height (m) of the actual nest structures or the potential nestable area on each electric station without nests; (3) "fenced area," the area (ha) of the fenced enclosure around each electric station; (4) "taller," the presence of a taller, nestable, anthropogenic structure within 100 m of each electric station; (5) "trees," the presence or absence of a

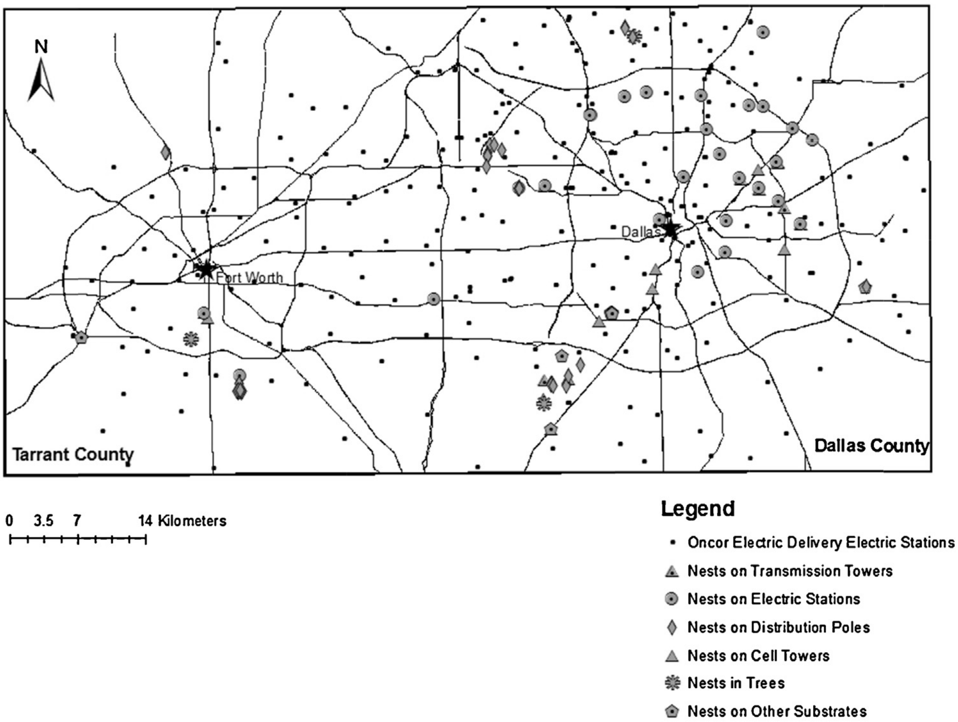

Fig. 2. Distribution of monk parakeet colonies in Tarrant and Dallas counties, Texas, 2010–2012.

Table 1
Twelve candidate models evaluating monk parakeet nest-site selection of electric stations in Dallas and Tarrant counties, Texas, 2010–2012.

Model, including a constant and random variable (paired electric station)		K	AIC$_c$	ΔAIC$_c$	w_i
5	Construction style + nestable height + fenced area + trees + active distance	7	37.300	0.0	0.8211
6	Construction style + nestable height + fenced area + active distance	6	41.250	4.0	0.1139
7	Construction style + trees + active distance	5	43.557	6.3	0.0359
4	Construction style + fenced area + active distance	5	45.907	8.6	0.0111
3	Construction style + active distance	4	46.089	8.8	0.0101
1	Construction style + nestable height + fenced area + trees + tree height + tree distance + taller + active distance	10	47.451	10.2	0.0051
8	Construction style + tree height + active distance	5	49.077	11.8	0.0023
11	Nestable height + fenced area + active distance	5	53.827	16.5	0.0002
9	Nestable height + fenced area + trees + tree height + tree distance + taller + active distance	9	54.940	17.6	0.0001
10	Nestable height + tree height + taller + active distance	6	55.170	17.9	0.0001
2	Construction style	3	65.050	27.8	<0.0001
12	Construction style + trees + taller	5	65.817	28.5	<0.0001

Variable notation: construction style, either multiple flat girder surfaces and acute angles or minimal flat girder surfaces and acute angles; nestable height, the height (m) of the actual nest structures or the potential nestable area on each electric station; fenced area, area (ha) of fenced enclosure around each electric station; trees, average number of nearest large canopy trees (diameter at breast height [dbh] > 30 cm) in each quadrant within 100 m; tree height, average height (m) of nearest large canopy trees (dbh > 30 cm) in each quadrant within 100 m; tree distance, average distance (m) of nearest large canopy trees (dbh > 30 cm) in each quadrant within 100 m; taller, absence or presence of a taller nestable anthropogenic structure within 100 m; and active distance, distance (m) to nearest electric station with active monk parakeet colony.

canopy tree with diameter at breast height (dbh) >30 cm in each quadrant within 100 m of each electric station; (6) "tree height," the height (m) of the nearest canopy tree with dbh >30 cm in each quadrant within 100 m of each electric station; (7) "tree distance," the distance (m) to the nearest canopy tree with dbh >30 cm in each quadrant within 100 m of each electric station. We added an eighth variable, "active distance," that accounted for the distance (m) from each electric station to the nearest electric station with an active monk parakeet colony. We measured all distances from the center between each electric station's two steel support tower structures where monk parakeets most often nested.

Using point-centered quarter sampling method, we identified the nearest tree with dbh >30 cm in each quadrant within 100 m of each electric station (see Cottam, Curtis, & Hale, 1953). We measured heights and distances with an InSight 400LH laser hypsometer and rangefinder (Opti-Logic, Tullahoma, TN, USA). We used a handheld GPS unit to obtain UTM points of the trees and taller nestable anthropogenic structures. We projected all UTM points onto our 2010 NAIP 1 m NC/CIR DOQQ imagery in ArcMap 10.0 and measured distances from the center between each electric station's two steel support structures to the trees, taller nestable anthropogenic structure, nearest electric station with a monk parakeet colony, and nearest electric station without a colony. We also calculated the area of the fenced enclosures around each electric station.

2.4. Land use and land cover classification

To understand the influence of the surrounding landscape on monk parakeet selection of electric stations as nest sites, we categorized urban LULC into five general classifications (pavement, building, canopy, grass, and water) on the 2010 NAIP 1 m NC/CIR DOQQ imagery using supervised Image Classification (Gorte, 1999) in ArcMap 10.0 Spatial Analyst Tool. The LULC classifications were clearly distinguishable; therefore, we used visual interpretation to identify pavement, buildings, canopy, grass, and water. The pavement classification included all paved areas, such as roads, parking lots, and walkways, as well as the herbicide-treated, graveled areas within the fenced electric stations. All residential, commercial, and industrial structures comprised the building classification. The canopy classification contained all tree and shrub cover. All manicured lawns and native and non-native grass areas comprised the grass classification. The water classification consisted of all lakes, ponds, rivers, creeks, and swimming pools. In ArcMap 10.0, we buffered concentric circles centered around the two steel structure towers of each electric station with and without nest structures and calculated hectare values for each LULC classification (pavement, building, canopy, grass, and water) on three spatial scales: 100 m, 625 m, and 1250 m. We chose the 1250 m scale because it was half the average 2.5 km distance between electric stations. For the second scale we chose 625 m, which was half the distance of the 1250 m scale. We chose the 100 m scale to investigate the immediate area around each electric station. Examining multiple scales in relation to the species and research question can offer broader insight to the animal–resource relationship (Litvaitis, Titus, & Anderson, 1996). Evaluating resources at different spatial scales also reduces the potential effects from subjectively defining what is perceived to be available to an animal (Porter & Church, 1987).

2.5. Data analyses

To understand how the features of electric stations ($n = 28$ pairs) and their surrounding environment (within $\leq$100 m) influenced monk parakeet nest-site selection, we developed 12 candidate models (Table 1) with the eight variables discussed above (construction style, nestable height, fenced area, taller, trees, tree height, tree distance, and active distance). We looked for correlations among variables and removed one of two variables with >0.70 correlation. During ground surveys, we discovered electric stations had two different construction designs (Fig. 1). We then developed 11 candidate models (Table 2) with all variables except construction style to examine selection of electric stations with multi-angled construction ($n = 23$ pairs). Fenced area and tree distance were highly correlated; therefore, we removed tree distance from this analysis.

To understand how LULC influenced monk parakeet nest-site selection of electric stations at different landscape scales (100 m, 625 m, and 1250 m), we developed seven candidate models (Supplementary Table 1) with the five LULC classifications (pavement, building, canopy, grass, and water) to explain the presence or absence of nest structures on paired electric stations ($n = 28$). We then developed eight candidate models (Table 3) to investigate the same three scales around electric stations with multi-angled construction with nest structures ($n = 23$) paired with their nearest electric stations with multi-angled construction without nest structures.

For all analyses, we fit each model using generalized linear mixed model (GLMM) with paired electric stations as a random effect, a binomial distribution (nest or no nest), and a log link using Package 'lme4' in R x64 2.15.0 (R Development Core Team,

Table 2
Eleven candidate models evaluating monk parakeet nest-site selection of electric stations with multiple flat surfaces and acute-angled construction in Dallas and Tarrant counties, Texas, 2010–2012.

Model, including a constant and random variable (paired electric station)		K	AIC$_c$	ΔAIC$_c$	w_i
10	Nestable height + Fenced + Taller	5	52.64	0	0.5866
1	Nestable height + Trees + Tree height + Fenced + Taller + Active	8	55.05	2.406	0.1762
11	Fenced + Taller	4	55.38	2.742	0.1489
9	Fenced	3	56.96	4.323	0.0675
5	Trees + Active	4	60.79	8.152	0.0100
8	Trees + Taller	4	62.7	10.06	0.0038
3	Nestable height + Trees + Active	5	63.52	10.88	0.0025
2	Active	3	65.11	12.47	0.0011
7	Nestable height + Tree height + Taller + Active	6	64.11	11.47	0.0019
6	Tree height + Active	4	64.89	12.25	0.0013
4	Nestable height	3	71	18.36	<.0.0001

Variable notation: nestable height, the height (m) of the actual nest structures or the potential nestable area on each electric station; fenced area, area (ha) of fenced enclosure around each electric station; trees, average number of nearest large canopy trees (diameter at breast height [dbh] > 30 cm) in each quadrant within 100 m; tree height, average height (m) of nearest large canopy trees (dbh > 30 cm) in each quadrant within 100 m; tree distance, average distance (m) of nearest large canopy trees (dbh > 30 cm) in each quadrant within 100 m; taller, absence or presence of a taller nestable anthropogenic structure within 100 m; and active distance, distance (m) to nearest electric station with active monk parakeet colony.

2012). We used an information-theoretic approach and evaluated the models using Akaike's Information Criterion (AIC) corrected for small sample size (AIC$_c$), the relative difference to the smallest AIC$_c$ (ΔAIC$_c$), and Akaike weights (w_i) to select the most parsimonious predictive model (Burnham & Anderson, 2002). We disregarded models >4 AIC$_c$ units from the best model, considering them implausible representations of the data (Burnham & Anderson, 2002). We calculated parameter estimates and 95% confidence intervals (CIs) for the parameters of the best and competing models, and considered a parameter relevant if its CI did not include zero (Burnham & Anderson, 2002).

3. Results

From June 2010 to August 2012, we located 56 monk parakeet colonies containing 235 nest structures. Forty-two (75%) of the nest colonies were on electric utility structures and 28 of those were on electric stations, with an average of 4.4 nest structures per station (*SD* = 3.1, range 1–11). At the electric stations, monk parakeets built their nest structures on the steel support structure towers (Fig. 1) at an average height of 13.4 m (*SD* = 3.0 m, range 5.0–24.0 m), usually within and around the C-beam supports and their intersecting flat-surfaced, multi-angled girders (Fig. 1).

3.1. Selection at the nest-site

Our best competing models for selection of features at the electric station and surrounding vicinity (≤100 m) included construction style, nestable height, fenced area, trees, and active distance (Table 1, models 5 and 6). Based on the model-averaged estimates, construction style ($\hat{\beta} = 5.224$, 95% CIs [0.809, 9.639]), presence of a large canopy trees ($\hat{\beta} = 2.089$, 95% CIs [0.264, 3.914]), and proximity to an active colony ($\hat{\beta} = 0.003$, 95% CIs [0.001, 0.005]) were relevant predictors of monk parakeet selection of electric

Table 3
Eight candidate models determining influence of five land use-land cover classifications at three scales on monk parakeet nest-site selection of electric stations with multiple flat surfaces and acute-angled construction in Dallas and Tarrant counties Texas, 2010–2012.

Model, including a constant and random variable (paired electric station)		K	AIC$_c$	ΔAIC$_c$	w_i
100-m scale					
8	Canopy + pavement	4	64.8	0.0	0.6129
3	Canopy + pavement + building	5	68.1	3.3	0.1185
5	Pavement + building	4	68.1	3.3	0.1177
7	Null model	2	68.4	3.5	0.1040
2	Grass + canopy + pavement + building	6	71.8	7.0	0.0184
6	Water + grass + canopy + building	6	72.0	7.1	0.0174
4	Water + grass + canopy	5	73.3	8.5	0.0089
1	Water + grass + canopy + pavement + building	7	76.0	11.2	0.0022
625-m scale					
7	Null model	2	68.4	0.0	0.8150
4	Water + grass + canopy	5	73.7	5.3	0.0567
5	Pavement + building	4	73.9	5.6	0.0503
8	Canopy + pavement	4	74.0	5.6	0.0490
3	Canopy + pavement + building	5	77.2	8.8	0.0099
2	Grass + canopy + pavement + building	6	77.4	9.0	0.0089
6	Water + grass + canopy + building	6	77.4	9.0	0.0089
1	Water + grass + canopy + pavement + building	7	81.3	12.9	0.0013
1250-m scale					
7	Null model	2	68.4	0.0	0.6575
4	Water + grass + canopy	5	71.8	3.4	0.1208
5	Pavement + building	4	72.4	4.0	0.0871
8	Canopy + pavement	4	73.1	4.7	0.0623
6	Water + grass + canopy + building	6	74.9	6.5	0.0256
2	Grass + canopy + pavement + building	6	74.9	6.5	0.0255
3	Canopy + pavement + building	5	75.6	7.3	0.0173
1	Water + grass + canopy + pavement + building	7	78.6	10.2	0.0039

stations as nest sites. Monk parakeets selected electric stations with multi-angled construction (with a nest $\bar{x} = 82\%$, without a nest $\bar{x} = 25\%$) over minimum angle construction and electric stations surrounded by more large trees (with a nest $\bar{x} = 3.4$, without a nest $\bar{x} = 3.0$; Appendix 1). The average distance from an electric station with a monk parakeet nest to another electric station with a nest was further ($\bar{x} = 4.0$ km) than the average distance from an electric station with a nest to an electric station without a nest ($\bar{x} = 2.2$ km; Appendix 1).

For the second analysis of features at the station and surrounding vicinity we excluded the construction style variable and examined the remaining seven variables for only electric stations with multi-angled construction with monk parakeet nest structures ($n = 23$) paired with their nearest electric station with multi-angled construction without nest structures. Our best models included nestable height, fenced area, presence of large canopy trees, proximity to an active colony, and presence of a taller nestable anthropogenic structure (Table 2, models 10, 1, and 11). Based on their model-averaged estimates of these variables, only fenced area ($\hat{\beta} = -2.713$, 95% CIs [−4.701, −0.725]) and taller nestable anthropogenic structure ($\hat{\beta} = 2.659$, 95% CIs [0.1331, 1.028]) were relevant predictors of monk parakeet nest-site selection of multi-angled electric stations. Monk parakeets selected electric stations with a smaller fenced area (with a nest $\bar{x} = 2964\,\text{m}^2$, without a nest $\bar{x} = 15,945\,\text{m}^2$) and the presence of a taller nestable anthropogenic structure within 100 m (with a nest $\bar{x} = 90\%$, without a nest $\bar{x} = 80\%$; Appendix 1).

3.2. LULC 3-scale analyses

The LULC of the urban landscape surrounding electric stations with and without monk parakeet nest structures consisted of building (27–34%), pavement (24–32%), grass (22–29%), and canopy (10–22%; Appendix 2). There was very little water ($\leq$2%) present around electric stations either with or without monk parakeet nests. We compared seven models containing the five LULC classifications at three scales (100 m, 625 m, and 1250 m) buffered around each electric station ($n = 28$ pairs) with nest structures paired with its nearest electric station without nest structures, and found the null model was the best model at all three scales (Supplementary Table 1, model 7). We compared eight models of the five LULC classifications at three scales buffered around each electric station ($n = 23$) with multi-angled construction and nest structures paired with its nearest electric station with multi-angled construction without nest structures. We found the null model was the best model for both the 625-m and 1250-m scales (Table 3, model 7). At the 100-m scale, our best competing models contained the variables canopy, pavement, and building (Table 3, models 3, 5, 7, and 8). However, only the amount of pavement ($\hat{\beta} = 2.772$, 95% CIs [0.326, 5.218]) and the area covered by canopy ($\hat{\beta} = 1.829$, 95% CIs [0.148, 3.510]) appeared to be relevant predictors of monk parakeet nest-site selection of electric stations. Monk parakeets selected areas with more pavement (used $\bar{x} = 31\%$, unused $\bar{x} = 25\%$) and canopy cover (used $\bar{x} = 16\%$, unused $\bar{x} = 11\%$) within 100 m of an electric station (Appendix 2).

4. Discussion

Monk parakeets have proven themselves an adaptable species capable of nesting on various substrates, both in their native and introduced ranges (Avery et al., 2002; Burger & Gochfeld, 2005; Humphrey & Peterson, 1978; Hyman & Pruett-Jones, 1995; Minor et al., 2012). Parakeets appeared to nest on electric utility structures considerably more than large canopy trees or other anthropogenic structures (i.e., athletic field lights and communication towers) prevalent on our study site in Dallas and Tarrant counties. Our results suggest monk parakeets selected electric stations as nest sites based on features and LULC at and within 100 m of the station.

As we predicted, monk parakeets selected electric stations with multi-dimensional surfaces consisting of flat surfaces and multiple acute angles. A likely explanation for their use of multi-angled construction is this design improves stability of nests (Avery et al., 2006; Newman et al., 2008). In addition to multi-angled construction, this design involves small spaces that provide perfect insertion points for securing the first nest twigs (Harrison, 1973). Monk parakeets in our study did not appear to select the electric station steel support towers because they were the tallest structures in the immediate vicinity. In fact, contrary to our predication, monk parakeets selected to nest on electric stations with taller anthropogenic structures in close proximity. The selection of areas with tall structures may provide more perches and mimic the nest-site selection of monk parakeets in their native range, where they nest in open areas with a cluster of a few large trees (Burger & Gochfeld, 2005).

In addition to construction style, as predicted we found monk parakeets preferred electric stations with more large canopy trees and more canopy cover within 100 m of the stations. Large canopy trees are an important resource for monk parakeets, as the trees provide nest twigs, food items, shaded perches, and protective cover. Monk parakeets obtain the majority of their nest twigs as live wood, cutting them by rotating their beaks back and forth to sever from the trees (Roscoe et al., 1973), and then carry the twigs in their beaks back to the nest site. Oaks and elms were common large canopy trees surrounding the electric stations, and during our research we observed monk parakeets utilizing these tree species for nest twigs, food items, and perching locations (J. E. Reed, unpublished data). The proximity to large canopy trees and increased canopy cover around nest sites may also be important for fledglings that need cover from potential predators, such as birds of prey (e.g., *Buteo jamaicensis*, *Accipiter cooperii*, and *A. striatus*) and feral domestic cats (*Felis catus*; J. E. Reed, unpublished data).

Contrary to our prediction, monk parakeets did not place their nests on electric stations closest to other electric stations with nesting colonies. In fact, occupied stations did not appear to be evenly distributed across the study area. Most of the colonies on our study site were clustered and <7 km apart. This spacing of nesting colonies could suggest monk parakeets place their colonies to reduce competition for resources around the nest site. Additionally, there were five colonies >7 km from the nearest colony. The presence of these peripheral colonies may be explained by long-distance dispersal or independent introductions, or both. Goncalves da Silva, Eberhard, Wright, Avery, and Russello (2010) found genetic evidence for frequent long-distance dispersal (~100 km) of monk parakeets in the US, which differed from previous estimates of shorter dispersal distances ($\leq$2 km) of the species in its native range (Bucher et al., 1991; Martín & Bucher, 1993). Alternatively, peripheral colonies may have started from independent releases known to have occurred across the two counties since the 1980s (B. J. Simmons, personal communication, March 19, 2010; R. Bell, personal communication, July 11, 2010).

Our results suggest the surrounding landscape did not influence monk parakeet selection of electric stations as nest sites at the larger scales (625 m and 1250 m). Within 100 m of electric stations with monk parakeet nest structures, however, proportions were greater for paved areas correlating positively with monk parakeet nest-site selection. Either this is a spurious correlation or biologically meaningful for water availability and usage. We never observed monk parakeets utilizing the water of lakes, ponds, rivers, creeks, swimming pools, or bird baths (J. E. Reed, unpublished data). Instead, pavement may be important to urban monk parakeets for water pooling. We often observed monk parakeets drinking from and bathing in pooled water on the pavement after lawn watering and rains.

5. Conclusions

As monk parakeet populations continue to grow and expand their range, the probability of future nesting on electric utility structures increases. Researchers have recently begun investigating multiple variables and scales to determine monk parakeet distribution or nest-site selection in urban, non-native ranges. Several large-scale studies in Spain found monk parakeets associated with high tree and human population density (Munoz & Real, 2006; Rodriguez-Pastor et al., 2012; Strubbe & Matthysen, 2009). A smaller scale study in south Florida, USA, found monk parakeets associated with both high and low human-populated residential areas (Newman et al., 2008). Another small-scale study in Chicago, Illinois, USA, found monk parakeet distribution there may be negatively affected by a large human population density (Minor et al., 2012). Our multi-variable, multi-scale examination of electric stations as nest sites revealed that electric stations of flat, multi-angled construction within small fenced enclosures surrounded by large canopy trees, ≥1 taller anthropogenic structure, and pavement appear to make suitable nesting sites for monk parakeets in urban landscapes.

Altering the amount of pavement and anthropogenic structures around electric utility stations in the urban environment may not be a plausible solution to prevent monk parakeets from nesting on the electric station structures. However, increasing the fenced footprint of an electric station and reducing canopy cover and number of large canopy trees around the station might be a viable strategy to reduce the risk of nesting on an electric substation. Modifying or retrofitting multi-angled construction styles is likely the most effective strategy to reduce the probability of monk parakeets nesting on vulnerable electric substations, yet it may not be an economically viable solution. We recommend electric utility managers conduct a cost–benefit analysis to compare the expense of modifying or replacing electric stations with the realized and potential costs from monk parakeet induced power outages. Nonetheless, it is clear that electric utility companies should strongly consider utilizing a minimum angle design for future electric station construction in a passive effort to reduce the risk of future monk parakeet nesting.

Acknowledgments

Funding and support for this research was provided by Luminant Environmental Research Program and Oncor Electric Delivery. We thank anonymous reviewers for their critiques and editing suggestions to improve this manuscript. We extend special thanks to Oncor Electric Delivery personnel for logistical assistance at electric stations. We thank undergraduate student A. Hudson for her hard work and dedication assisting with electric station surveys.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2014.04.016.

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