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ROOST CHARACTERISTICS OF INVASIVE MYNAS IN SINGAPORE

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Abstract: We identified factors affecting the selection of roost sites by invasive white-vented (*Acridotheres javanicus*) and common (*A. tristis*) mynas in urban Singapore. In addition, we examined the effects of experimentally manipulating canopy cover and food abundance on roosting populations. Multivariate analysis, binary logistic regression, and the Akaike Information Criterion (AIC) showed that mynas selected roost trees with dense canopies that were closer by 603.5 m to food centers and surrounded by 2.6% more vegetation than random non-roost trees. Based on Wilks' Lambda, we ranked canopy density as the most important variable, followed by proximity to food centers. Canopy density and food abundance manipulation experiments showed that although both resulted in a decrease in the number of roosting mynas, canopy density reduction had a greater effect, as predicted by the roost-selection model. The canopy of existing roosts can be thinned to alleviate the problem caused by roosting mynas. Stringent control of refuse at food centers also should be implemented to make such areas less attractive to mynas. Planting large and densely covered trees, particularly angsana (*Pterocarpus indicus*) and tropical apple (*Eugenia grandis*), near food centers should be avoided by park and urban managers.

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Mynas are invading urban areas throughout the world, particularly in Asia and Australia (Pell and Tidemann 1997, Feare and Craig 1998). The most common species of mynas in Singapore are white-vented and common mynas (Ward 1968, Kang 1989). Mynas are not indigenous to Singapore. White-vented mynas were probably introduced there around 1924, while common mynas extended their natural range from the Malay Peninsula to Singapore in 1936 (Gibson-Hill 1949). Mynas thrive in areas of human habitation such as cities and gardens (King et al. 1975). In urban areas, they rely on human refuse as a supply of food (Kang 1989). The urbanization of the Singapore landscape has been accompanied by a dramatic rise in myna populations. In 2000, there were about 168,000 white-vented and 27,000 common mynas on the main island of Singapore (H. C. Lim, National University of Singapore, unpublished data).

Large roosting populations of white-vented and common mynas are a source of noise pollution in residential parts of Singapore and other parts of Asia and Australia (MacDonald 1973, Feare and Craig 1998). Mynas roost communally throughout the year, and these roosts can house several hundred individuals (Gadgil and Ali 1975). Mynas call loudly when entering and leaving their communal roosts—even at night when they are startled (C. J. Hails, Ministry of National Development, Singapore, unpublished data). This chorus of hundreds of mynas can be loud and has prompted many complaints from residents to authorities in Singapore (S. P. Tee, National Parks Board of Singapore [Nparks], personal communication). Their fecal droppings pollute reservoirs, walkways, cars, buildings, and pedestrians. Other negative ecological effects stemming from communal roosts include substantial damage to trees from both limb-breaking and accumulation of droppings, unpleasant odors, hazards to aircraft when roosts are near airfields, and growth of fungi (e.g., *Histoplasma capsulatum*) in feces that may cause human respiratory ailments (Brough 1969, Vining and Weeks 1974).

Consequently, many people regard these large communal bird roosts as a major nuisance (Garner 1978). Attempts have been made in many parts of the world to disperse or eradicate roosts of many bird species by shooting, poisoning, or scaring them (e.g., with balloons), but all with limited success (Cummings 1979, Mott 1980). The use of short-term control measures (e.g., bioacoustics, chemical repellents, shooting) to eliminate myna roosts in Singapore has been largely unsuccessful (Kang et al. 1990).

Many wildlife management programs have shifted their emphasis toward ecological

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approaches to vertebrate pest control, based on understanding the ecology of the pest species, specifically its habitat and food requirements (Dyer and Ward 1977, Kang et al. 1990). Because mynas have highly diverse habitat requirements, a control program aimed at removing all resources such as food, nesting, or roosting sites would be logistically unrealistic (Kang et al. 1990). Habitat modification is considered a more feasible long-term approach to roost management (C. J. Hails, Ministry of National Development, Singapore, unpublished data). Once the habitat has been modified to deter roosting birds, maintaining the changes to the habitat would be logistically more feasible in terms of the personnel and equipment needed to carry out the maintenance. Roost-site preferences of mynas and other bird species have been studied with the aim of manipulating roost habitats. Structural characteristics of roost trees (e.g., tree canopy density and girth of the trunk) that differentiated them from non-roost trees have been identified for some species of birds such as blackbirds (*Agelaius* spp.; Lyon and Caccamise 1981), turkeys (*Meleagris* spp.; Rumble 1992), and mynas (*Acridotheres* spp.; Kang and Yeo 1993). Other factors including proximity to food sources, drinking water, and human structures, combined with the structural characteristics of the habitat to influence the selection of roosting sites by birds such as starlings (*Sturnus* spp.; Kuroda 1973), blackbirds (Meanly 1965), and mynas (Kang and Yeo 1993).

The impact of the large roosting myna population on the public in Singapore has prompted the search for a long-term management solution. Previous studies have been conducted to determine the roost-site preference of mynas in Singapore (Kang and Yeo 1993; C. J. Hails, Ministry of National Development, Singapore, unpublished data). However, these studies were not comprehensive, as they did not include other crucial factors such as access to food resources and the percentage of different types of land use around the roost.

The purpose of our study was to comprehensively determine the myna roost site characteristics in Singapore with the aim of formulating sound, ecologically based management strategies for the long-term control of roosting sites. First, we identified the most important factors affecting the selection of roost trees by mynas. Second, we compared the effect of experimentally manipulating the 2 most important roost determinants (canopy cover and food abundance) on the number of roosting mynas.

STUDY AREA

We conducted this study on the main island of Singapore (01°37′N, 103°75′E). The island has an area of 648 km^2 and a human population of 3.9 million (Singapore Department of Statistics, http://www.singstat.gov.sg/). The annual precipitation was 2,353 mm, and average daily humidity was 84%. The temperature ranged annually from the average minimum of 24 °C to the average maximum of 31 °C (Meteorological Service Singapore, http://www.gov.sg/metsin/).

METHODS

Identification of Roost-Site Characteristics

Field research for the roost-site-selection component of the study was carried out in Singapore from 20 April to 5 June 2001. We obtained a list of possible roost sites from Nparks, the Agri-food and Veterinary Authority of Singapore, and personal contacts. We defined a roost site as an area in which a concentration of roost trees was found. We surveyed all the potential sites from the list and selected 30 sites where more than half of the ground directly under the trees was covered by bird feces and which residents confirmed were active roost sites. We reconfirmed the sites by actual sightings during subsequent field surveys conducted between 1800 and 2000. As both species of mynas commonly roost together (Feare and Craig 1998), we assumed that the roost-site characteristics of both species were the same, and selected roosts that were occupied by either 1 or both species of mynas. The total number of mynas at each site ranged from approximately 1,000 to 17,000. At each roost site, we randomly chose 1 roost tree for measurement. A non-roost tree was defined as a tree not used by roosting mynas. We randomly chose 30 non-roost trees from maps obtained from the *Singapore Street Directory* (Anonymous 1998). If any of these randomly chosen trees were used by roosting mynas, then another tree not used by roosting mynas was chosen randomly instead for measurements. All roost and non-roost trees were planted by Nparks in a similar fashion.

Using Wee (1989), we identified the trees to species. We measured total tree height, clear bole height, canopy height, canopy radius, and diameter at breast height. We estimated canopy volume using the Arbor Structure method (Melville et al. 1999) and estimated canopy density using a densiometer (Lemmon 1957). We estimated the distance from the tree to the nearest food center and railway track from the *Singapore Street Directory*

(Anonymous 1998). Food centers are low-rise open-air buildings with numerous food stalls that operate throughout the day. All railway tracks measured were above ground level. We estimated the distance from the tree to the nearest road, lamppost, adjacent tree (this tree would be a roost tree if the measured tree was a roost tree, and vice versa), and building by pacing (Stoddard and Stoddard 1987). The roads varied in width from 1 to 3 lanes. Lampposts were of similar wattage and height from the ground. We measured the surface area of the nearest building by measuring its length (using a measuring tape) and height (using a clinometer) and multiplying the 2 figures. Illumination was measured at night between 2000 and 2100 using a photometer. We used human activity index (HAI) as a measure of the potential human disturbance at the sites (Gorenzal and Salmon 1995). The components were the distance from the tree to the nearest building, road and railway track, tree-height class, the number of vehicles and parking activities on the nearest road, and the number of pedestrians on the nearest walkway. We estimated the components for the HAI at all sites for 10 minutes between 2000 and 2100. We estimated the percentage of different land use within a 500-m circular plot around each tree from maps in the *Singapore Street Directory* (Sodhi et al. 1999). The categories were built environment (areas covered by buildings), open space (areas covered by hard standings, car parks, roads), vegetation (areas covered by natural and managed vegetation, which included trees, shrubs and grass, such as fields, parks, and golf courses), and water (areas covered by natural bodies of water as well as artificial ponds and lakes).

Statistical Analysis

We performed Kolmogorov-Smirnov tests to determine whether the values for each variable were normally distributed. Variables measured in percentages were arcsine-transformed while the remaining nonnormal variables were log-transformed before proceeding with correlative statistical analyses.

We performed Pearson's product–moment correlation test to identify highly correlated variables ($r > 0.50$). We excluded these variables from further analysis. We used stepwise discriminant function analysis (DFA; SAS Institute [1990]) to identify the most important variables discriminating the roost sites, which we subjected to binary logistic regression in different permutations. We obtained the percentage concordance, Somers' D correlation statistic, and log-likelihood. Concordance indicates the degree of accuracy of classification by the models and is calculated by pairing the observations with the different response values and in each case determining whether the model predicted a higher probability for the observed response than the opposite response. Somers' D is a measure of the predictive ability of the model, and its value lies between 0 and 1, with higher values indicating a better predictive ability.

We used the log-likelihood values obtained from logistic regression to determine the most suitable model for identifying roost sites using AIC (Burnham and Anderson 2001). The AIC values were corrected for small sample size (determined by the fact that the number of observations was <40 times the number of explanatory variables) and converted into AIC_c. The AIC_c values for each model were rescaled by subtraction of the lowest AIC_c value and termed delta AIC_c (Δ_i). Delta AIC_c values allow a comparison of the relative strengths of the different models, where a Δ_i of 0-2 indicates models have approximately equal support and a Δ_i >10 indicates models have essentially no support. The Akaike weights (w_i) were calculated from the delta AIC_c values. Akaike weights more precisely indicate the relative weight of evidence in favor of the models. The AIC ranking process reflects a process of model selection based on the optimal trade-off between bias and variance, and the number of parameters used in a model. The delta AIC_c values, the Akaike weights, Somers' D statistic, and the percentage of concordance of the models were factored into our final selection of the best model.

We performed linear DFA (SAS Institute 1990) to determine the accuracy in classifying the roost and random trees based on the variables selected for the final model. A random subset of 30 observations (15 roost and 15 non-roost) was used to generate the model and a second subset of 30 observations (15 roost and 15 non-roost) was used as test data for the linear DFA. The scaled coefficients for the selected variables (i.e., coefficients multiplied by the range of their respective independent variables, and rescaled by dividing by the largest value) were calculated from the binary regression table and the raw data.

Tree Species Preference

We performed a chi-square test (SAS Institute 1990) to determine whether there was a tree species preference by roosting mynas. Random trees were used as expected frequencies. To satisfy the requirements for this test, we pooled angsana and tropical apples in 1 category and all the other trees into "Others" category.

Canopy-Density Manipulation Experiment

We conducted the canopy-density manipulation experiment from 22 June to 2 August 2001. We selected 2 roost sites, Jurong East (JE) and Woodlands (WD), to carry out the experiment and 2 reference roost sites, Bedok (BK) and Sin Ming (SM).

Jurong East was situated in a residential area close to high-rise buildings, a 4-lane road, a food center (23 m away), and a wet market (25 m away). A wet market is an open-air market that sells fresh food. All 25 roost trees were tropical almonds (*Terminalia catappa*). The estimated total roost population was 9,000 mynas.

Woodlands was situated in a mixed residential and commercial area close to a highway (380 m away), a 4-lane road (1 m away), and a food center (97 m away). The roost trees comprised 14 angsanas along 1 road and 11 purple millettias (*Millettia atropurpurea*) along another road. The estimated population was 14,000 mynas.

Sin Ming was situated in an industrial area close to low-rise buildings and a 4-lane road (3 m away). The nearest food center was 600 m away. All 4 roost trees were tropical apples. The estimated population was 1,200 mynas. Bedok was situated in a residential area close to high-rise buildings, a busy 4-lane road (2 m away), a food center (128 m away), and a wet market (130 m away). All 9 roost trees were tropical apples. The estimated population was 4,500 mynas.

The distances between the 4 sites ranged from approximately 12 to 24 km (calculated from the *Singapore Street Directory* [Anonymous 1998]). This is more than the maximum known distance (6 km) traveled by mynas from a roost in Singapore (Kang 1992). Mynas probably did not move between all 4 sites.

The canopies of all 25 roost trees at JE and all 25 roost trees at WD were pruned from 1 July to 3 July 2001 to reduce density. We counted the number of mynas roosting on 1 of 25 pruned trees each at JE and WD. We conducted 3 counts before and 12 counts after the tree was pruned. The number of roosting mynas was calculated by subtracting the total number that flew away from the total number that landed during our observation period. At JE, WD, and SM, 1 observer counted the birds at each site. At BK, 2 observers counted on different days. The observations were always carried out from the same position in fine weather from 1800 to 2000. We estimated the tree-canopy density on days that the mynas were counted. We compared the number of roosting mynas before and after the start of the experiment using a nonparametric Mann-Whitney 2-sample test (SAS Institute 1990).

FOOD-ABUNDANCE MANIPULATION EXPERIMENT

We conducted the food manipulation experiment from 6 August to 12 September 2001. We used the same experimental sites, JE and WD. The 2 reference sites chosen were Bedok (BK) and Potong Pasir (PP). Sin Ming was not selected for this experiment because the nearest food center was situated outside the 1-km^2 study area.

Potong Pasir was situated in a mixed residential and commercial area close to a 4-lane road. The nearest food center was 105 m away. The roost comprised 7 angsana trees. The estimated population was 4,000 mynas. The distances between the 4 sites ranged from approximately 10 to 24 km. Hence, mynas probably did not move between all 4 sites.

A 1-km^2 area around each experimental roost site was kept free of garbage for the 5-week experimental period. This sampling area was larger than the home range of white-vented mynas (0.30 km^2) and common mynas (0.10 km^2) in Singapore (Kang 1989). Additional cleaning workers were deployed to the study area to increase the cleaning efficiency there during this period. All waste food found within this area was removed and all bins were checked frequently to ensure that they were closed and not overfilled. We set up 12 10-m circular plots inside the 1-km^2 area and counted the number of food particles seen once a week from 0700 to 0900 and from 1400 to 1600 for 3 weeks before and 5 weeks after the start of the experiment at the 4 sites. The plots were 250 m apart and evenly distributed around the 1-km^2 area. We defined a food particle as either a single discrete item such as an apple, or a collectable unit such as a handful of rice.

In food centers, leftover food on tables and floors and in open garbage bins attracts many birds. At JE and WD, the bins in the food center within the 1-km^2 study area were covered during the 5-week experimental period. By deploying more cleaners to these centers, waste food was removed more efficiently from the tables, thus shortening the time that food was left unattended

Table 1. Occurrence of different species of 30 myna roost trees and 30 randomly selected non-roost trees in Singapore, 20 Apr–5 Jun 2001.

Tree species		Roost trees		Non-roost trees	
Common name	Scientific name	Number of trees	Proportion of trees	Number of trees	Proportion of trees
Angsana	*Pterocarpus indicus*	14	0.47	3	0.10
Tropical apple	*Eugenia grandis*	11	0.37	3	0.10
Broad-leaved mahogany	*Swietenia macrophylla*	2	0.07	3	0.10
African mahogany	*Khaya grandifolia*	1	0.03	1	0.03
Tropical almond	*Terminalia catappa*	1	0.03	0	0.00
Yellow flame	*Peltophorum pterocarpum*	1	0.03	5	0.17
Droopy cassia	*Cassia spectabilis*	0	0.00	1	0.03
Great frangipani	*Plumeria obtusifolia*	0	0.00	1	0.03
Mango	*Mangifera indica*	0	0.00	1	0.03
Pink tecoma	*Tabebuia pallida*	0	0.00	1	0.03
Raintree	*Samanea saman*	0	0.00	5	0.17
Salam	*Eugenia polyantha*	0	0.00	2	0.07
Tamalan	*Dalbergia oliveri*	0	0.00	1	0.03
Umbrella tree	*Schefflera actinophylla*	0	0.00	1	0.03
Wild cinnamon	*Cinnamomum iners*	0	0.00	2	0.07

on tables. Based on our observations of foraging mynas, the number of garbage bins with and without lids and the number of improper disposal sites at the food centers might be important variables. Therefore, we recorded these variables once a week at 0900 and 1400 for 3 weeks before and 5 weeks after the start of the experiment. Improper disposal sites were sites on the floor where dishes had been left unattended.

After the pruning experiment, the mynas at JE and WD moved to unpruned trees <20 m away and roosted there. To avoid confounding the effects of the 2 experiments, we selected 1 unpruned tree at each site and counted the number of roosting birds using the method already stated. Using a Mann-Whitney 2-sample test, we compared the number of roosting mynas, bins with lids and without lids, improper disposal sites, and food particles in the circular plots before and after the start of the experiment.

RESULTS

Tree Species Composition

Angsana and tropical apple trees were most frequently used and preferred by mynas as roosts ($\chi^2 = 24.09$, df = 1, $P = 0.001$; Table 1).

Identification of Roost-Site Characteristics

Mynas roosted on tall, thick trees that had large amounts of dense foliage, with an average canopy volume of 149.1 m^3 and an average canopy density of 95.6%. These trees generally were located 603.5 m closer to food centers and were surrounded by 2.6% more vegetation within a 500-m radius than random non-roost trees (Table 2).

Total tree height was highly correlated to clear bole height and diameter at breast height (r = 0.916 and 0.827, respectively). Clear bole height

Table 2. Characteristics of 30 myna roost trees and 30 randomly selected trees measured 20 Apr–5 Jun 2001 in Singapore.

Tree and habitat characteristics	Roost site Mean	Roost site SE	Random site Mean	Random site SE
Total tree height (m)	19.1	1.3	11.6	1.1
Clear bole height (m)	8.5	0.5	6.1	0.7
Canopy height (m)	10.6	1.0	5.4	0.5
Diameter at breast height (cm)	57.2	4.9	38.1	4.5
Canopy radius (m)	6.3	0.5	5.5	0.6
Canopy volume (m^3)	149.1	19.9	65.7	11.1
Canopy density (%)	95.6	0.4	87.2	1.3
Distance to nearest tree (m)	12.6	1.0	12.4	1.4
Distance to nearest road (m)	2.6	0.6	6.5	2.2
Distance to nearest lamp-post (m)	12.9	1.6	11.8	2.1
Distance to nearest building (m)	132.0	18.5	138.3	24.5
Distance to nearest food center (m)	545.0	133.8	1,148.5	164.3
Dimension of nearest building (m^2)	1,486.0	257.6	798.9	203.1
Illumination (lux)	9.8	1.9	5.0	1.0
Human activity index	8.0	1.4	9.8	1.2
Built environment (%)	33.0	1.8	32.7	2.9
Open space (%)	31.4	1.0	31.4	1.5
Vegetation (%)	34.0	1.7	31.4	3.0
Water (%)	3.0	1.0	4.7	1.6

Table 3. Results of stepwise discriminant function analysis of measurements of tree and habitat characteristics of 30 myna roost trees and 30 randomly selected trees, 20 Apr–5 Jun 2001 in Singapore.

Variable	Partial R^2	F[a]	P[b]	Wilks' Lambda
Canopy density	0.4322	44.149	≤0.001	0.57
Proximity to nearest food center	0.1349	8.886	0.004	0.49
Vegetation	0.1850	12.710	0.001	0.40
Distance to nearest road	0.1450	9.329	0.004	0.34
Illumination	0.0850	5.014	0.029	0.31
Surface area of nearest building	0.0600	3.381	0.072	0.29
Water	0.0484	2.644	0.110	0.28
Clear bole height	0.0230	1.199	0.279	
Canopy volume	0.0322	1.697	0.199	
Distance to nearest tree	0.0028	0.145	0.705	
Distance to nearest lamppost	0.0304	1.602	0.211	
Distance to nearest building	0.0013	0.069	0.794	
Disturbance index	0.0047	0.239	0.627	
Open space	0.0244	1.277	0.264	

[a] *F*-statistic for entering and removing variables.
[b] $P > F$ is the probability level for the *F*-statistic.

and diameter at breast height also were highly correlated ($r = 0.800$). Canopy volume was correlated to canopy height and radius ($r = 0.898$ and 0.862, respectively). Canopy height and radius were correlated ($r = 0.552$). Built environment and vegetation were highly negatively correlated ($r = –0.838$). We removed the variables total tree height, diameter at breast height, canopy radius, canopy height, and built environment from the data set used for stepwise DFA, and retained the variables clear bole height, canopy volume, and vegetation that were significant to the functions of a roost. For instance, we hypothesized that clear bole height gave a better measure of the level of protection from ground predators offered by a tree to a roosting bird than total tree height. The most important variables for myna roosts identified by stepwise DFA were canopy density, proximity to food centers, and vegetation. Less important variables were proximity to roads and degree of illumination (Table 3).

Binary logistic regression on canopy density, proximity to food, and vegetation (Model A) showed a high degree of concordance (96.6%). The same analysis using the variable illumination instead of vegetation (Model B) showed less concordance (Table 4). The concordance indicates the degree of accuracy of classification by the models. The correlation statistic, Somers' D, which is a measure of the predictive ability of the model, was highest for Model A (0.93; Table 4).

The Akaike Information Criterion showed that the best model, Model A, had an Akaike weight of 96.3%, with the next best model, Model B, in which vegetation was replaced by illumination, having essentially no support from the data (Akaike weight = 2.1%; Table 4). The models were ranked according to their delta AIC_c values and weights, with the best model having the lowest delta AIC_c value and the greatest weight.

Table 4. Model selection statistics to determine myna roost site selection variables based on 30 roost trees and 30 randomly selected trees in Singapore, 20 Apr–5 Jun 2001.

Model	Variables[a]	Number of parameters, Kb	Concordance[c]	Log-likelihood[d]	Somers' D[e]	Delta AIC_c[f]	Akaike weight[g]
A	*CD + TF + VG*	4	0.966	–13.94	0.93	0.00	0.963
B	*CD + TF + Illum*	4	0.941	–17.78	0.88	7.69	0.021
C	*CD + TF + TR*	4	0.931	–19.02	0.86	10.17	0.006
D	*CD + VG*	3	0.937	–20.11	0.87	10.04	0.006
E	*CD + TF*	3	0.912	–20.73	0.83	11.29	0.003

[a] Variable: CD = Canopy density, Illum = illumination, TF = proximity to food center, TR = proximity to road, VG = vegetation.
[b] Number of parameters = number of variables + a fitted intercept (*I*).
[c] Concordance is an indication of the degree of accuracy of classification by the models. It is calculated by pairing the observations with the different response values and in each case determining whether the model predicts a higher probability for the observed response than for the opposite response.
[d] Log-likelihood was derived from logistic regression.
[e] Somers' D correlation statistic is a measure of the predictive ability of the model. The range is between 0 and 1, with larger values indicating a better predictive ability.
[f] The Akaike Information Criterion (AIC) values for each model were determined from log-likelihood values and the number of parameters used. The AIC values were corrected for small sample size and converted into AIC_c, which were rescaled and termed delta AIC_c (D_i). Delta AIC_c values allow a comparison of the relative strengths of the different models, where a D_i of 0-2 indicates models have approximately equal support and a D_i >10 indicates models have essentially no support.
[g] The Akaike weights were calculated from the delta AIC_c values. Akaike weights more precisely indicate the relative weight of evidence in favor of the models.

Table 5. Canopy density (%) and number of mynas roosting on trees before and after the start of the canopy density manipulation experiment, 22 Jun–2 Aug 2001 in Singapore.

	Canopy density				No. of roosting mynas			
	Before start of experiment		After start of experiment		Before start of experiment		After start of experiment	
Roost site	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Jurong East	93.2	0.3	78.6*	2.7	371.00	5.51	61.67*	16.28
Woodlands	97.6	0.1	83.5*	1.8	725.33	18.46	354*	51.38
Sin Ming (reference)	97.5	0.0	97.5ns	0.0	284.33	14.19	154.42*	19.48
Bedok (reference)	94.8	0.1	94.6ns	0.2	514.00	24.00	449.5ns	18.59

* $P < 0.05$, based on Mann-Whitney 2-sample test.
ns Not significant, based on Mann-Whitney 2-sample test.

Linear discriminant function analysis of Model A showed that the model correctly identified 100.0% of 15 roost trees and 80.0% of 15 non-roost trees. Non-roost trees were defined as trees not used by roosting mynas. Model B identified 100.0% (roost) and 73.3% (non-roost), while Model C correctly identified 86.7% (roost) and 73.3% (non-roost).

Model A was selected as the best model to describe roost characteristics, based on the strong agreement between the Akaike weight, the Wilks' Lambda statistics, the degree of concordance, and the linear DFA findings. The evidence ratio (based on the Akaike weights) for the best model (Model A) versus the second best model (Model B) was 0.96/0.02 = 48. Model B therefore had 48 times less support than the best model.

Based on Wilks' Lambda, the most important variable was canopy density, followed by proximity to food centers and vegetation (Table 3). The scaled coefficients (i.e., coefficients scaled against the parameter range) supported this ranking of the variables, with canopy density (scaled coefficient = 1.00) ranked twice as important as proximity to food (0.51) and vegetation (0.51).

Canopy Density Manipulation Experiment

The canopy densities of the observed trees were significantly reduced by an average of 14.6% and 14.1% after pruning at JE (Mann-Whitney U-test, $z = 2.528$, df = 3, 12, $P = 0.012$) and WD ($z = 2.533$, df = 3, 12, $P = 0.011$), respectively. The canopy densities of the observed trees remained unchanged at sites SM and BK ($z = -0.413$, $z = 1.556$, $P = 0.679$, $P = 0.120$, df = 3, 12). The roosting myna numbers following canopy density reduction dropped substantially by 83% at JE ($z = 2.526$, df = 3, 12, $P = 0.012$), 51% at WD ($z = 2.526$, df = 3, 12, $P = 0.012$), and 46% at SM ($z = 2.093$, df = 3, 12, $P = 0.036$). No change occurred in the number of roosting mynas at BK ($z = 1.372$, df = 3, 12, $P = 0.170$; Table 5).

Food Abundance Manipulation Experiment

The number of roosting mynas decreased significantly by 68% at JE ($z = 2.245$, df = 3, 12, $P = 0.025$) after manipulating the food abundance. The roosting numbers at WD dropped insignificantly ($z = 0.808$, df = 3, 12, $P = 0.419$). The roosting numbers at PP increased significantly by 19% ($z = -2.093$, df = 3, 12, $P = 0.036$), but BK showed no significant change ($z = 0.434$, df = 3, 12, $P = 0.664$; Table 6).

The number of bins with lids increased (from [mean ± SE] 12.1 ± 0.9 to 25.3 ± 1.3) and those without lids decreased (from 39.0 ± 2.9 to 16.1 ± 1.1) significantly at JE ($z = -2.100$, $z = 2.087$, $P = 0.036$, $P = 0.037$, df = 3, 5), but the decrease in the number of improper disposal sites (from 0.6 ± 0.2 to 0.1 ± 0.2) was not significant ($z = 1.633$, df = 3, 5, $P = 0.103$). The number of bins with lids at WD increased (from 7.9 ± 1.7 to 37.8 ± 1.6) significantly ($z = -2.100$, df = 3, 5, $P = 0.036$), the numbers of bins without lids decreased (from 20.4 ± 0.6 to 16.6 ± 1.4), and improper disposal sites (1.7 ± 0.4 to 0.1 ± 0.1) decreased significantly ($z = 2.087$, $z = 2.224$, $P = 0.037$, $P = 0.026$, df = 3, 5). There was no significant change in the mean numbers of bins with lids (from 6.2 ± 0.1 to 6.0 ± 0.0), bins without lids (from 19.4 ± 1.1 to 20.9 ± 1.1), and disposal sites (from 0.1 ± 0.1 to 0.7 ± 0.5) at the reference sites PP ($z = 1.033$, $z = -0.900$, $z = -0.406$, $P = 0.302$, $P = 0.368$, $P = 0.685$, df = 3, 5), and in the mean numbers of bins with lids (from 2.1 ± 0.6 to 1.1 ± 0.3), bins without lids (from 33.4 ± 6.3 to 9.3 ± 1.4), and disposal sites (from 2.4 ± 0.8 to 0.5 ± 0.2) at BK ($z = 1.518$, $z = 1.063$, $z = 1.833$, $P = 0.129$, $P = 0.288$, $P = 0.068$, df = 3, 5).

The mean number of food particles per 10-m circular plot seen at JE decreased significantly (from 0.5 ± 0.1 to 0.0 ± 0.0; $z = 2.139$, df = 3, 5, $P = 0.033$), but not at WD (from 0.2 ± 0.1 to 0.1 ± 0.0; $z = 1.800$, df = 3, 5, $P = 0.072$), and the reference sites PP (from 1.2 ± 0.4 to 0.5 ± 0.1) and BK (from 0.2 ± 0.1 to 0.2 ± 0.2; $z = 0.900$, $z = 1.222$, $P = 0.368$, $P = 0.222$, df = 3, 5).

DISCUSSION

Canopy density was identified as the most important factor for roost site selection by mynas. This has been reported for blackbirds and European starlings (*Sturnus vulgaris*; Lyon and Caccamise 1981) and for house crows (*Corvus splendens*; Peh and Sodhi 2002). In Singapore's tropical climate, strong winds occur frequently during monsoons from December to March and from June to September. Thunderstorms are frequent during the inter-monsoon months of April to May and October to November (Meteorological Service Singapore, http://www.gov.sg/metsin/). Dense tree canopies may offer protection from rain, wind, dust, and exposure, and provide concealment for the birds. Trees with dense canopies also could have a dense twig and perch configuration preferred by some species of birds. For example, Lyon and Caccamise (1981) reported that the canopy of blackbird and starling roosts consistently had compact vertical twig arrangements. During this study, we observed mynas congregating in tight bunches and roosting close to each other. Good and Johnson (1978) observed that brown-headed cowbirds (*Molothrus ater*) roosted in a compact formation.

The proximity of roost sites to food centers was identified as the next most important factor in roost-site selection of mynas. This has been observed for gray starlings (*Sturnus cineraceus*; Kuroda 1973) and European starlings (Caccamise and Morrison 1988). Mynas rely on scraps of human refuse as either an unpredictable or a regular supply of food (Kang 1989). Uncovered trash bins and discarded food particles usually are found in food centers. Food centers are not enclosed and mynas, are free to enter and forage. We observed many mynas taking food from these food centers. The proximity of food sources to roosts makes intuitive sense since the shorter distance traveled daily by the birds could mean longer feeding time and less energy expended during foraging flights.

Another important factor in roost-site selection was the proportion of vegetation around the roost trees. Grass and scrub are the main natural foraging grounds for mynas, where they feed on arthropods and annelids (Jalil 1985, Kang 1989). Mynas also take fruit and nectar and catch insects from trees (Feare and Craig 1998). Thus, the presence of vegetation surrounding the roosts is important as a natural food source for the mynas.

Table 6. Number of roosting mynas before and after the start of the food abundance manipulation experiment, 6 Aug–12 Sep 2001 in Singapore.

	Before start of experiment		After start of experiment	
Roost site	Mean	SE	Mean	SE
Jurong East	748.33	26.42	236.83*	67.84
Woodlands	461.00	5.57	258.08ns	68.73
Potong Pasir (reference)	713.67	54.11	847.25*	10.91
Bedok (reference)	402.00	21.96	388.25ns	7.67

* $P < 0.05$, based on Mann-Whitney 2-sample test.
ns Not significant, based on Mann-Whitney 2-sample test.

Both the canopy-density and food-abundance manipulation experiments resulted in a drop in myna roosting numbers at the observed trees at both experimental sites, providing a useful empirical validation of the habitat-selection model. Canopy-density manipulation resulted in a significant decrease in myna numbers at both sites, whereas the food-abundance manipulation led to a significant decrease at only 1 site. Furthermore, canopy-density manipulation resulted in a bigger drop in roosting numbers at both sites than food-abundance manipulation. It appears that canopy-density manipulation had a greater effect on myna roosting numbers than food-abundance manipulation. This finding agrees with the results of the first part of the study, which identified canopy density as a more important factor than proximity to food centers.

However, not all the changes in myna roosting numbers could be attributed to the experiments. For instance, the roosting numbers at the observed tree from SM decreased and the roosting numbers at the observed tree from PP increased, even though no manipulations occurred at these sites. We suggest several factors that could have affected the roosting numbers.

First, the populations of smaller roosts have been found to be less stable than those of bigger roosts. Mahabal et al. (1990) observed more pronounced daily fluctuations in the roosting numbers in smaller roosts than in bigger roosts, by as much as –25% to +18.2%. Sin Ming was a smaller roost than the other 3 sites in terms of total roosting population and number of roost trees. At PP, the observed tree was 150 m away from half of the roost trees in this site and separated by tall buildings. Effectively, the observed tree was isolated and could be considered part of a small roost. Second, the roost trees at SM were further from the food center than at BK. The first part of our study suggests that roost trees further from food centers were less attractive to roosting birds, perhaps decreasing their site fidelity. Last, although mynas exhibit considerable site fidelity, they have been observed to use several roost sites (Eiserer 1984, Kang 1992).

The number of food particles at WD did not change significantly. This could be a possible explanation for the insignificant change in roosting numbers in WD. Both the drop in the number and percentage of uncovered bins were greater for JE site than for WD site. The slightly reduced number of bins at WD could still provide enough waste food for the mynas at WD.

Twenty percent of the non-roost trees were not classified by linear DFA as non-roost trees and may be suitable as roosts. We observed angsana trees with similar structural and habitat characteristics to roost trees that were not used as roosts. These observations suggest that roosting sites currently may not be a limiting factor in Singapore. Furthermore, we observed that the new roost trees used by the mynas were of the same species and situated less than 20 m away from the old roost trees.

MANAGEMENT IMPLICATIONS

This study clearly demonstrates that several important variables exist in determining the selection of roost sites by mynas. This suggests that management of roosting mynas in Singapore must be approached from various angles and has to be a sustained effort for as long as necessary to keep the numbers of these birds low.

The canopy of existing roosts can be thinned to alleviate the problem caused by roosting mynas. However, this measure may be a short-term remedy, and could result in displaced birds establishing new roosts nearby, since mynas exhibit considerable site fidelity (Eiserer 1984), and roost sites may not be limited in Singapore. Modifications to roost trees or their surrounding habitat therefore have to be made to all trees throughout the entire area of concern.

Stringent control of refuse at food centers should be implemented to make the proximity of such areas less attractive to roosting mynas. Trash bins should be covered and the floors kept free of food. Situating the food centers in enclosed air-conditioned buildings could restrict access by mynas and limit their human food source. Admittedly, our study showed limited support for this factor, but it is difficult to completely control and manipulate food abundance.

Our data suggest a preference among roosting mynas for angsana and tropical apple trees, which are tall and have dense canopies with deep crowns. Planting of these trees in urban areas, particularly near food centers, should be avoided. It is possible that rows of monospecific trees of similar height are preferred by roosting mynas, since the trees could form a continuous canopy. Our study sites WD, JE, and LV showed this type of structure. New areas should be planted with trees of different species and height to prevent continuous canopies from forming. Trees with flattened, less dense canopies, or with leaves that close at night such as raintrees (*Samanea saman*) should be considered.

Although roosting mynas have been shown in our study to be repelled to some extent by the pruning of tree canopies, we cannot predict their long-term response to such treatments. They may become acclimatized to thinner canopies and persist roosting in pruned trees. However, during our experiments, the mynas readily moved to new unpruned trees, as these were available. Therefore, a possible long-term approach would be to complement heavy pruning at affected sites with the planting of suitable and attractive roost trees (such as angsana and tropical apple trees) in other areas where the impact of roosts on humans would be minimal. These new areas should be located close to the original sites to increase the likelihood of usage by roosting mynas.

However, none of these control measures should be taken alone, since each seems to have a limited effect on the roosting behavior of mynas. The implementation of sustained, multifaceted, ecologically sound management systems, based on the modification of existing roost sites and the habitat around them, combined with new approaches to urban landscape planning, offer the best hope of effective long-term control of pest bird roosts, such as those of mynas, in tropical urban areas. Because mynas are abundant in cities throughout Asia and Australia, our study has implications throughout this region and perhaps for other communally roosting birds that have become nuisances in urban areas.

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LITERATURE CITED

ANONYMOUS. 1998. The Singapore street directory. SNP Publishing, Singapore.

BROUGH, T. 1969. The dispersal of starlings from woodland roosts and the use of bio-acoustics. Journal of Applied Ecology 6:403–410.

BURNHAM, K. P., AND D. R. ANDERSON. 2001. Kullback-Leibler information as a basis for strong inference in ecological studies. Wildlife Research 28:111–119.

CACCAMISE, D. F., AND D. W. MORRISON. 1988. Avian communal roosting: a test of the patch-sitting hypothesis. Condor 90:453–458.

CUMMINGS, J. L. 1979. An evaluation of 4-amino-pyridine for dispersing winter blackbird roosts in Colorado. Proceedings—Bird Control Seminar 8:258–263.

DYER, M. T., AND P. WARD. 1977. Management of pest situations. Pages 267–300 *in* J. Pinowski and S. C. Kendeigh, editors. Granivorous birds in ecosystems. Cambridge University Press, New York, USA.

EISERER, L. A. 1984. Communal roosting in birds. Bird Behaviour 5:61–80.

FEARE, C., AND A. CRAIG. 1998. Starlings and mynas. Christopher Helm (A & C Black), London, United Kingdom.

GADGIL, M., AND S. ALI. 1975. Communal roosting habits of Indian Birds. Journal of the Bombay Natural History Society 72:716–727.

GARNER, K. M. 1978. Management of blackbird and starling winter roost problems in Kentucky and Tennessee. Proceedings of the Vertebrate Pest Conference 8:54–59.

GIBSON-HILL, C. A. 1949. An annotated checklist of the birds of Malaya. Bulletin of the Raffles Museum 20:1–299.

GOOD, H. B., AND D. M. JOHNSON. 1978. Non-lethal blackbird roost control. Pest Control 46:14–18.

GORENZAL, W. P., AND T. P. SALMON. 1995. Characteristics of American crow urban roosts in California. Journal of Wildlife Management 59:638–645.

JALIL, A. K. 1985. Feeding ecology of two species of mynas (Sturnidae: (*Acridotheres* sp.)) in Singapore. Thesis, National University of Singapore, Singapore.

KANG, N. 1989. Comparative behavioural ecology of the mynas, (*Acridotheres tristis*) (Linnaeus) and (*A. javanicus*) (Cabanis) in Singapore. Dissertation, National University of Singapore, Singapore.

———. 1992. Radiotelemetry in an urban environment: a study of mynas (*Acridotheres* spp.) in Singapore. Pages 633–641 *in* I. G. Priede and S. M. Swift, editors. Wildlife telemetry: remote monitoring and tracking of animals. Ellis Horwood, Chichester, United Kingdom.

———, J. B. SIGURDSSON, C. J. HAILS, AND J. J. COUNSILMAN. 1990. Some implications of resource removal in the control of mynas (*Acridotheres* spp.) in Singapore. Malayan Nature Journal 44:103–108.

———, AND V. Y. Y. YEO. 1993. Roost site selection and the waking and roosting behaviour of mynas in relation to light intensity. Malayan Nature Journal 46:255–263.

KING, B., M. WOODCOCK, AND E. C. DICKINSON. 1975. A field guide to the birds of South-east Asia. Collins, London, United Kingdom.

KURODA, N. 1973. Fluctuation of winter roosting flock of *Sturnus cineraceus* at Koshigaya and the roost change to Omatsu in summer. Miscellaneous Reports of the Yamashina Institute for Ornithology 7:34–55.

LEMMON, P. E. 1957. A new instrument for measuring forest overstory density. Journal of Forestry 55:667–668.

LYON, L. A., AND D. F. CACCAMISE. 1981. Habitat selection by roosting blackbirds and starlings: management implications. Journal of Wildlife Management 45:435–443.

MACDONALD, J. D. 1973. Birds of Australia. A. H. & A. W. Reed, Chartswood, New South Wales, Australia.

MAHABAL, A., D. B. BASTAWADE, AND V. G. VAIDYA. 1990. Spatial and temporal fluctuations in the populations of common myna (*Acridotheres tristis*) (Linnaeus) in and around an Indian city. Journal of the Bombay Natural History Society 87:392–398.

MEANLY, B. 1965. The roosting behavior of the red-winged blackbird in the southern United States. Wilson Bulletin 77:217–228.

MELVILLE, H. I. A. S., A. E. CAULDWELL, AND J. DU P. BOTHMA. 1999. A comparison of two techniques for estimating tree canopy volume. South African Journal of Wildlife Research 29:113–117.

MOTT, D. F. 1980. Dispersing blackbirds and starlings from objectionable roost sites. Proceedings of the Vertebrate Pest Conference 9:38–42.

PEH, K. S.-H., AND N. S. SODHI. 2002. Characteristics of nocturnal roosts of house crows in Singapore. Journal of Wildlife Management 66:1128–1133.

PELL, A. S., AND C. R. TIDEMANN. 1997. The ecology of the common myna in urban nature reserves in the Australian Capital Territory. Emu 97:141–149.

RUMBLE, M. A. 1992. Roosting habitat of Merriam's turkeys in the Black Hills, South Dakota. Journal of Wildlife Management 56:750–759.

SAS INSTITUTE. 1990. SAS/STAT user's guide. Version 6. Fourth edition. Volumes 1–2. SAS Institute, Cary, North Carolina, USA.

SODHI, N. S., C. BRIFFET, L. KONG, AND B. YUEN. 1999. Bird use of linear areas of a tropical city: implications for park connector design and management. Landscape and Urban Planning 45:123–130.

STODDARD, C. H., AND G. M. STODDARD. 1987. Essentials of forestry practice. Fourth edition. John Wiley & Sons, New York, USA.

VINING, L. K., AND R. J. WEEKS. 1974. A preliminary chemical and physical comparison of blackbird–starling roost soils which do or do not contain *Histoplasma capsulatum*. Mycopathologia et Mycologia Applicata 54:541–548.

WARD, P. 1968. Origin of the avifauna of urban and suburban Singapore. Ibis 110:239–255.

WEE, Y. C. 1989. A guide to the wayside trees of Singapore. Singapore Science Centre, Singapore.

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